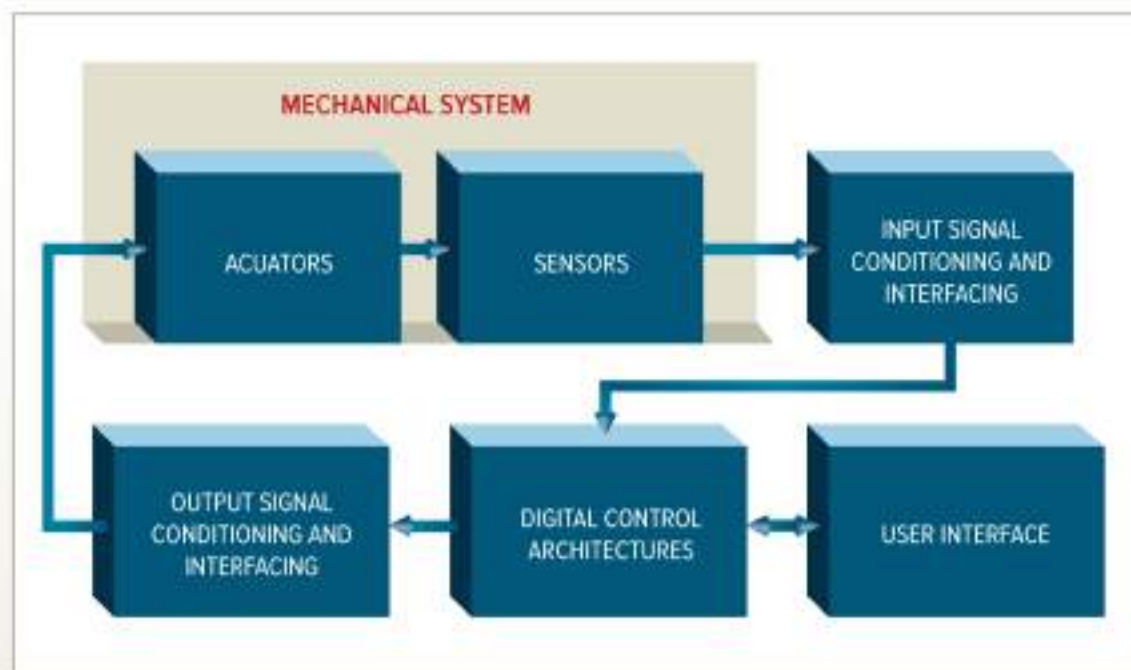


Introduction to

Fifth Edition

MECHATRONICS and MEASUREMENT SYSTEMS

David G. Alciatore



Introduction to Mechatronics and Measurement Systems

Fifth Edition

David G. Alciatore

*Department of Mechanical Engineering
Colorado State University*





INTRODUCTION TO MECHATRONICS AND MEASUREMENT SYSTEMS, FIFTH EDITION

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THREADED DESIGN EXAMPLES

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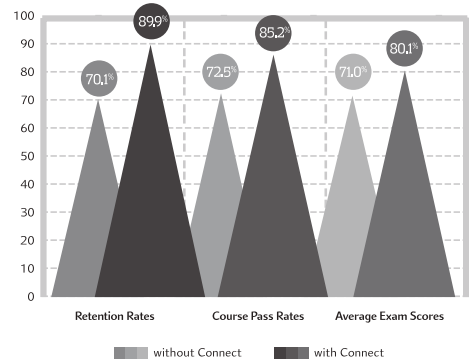
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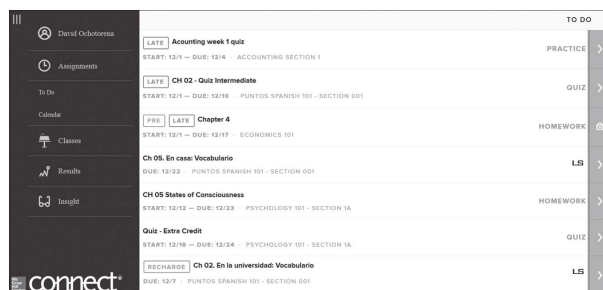
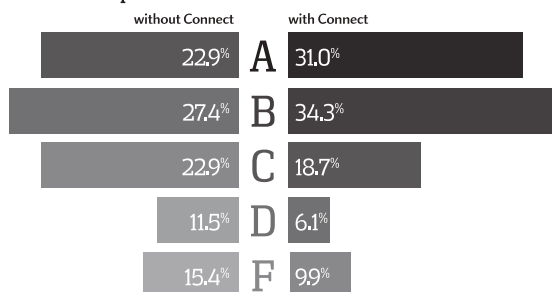
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PREFACE

APPROACH

The formal boundaries of traditional engineering disciplines have become fuzzy following the advent of integrated circuits and computers. Nowhere is this more evident than in mechanical and electrical engineering, where products today include an assembly of interdependent electrical and mechanical components. The field of mechatronics has broadened the scope of the traditional field of electromechanics. *Mechatronics* is defined as the field of study involving the analysis, design, synthesis, and selection of systems that combine electronic and mechanical components with modern controls and microprocessors.

This book is designed to serve as a text for (1) a modern instrumentation and measurements course, (2) a hybrid electrical and mechanical engineering course replacing traditional circuits and instrumentation courses, (3) a stand-alone mechatronics course, or (4) the first course in a mechatronics sequence. The second option, the hybrid course, provides an opportunity to reduce the number of credit hours in a typical mechanical engineering curriculum. Options 3 and 4 could involve the development of new interdisciplinary courses and curricula.

Currently, many curricula do not include a mechatronics course but include some of the elements in other more traditional courses. The purpose of a course in mechatronics is to provide a focused interdisciplinary experience for undergraduates that encompasses important elements from traditional courses as well as contemporary developments in electronics and computer control. These elements include measurement theory, electronic circuits, computer interfacing, sensors, actuators, and the design, analysis, and synthesis of mechatronic systems. This interdisciplinary approach is valuable to students because virtually every newly designed engineering product is a mechatronic system.

NEW TO THE FIFTH EDITION

The fifth edition of *Introduction of Mechatronics and Measurement Systems* has been improved, updated, and expanded beyond the previous edition. Additions and new features include:

- Arduino resources and examples added to supplement PIC microcontroller programming.
- Matlab solutions added for all MathCAD analysis files provided in previous editions.
- More microcontroller programming and interfacing examples, including serial communication.
- Expanded coverage of practical circuit and microcontroller-project debugging and troubleshooting advice.

- New section dealing with diode applications.
- New coverage of how to use an A/D reconstruction filter to produce high-fidelity representations of sampled data.
- Expanded section dealing with virtual instrumentation and the NI ELVIS Laboratory Platform.
- More website resources, including Internet links and online video demonstrations, cited and described throughout the book.
- Additional end-of-chapter questions throughout the book provide more homework and practice options for professors and students.
- Corrections and many small improvements throughout the entire book.

Also, the Laboratory Exercises Manual that supplements and supports this book is now available on-line for free and unlimited use by faculty and students. It is located, along with video demonstrations, on the Lab Book web page at: ***mechatronics.colostate.edu/lab_book.html***

CONTENT

Chapter 1 introduces mechatronic and measurement system terminology. Chapter 2 provides a review of basic electrical relations, circuit elements, and circuit analysis. Chapter 3 deals with semiconductor electronics. Chapter 4 presents approaches to analyzing and characterizing the response of mechatronic and measurement systems. Chapter 5 covers the basics of analog signal processing and the design and analysis of operational amplifier circuits. Chapter 6 presents the basics of digital devices and the use of integrated circuits. Chapter 7 provides an introduction to microcontroller programming and interfacing, and specifically covers the PIC microcontroller and PicBasic Pro programming. Chapter 8 deals with data acquisition and how to couple computers to measurement systems. Chapter 9 provides an overview of the many sensors common in mechatronic systems. Chapter 10 introduces a number of devices used for actuating mechatronic systems. Finally, Chapter 11 provides an overview of mechatronic system control architectures and presents some case studies. Chapter 11 also provides an introduction to control theory and its role in mechatronic system design. The appendices review the fundamentals of unit systems, statistics, error analysis, and mechanics of materials to support and supplement measurement systems topics in the book.

It is practically impossible to write and revise a large textbook without introducing errors by mistake, despite the amount of care exercised by the authors, editors, and typesetters. When errors are found, they will be published on the book website at: ***mechatronics.colostate.edu/book/corrections_5th_edition.html***. You should visit this page now to see if there are any corrections to record in your copy of the book. If you find any additional errors, please report them to *David.Alciatore@colostate.edu* so they can be posted for the benefit of others. Also, please let me know if you have suggestions or requests concerning improvements for future editions of the book. Thank you.

LEARNING TOOLS

Class discussion items (CDIs) are included throughout the book to serve as thought-provoking exercises for the students and instructor-led cooperative learning activities in the classroom. They can also be used as out-of-class homework assignments to supplement the questions and exercises at the end of each chapter. Hints and partial answers for many of the CDIs are available on the book website at **mechatronics.colostate.edu**. Analysis and design examples are also provided throughout the book to improve a student's ability to apply the material. To enhance student learning, carefully designed laboratory exercises coordinated with the lectures should accompany a course using this text. A supplemental Laboratory Exercises Manual is available for this purpose (see **mechatronics.colostate.edu/lab_book.html** for more information). The combination of class discussion items, design examples, and laboratory exercises exposes a student to a real-world practical approach and provides a useful framework for future design work.

In addition to the analysis Examples and design-oriented Design Examples that appear throughout the book, Threaded Design Examples are also included. The examples are mechatronic systems that include microcontrollers, input and output devices, sensors, actuators, support electronics, and software. The designs are presented incrementally as the pertinent material is covered throughout the chapters. This allows the student to see and appreciate how a complex design can be created with a divide-and-conquer approach. Also, the threaded designs help the student relate to and value the circuit fundamentals and system response topics presented early in the book. The examples help the students see the “big picture” through interesting applications beginning in Chapter 1.

ACKNOWLEDGMENTS

To ensure the accuracy of this text, it has been class-tested at Colorado State University and the University of Wyoming. I'd like to thank all of the students at both institutions who provided me valuable feedback throughout this process. In addition, I'd like to thank my many reviewers for their valuable input.

YangQuan Chen *Utah State University*
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Venkat N. Krovi *State University of New York, Buffalo*
Satish Nair *University of Missouri*
Ramendra P. Roy *Arizona State University*
Ahmad Smaili *Hariri Canadian University, Lebanon*
David Walrath *University of Wyoming*

I'd also like to thank all of the users and readers who have sent in corrections and recommendations for improvement via email. This input has helped me make the new edition of the book better and as error-free as possible for everyone.

ABOUT THE AUTHOR

Dr. David G. Alciatore has been a mechanical engineering professor at Colorado State University (CSU) since 1991. Dr. Dave, as his students know him, is a dedicated teacher and has received numerous awards for his contributions, including the university-wide Board of Governors “Excellence in Undergraduate Teaching Award.” His major research, consulting, and teaching interests include modeling and simulation of dynamic systems, mechatronic system design, high-speed video motion analysis, and engineering education. Over his career, Dr. Dave has done research and consulting dealing with robotics, computer graphics modeling, rapid prototyping (3D printing), sports mechanics, and mechatronics.

Dr. Dave has a PhD (1990) and an MS (1987) in Mechanical Engineering from the University of Texas at Austin, and a BS (1986) in Mechanical Engineering from the University of New Orleans. He has been an active member of the American Society of Mechanical Engineers (ASME) since 1984 and has served on many ASME committees, boards, and task forces. He also served as an ASME *Distinguished Lecturer*, and is a *Fellow* of the society. He is also a Professional Engineer.

In addition to his interest in mechatronics, Dr. Dave is passionate about the physics and engineering of billiards equipment and techniques. He is author of the book: *The Illustrated Principles of Pool and Billiards* and has published numerous instructional-video DVDs dealing with understanding and playing the wonderful game of pool. He also writes a monthly column for *Billiards Digest* magazine and has a very active pool-related YouTube Channel. Dr. Dave incorporates his passion for pool into the engineering classroom every chance he gets (e.g., when he teaches Advanced Dynamics).

If you have used this book in the past, you will notice that a second author is no longer listed. Dr. Dave co-authored earlier editions of this book with Michael B. Hestand. Dr. Hestand retired in 2005 after a 37-year career at Colorado State University. Dr. Dave has worked on the last two editions of this book on his own; but in the early editions, Dr. Hestand contributed a wealth of knowledge and experience dealing with electronics, sensors, and instrumentation. Dr. Dave will always cherish the time he spent with Mike, and he sincerely thanks him for the many enjoyable years working together. He and Mike are good friends and still see each other on a regular basis.

SUPPLEMENTAL MATERIALS ARE AVAILABLE ONLINE AT: **mechatronics.colostate.edu**

Cross-referenced visual icons appear throughout the book to indicate where additional information is available on the book website at **mechatronics.colostate.edu**.

Shown below are the icons used, along with a description of the resources to which they point:



Video Demo

This sign indicates where an online video demonstration is available for viewing. The online videos are YouTube videos or Windows Media (WMV) files viewable in an Internet browser. The clips show and describe electronic components, mechatronic devices and system examples, and as well as laboratory exercise demonstrations.

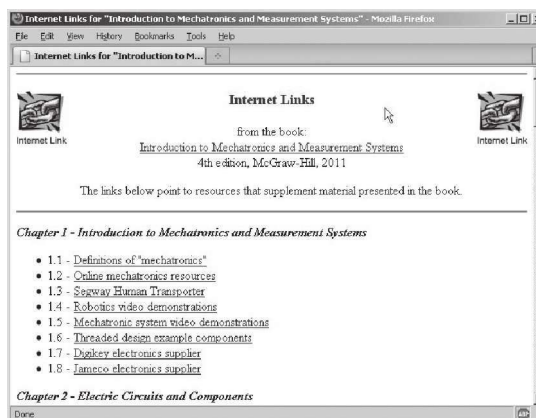


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Internet Link

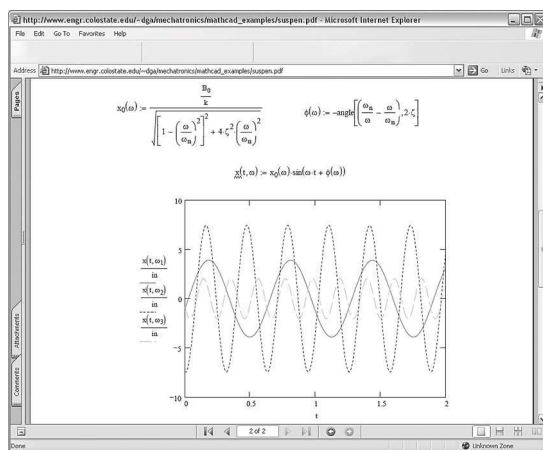
This sign indicates where a link to additional Internet resources is available on the book website. These links provide students and instructors with reliable sources of information for expanding their knowledge of certain concepts.



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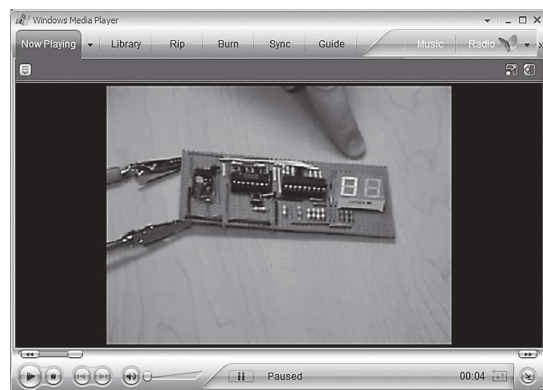
This sign indicates where Mathcad/Matlab files are available for performing analysis calculations. The files can be edited to perform similar and expanded analyses. PDF versions are also posted for those who do not have access to Mathcad/Matlab software.

MATLAB®
examples



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This sign indicates where a laboratory exercise is available in the supplemental Laboratory Exercises Manual that parallels the book. The manual provides useful hands-on laboratory exercises that help reinforce the material in the book and allow students to apply what they learn. Resources and short video demonstrations of most of the exercises are available on the book website. For information about the Laboratory Exercises Manual, visit mechatronics.colostate.edu/lab_book.html.



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ADDITIONAL SUPPLEMENTS

More information, including a recommended course outline, a typical laboratory syllabus, Class Discussion Item hints, and other supplemental material, is available on the book website.

In addition, a complete password-protected Solutions Manual containing solutions to all end-of-chapter problems is available at the McGraw-Hill book website at www.mhhe.com/alciatore.

These supplemental materials help students and instructors apply concepts in the text to laboratory or real-world exercises, enhancing the learning experience.

Introduction

CHAPTER OBJECTIVES

After you read, discuss, study, and apply ideas in this chapter, you will be able to:

1. Define mechatronics and appreciate its relevance to contemporary engineering design
2. Identify a mechatronic system and its primary elements
3. Define the elements of a general measurement system

1.1 MECHATRONICS

Mechanical engineering, as a widespread professional practice, experienced a surge of growth during the early 19th century because it provided a necessary foundation for the rapid and successful development of the industrial revolution. At that time, mines needed large pumps never before seen to keep their shafts dry, iron and steel mills required pressures and temperatures beyond levels used commercially until then, transportation systems needed more than real “horse power” to move goods; structures began to stretch across ever wider abysses and to climb to dizzying heights, manufacturing moved from the shop bench to large factories; and to support these technical feats, people began to specialize and build bodies of knowledge that formed the beginnings of the engineering disciplines.

The primary engineering disciplines of the 20th century—mechanical, electrical, civil, and chemical—retained their individual bodies of knowledge, textbooks, and professional journals because the disciplines were viewed as having mutually exclusive intellectual and professional territory. Entering students could assess their individual intellectual talents and choose one of the fields as a profession. We are now witnessing a new scientific and social revolution known as the information revolution, where engineering specializations ironically seem to be simultaneously focusing and diversifying. This contemporary revolution was spawned by the engineering development of semiconductor electronics, which has driven an information and communications explosion that is transforming human life. To practice engineering today, we



Internet Link

1.1 Definitions of “mechatronics”

must understand new ways to process information and be able to utilize semiconductor electronics within our products, no matter what label we put on ourselves as practitioners. Mechatronics is one of the new and exciting fields on the engineering landscape, subsuming parts of traditional engineering fields and requiring a broader approach to the design of systems that we can formally call mechatronic systems.

Then what precisely is mechatronics? The term **mechatronics** is used to denote a rapidly developing, interdisciplinary field of engineering dealing with the design of products whose function relies on the integration of mechanical and electronic components coordinated by a control architecture. Other definitions of the term “mechatronics” can be found online at Internet Link 1.1. The word mechatronics was coined in Japan in the late 1960s, spread through Europe, and is now commonly used in the United States. The primary disciplines important in the design of mechatronic systems include mechanics, electronics, controls, and computer engineering. A mechatronic system engineer must be able to design and select analog and digital circuits, microprocessor-based components, mechanical devices, sensors and actuators, and controls so that the final product achieves a desired goal.

Mechatronic systems are sometimes referred to as smart devices. While the term “smart” is elusive in precise definition, in the engineering sense we mean the inclusion of elements such as logic, feedback, and computation that in a complex design may appear to simulate human thinking processes. It is not easy to compartmentalize mechatronic system design within a traditional field of engineering because such design draws from knowledge across many fields. The mechatronic system designer must be a generalist, willing to seek and apply knowledge from a broad range of sources. This may intimidate the student at first, but it offers great benefits for individuality and continued learning during one’s career.

Today, practically all mechanical devices include electronic components and some type of digital monitoring or control. Therefore, the term mechatronic system encompasses a myriad of devices and systems. Increasingly, microcontrollers are embedded in electromechanical devices, creating much more flexibility and control possibilities in system design. Examples of mechatronic systems include an aircraft flight control and navigation system (including those on consumer drones), automobile air-bag safety system and antilock brake systems, automated manufacturing equipment such as robots and numerically controlled (NC) machine tools, smart kitchen and home appliances such as bread machines and clothes washing machines, and even toys.

Figure 1.1 illustrates all the components in a typical mechatronic system. The actuators produce motion or cause some action; the sensors detect the state of the system parameters, inputs, and outputs; digital devices control the system; conditioning and interfacing circuits provide connections between the control circuits and the input/output devices; and a user interface enables manual inputs and provides graphical displays or visual feedback to the user. The subsequent chapters provide an introduction to the elements listed in this block diagram and describe aspects of their analysis and design. At the beginning of each chapter, the elements presented are emphasized in a copy of Figure 1.1. This will help you maintain a perspective on the importance of each element as you gradually build your capability to design a mechatronic system. Internet Link 1.2 provides links to various vendors and sources of information for researching and purchasing different types of mechatronics components.



Internet Link

1.2 Online mechatronics resources

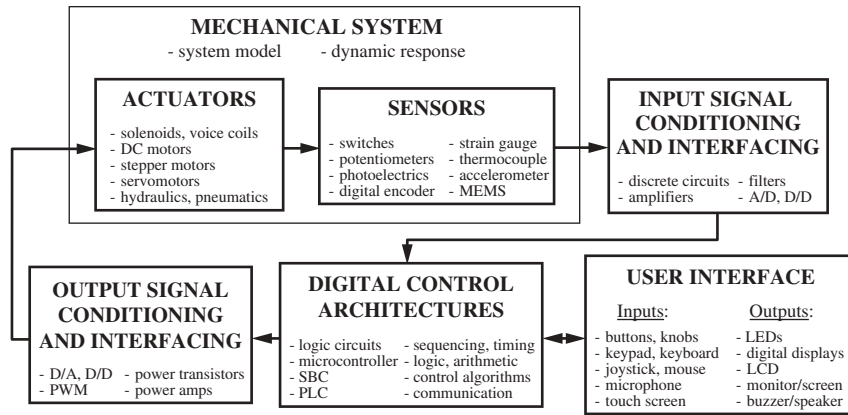


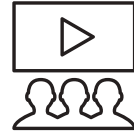
Figure 1.1 Mechatronic system components.

Example 1.1 describes a good example of a mechatronic system—an office copy machine. All of the components in Figure 1.1 can be found in this common piece of office equipment. Other mechatronic system examples can be found on the book website. See the Segway Human Transporter at Internet Link 1.3, the Adept pick-and-place industrial robot in Video Demos 1.1 and 1.2, the Honda Asimo and Sony Qrio humanoid-like robots in Video Demos 1.3 and 1.4, and the inkjet printer in Video Demo 1.5. As with the copy machine in Example 1.1, these robots and printer contain all of the mechatronic system components shown in Figure 1.1. Figure 1.2 labels the specific components mentioned in Video Demo 1.5. Video demonstrations of many more robotics-related devices can be found



Internet Link

1.3 Segway human transporter



Video Demo

1.1 Adept One robot demonstration

1.2 Adept One robot internal design and construction

1.3 Honda Asimo Raleigh, NC, demonstration

1.4 Sony “Qrio” Japanese dance demo

1.5 Inkjet printer components

Mechatronic System—Copy Machine

EXAMPLE 1.1

An office copy machine is a good example of a contemporary mechatronic system. It includes analog and digital circuits, sensors, actuators, and microprocessors. The copying process works as follows: The user places an original in a loading bin and pushes a button to start the process; the original is transported to the platen glass; and a high-intensity light source scans the original and transfers the corresponding image as a charge distribution to a drum. Next, a blank piece of paper is retrieved from a loading cartridge, and the image is transferred onto the paper with an electrostatic deposition of ink toner powder that is heated to bond to the paper. A sorting mechanism then optionally delivers the copy to an appropriate bin.

Analog circuits control the lamp, heater, and other power circuits in the machine. Digital circuits control the digital displays, indicator lights, buttons, and switches forming the user interface. Other digital circuits include logic circuits and microprocessors that coordinate all of the functions in the machine. Optical sensors and microswitches detect the presence or absence of paper, its proper positioning, and whether or not doors and latches are in their correct positions. Other sensors include encoders used to track motor rotation. Actuators include servo and stepper motors that load and transport the paper, turn the drum, and index the sorter.



Internet Link

1.4 Robotics video demonstrations

1.5 Mechatronic system video demonstrations

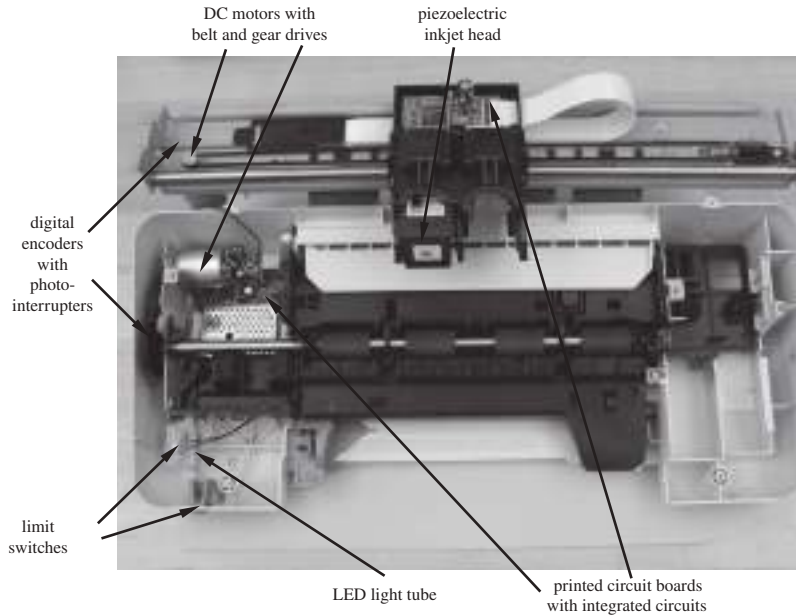


Figure 1.2 Inkjet printer components.

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at Internet Link 1.4, and demonstrations of other mechatronic system examples can be found at Internet Link 1.5.

■ CLASS DISCUSSION ITEM 1.1

Household Mechatronic Systems

What typical household items can be characterized as mechatronic systems? What components do they contain that help you identify them as mechatronic systems? If an item contains a microprocessor, describe the functions performed by the microprocessor.

1.2 MEASUREMENT SYSTEMS

A fundamental part of many mechatronic systems is a **measurement system** composed of the three basic parts illustrated in Figure 1.3. The **transducer** is a sensing element that converts a physical input into an output, usually a voltage. The **signal processor** performs filtering, amplification, or other signal conditioning on the transducer output. The term **sensor** is often used to refer to the transducer or to the combination of transducer and signal processor. Finally, the **recorder** is an instrument, a computer, or an output device that stores or displays the sensor data for monitoring or subsequent processing.

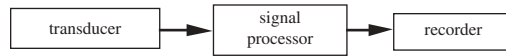


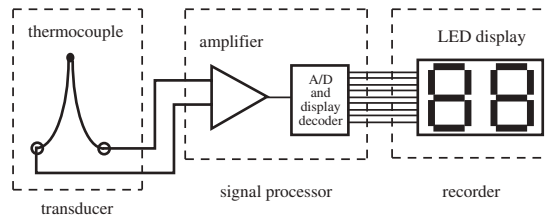
Figure 1.3 Elements of a measurement system.

These three building blocks of measurement systems come in many types with wide variations in cost and performance. It is important for designers and users of measurement systems to develop confidence in their use, to know their important characteristics and limitations, and to be able to select the best elements for the measurement task at hand. In addition to being an integral part of most mechatronic systems, a measurement system is often used as a stand-alone device to acquire data in a laboratory or field environment.

Measurement System—Digital Thermometer

EXAMPLE 1.2

The following figure shows an example of a measurement system. The thermocouple is a transducer that converts temperature to a small voltage; the amplifier increases the magnitude of the voltage; the A/D (analog-to-digital) converter is a device that changes the analog signal to a coded digital signal; and the LEDs (light-emitting diodes) display the value of the temperature.



Supplemental information important to measurement systems and analysis is provided in Appendix A. Included are sections on systems of units, numerical precision, and statistics. You should review this material on an as-needed basis.

1.3 THREADED DESIGN EXAMPLES

Throughout the book, there are Examples, which show basic analysis calculations, and Design Examples, which show how to select and synthesize components and subsystems. There are also three more complex Threaded Design Examples, which build upon new topics as they are covered, culminating in complete mechatronic systems by the end. These designs involve systems for controlling the position and speed of different types of motors in various ways. Threaded Design Examples A.1, B.1, and C.1 introduce each thread. All three designs incorporate components important in mechatronic systems: microcontrollers, input devices, output devices, sensors, actuators, and support electronics and software. Please read through the



Internet Link

1.6 Threaded design example components

1.7 Digikey electronics supplier

1.8 Jameco electronics supplier

following information and watch the introductory videos. It will also be helpful to watch the videos again when follow-on pieces are presented so that you can see how everything fits in the “big picture.” The list of Threaded Design Example citations at the beginning of the book, with the page numbers, can be useful for looking ahead or reflecting back as new portions are presented.

All of the components used to build the systems in all three threaded designs are listed at Internet Link 1.6, along with descriptions and price information. Most of the parts were purchased through Digikey Corporation (see Internet Link 1.7) and Jameco Electronics Corporation (see Internet Link 1.8), two of the better online suppliers of electronic parts. By entering part numbers from Internet Link 1.6 at the supplier websites, you can access technical datasheets for each product.

THREADED DESIGN EXAMPLE

A.1 DC motor power-op-amp speed controller—Introduction

This design example deals with controlling the rotational speed of a direct current (DC) permanent magnet motor. Figure 1.4 illustrates the major components and interconnections in the system. The light-emitting diode (LED) provides a visual cue to the user that the microcontroller is running properly. The speed input device is a potentiometer (or pot), which is a variable resistor. The resistance changes as the user turns the knob on top of the pot. The pot can be wired to produce a voltage input. The voltage signal is applied to a microcontroller (basically a small computer on a single integrated circuit) to control a DC motor to rotate at a speed proportional to the voltage. Voltage signals are “analog” but microcontrollers are “digital,” so we need analog-to-digital (A/D) and digital-to-analog (D/A) converters in the system to allow us to communicate between the analog and digital components. Finally, because a motor can require significant current, we need a power amplifier to boost the voltage and source the necessary current. Video Demo 1.6 shows a demonstration of the complete working system shown in Figure 1.5.

With all three Threaded Design Examples (A, B, and C), as you progress sequentially through the chapters in the book you will gain fuller understanding of the components in the design.



Video Demo

1.6 DC motor power-op-amp speed controller

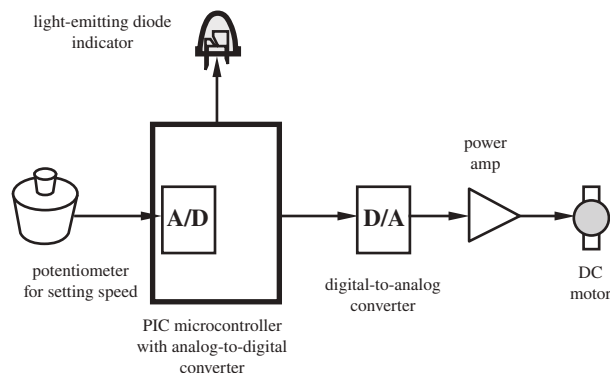


Figure 1.4 Functional diagram of the DC motor speed controller.

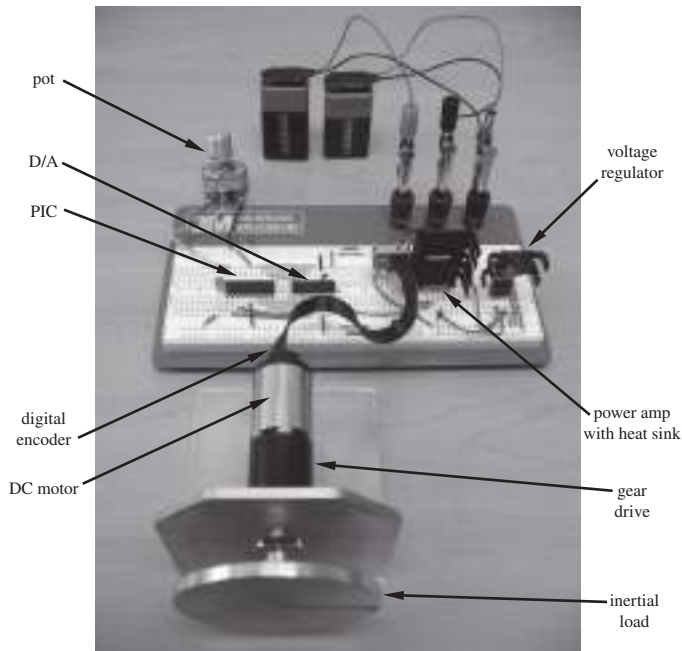


Figure 1.5 Photograph of the power-amp speed controller.

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Note that the PIC microcontroller (with the A/D) and the external D/A converter are not actually required in this design, in its current form. The potentiometer voltage output could be attached directly to the power amp instead, producing the same functionality. The reason for including the PIC (with A/D) and the D/A components is to show how these components can be interfaced within an analog system (this is useful to know in many applications). In addition, the design serves as a platform for further development, where the PIC can be used to implement feedback control and a user interface, in a more complex design. An example where you might need the microcontroller in the loop is in robotics or numerically controlled mills and lathes, where motors are often required to follow fairly complex motion profiles in response to inputs from sensors and user programming, or from manual inputs.

THREADED DESIGN EXAMPLE

Stepper motor position and speed controller—Introduction

B.1

This design example deals with controlling the position and speed of a stepper motor, which can be commanded to move in discrete angular increments. Stepper motors are useful in position indexing applications, where you might need to move parts or tools to and from various fixed positions (e.g., in an automated assembly or manufacturing line). Stepper motors are also useful in accurate speed control applications (e.g., controlling the spindle speed of a magnetic hard-drive or optical DVD player), where the motor speed is directly proportional to the step rate.

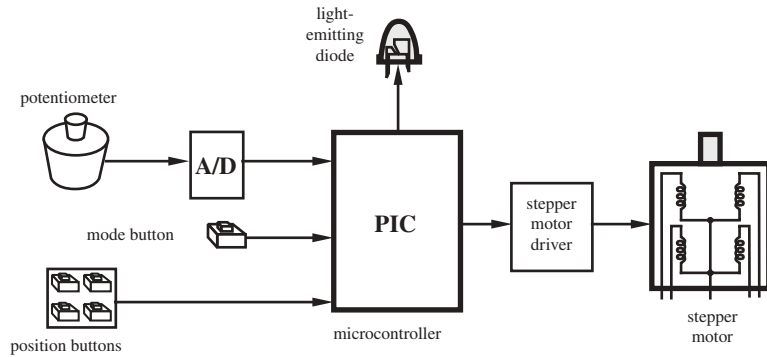


Figure 1.6 Functional diagram of the stepper motor position and speed controller.



Video Demo

1.7 Stepper motor position and speed controller

Figure 1.6 shows the major components and interconnections in the system. The input devices include a pot to control the speed manually, four buttons to select predefined positions, and a mode button to toggle between speed and position control. In position control mode, each of the four position buttons indexes the motor to specific angular positions relative to the starting point (0° , 45° , 90° , 180°). In speed control mode, turning the pot clockwise (or counterclockwise) increases (or decreases) the speed. The LED provides a visual cue to the user to indicate that the PIC is cycling properly. As with Threaded Design Example A, an A/D converter is used to convert the pot's voltage to a digital value. A microcontroller uses that value to generate signals for a stepper motor driver circuit to make the motor rotate.

Video Demo 1.7 shows a demonstration of the complete working system shown in Figure 1.7. As you progress through the book, you will learn about the different elements in this design.

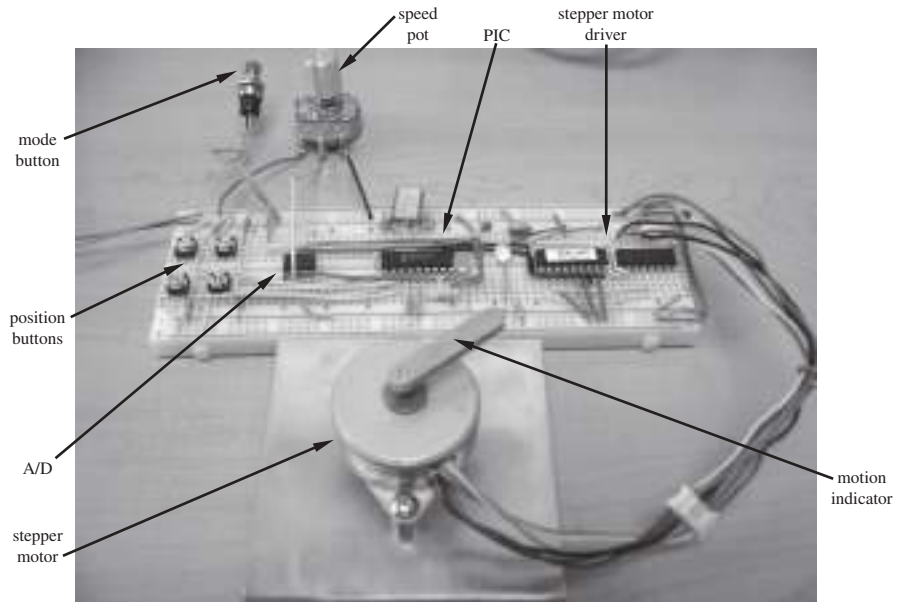


Figure 1.7 Photograph of the stepper motor position and speed controller.

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THREADED DESIGN EXAMPLE

DC motor position and speed controller—Introduction

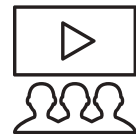
C.1

This design example illustrates control of position and speed of a permanent magnet DC motor. Figure 1.8 shows the major components and interconnections in the system. A numerical keypad enables user input, and a liquid crystal display (LCD) is used to display messages and a menu-driven user interface. The motor is driven by an H-bridge, which allows the voltage applied to the motor (and therefore, the direction of rotation) to be reversed. The H-bridge also allows the speed of the motor to be easily controlled by pulse-width modulation (PWM), where the power to the motor is quickly switched on and off at different duty cycles to change the average effective voltage applied.

A digital encoder attached to the motor shaft provides a position feedback signal. This signal is used to adjust the voltage signal to the motor to control its position or speed. This is called a servomotor system because we use feedback from a sensor to control the motor. Servomotors are very important in automation, robotics, consumer electronic devices, flow-control valves, and office equipment, where mechanisms or parts need to be accurately positioned or moved at certain speeds. Servomotors are different from stepper motors (see Threaded Design Example B.1) in that they move smoothly instead of in small incremental steps.

Two PIC microcontrollers are used in this design because there is a limited number of input/output pins available on a single chip. The main (master) PIC gets input from the user, drives the LCD, and sends the PWM signal to the motor. The secondary (slave) PIC monitors the digital encoder and transmits the position signal back to the master PIC upon command via a serial interface.

Video Demo 1.8 shows a demonstration of the complete working system shown in Figure 1.9. You will learn about each element of the design as you proceed sequentially through the book.



Video Demo

1.8 DC motor position and speed controller

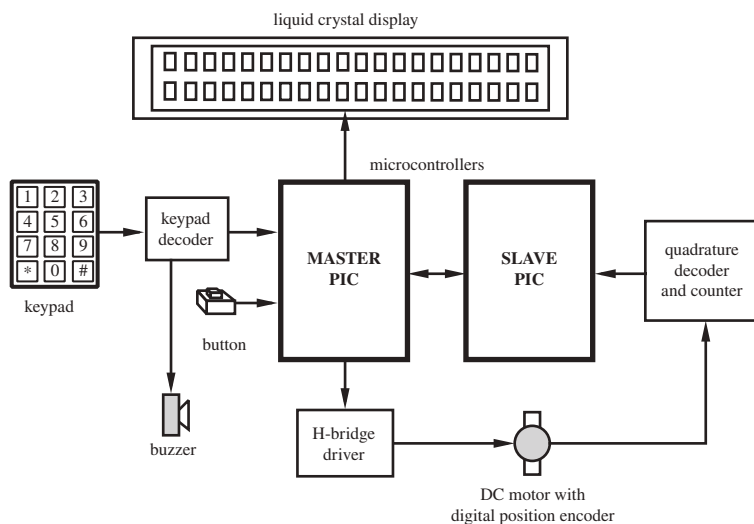


Figure 1.8 Functional diagram for the DC motor position and speed controller.

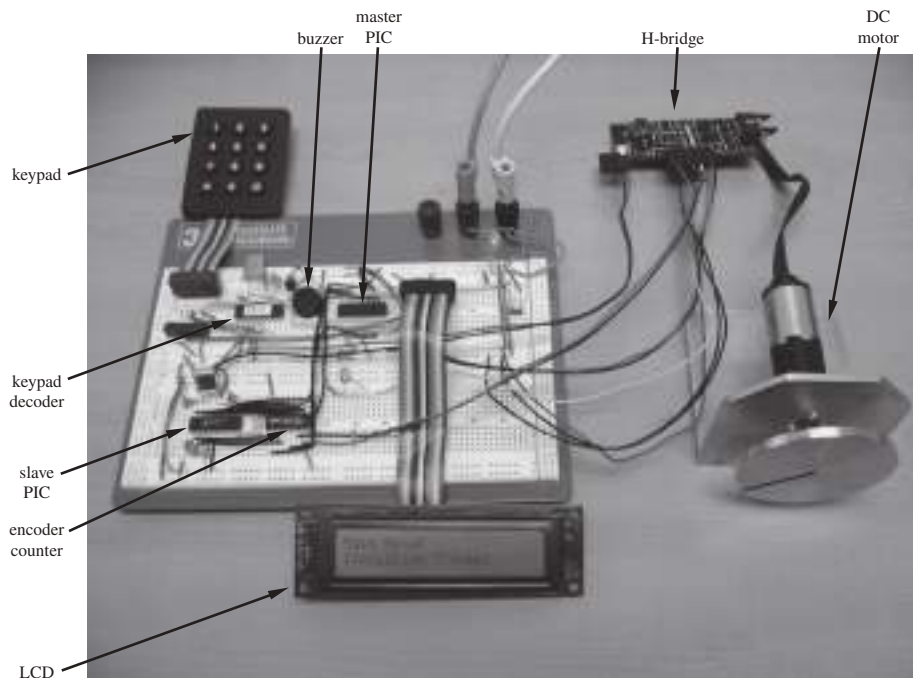


Figure 1.9 Photograph of the DC motor position and speed controller.

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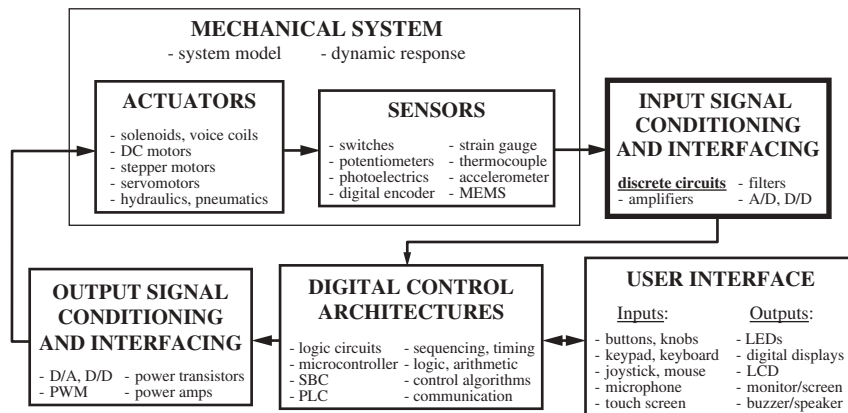
BIBLIOGRAPHY

- Alciatore, D., and Hstand, M., "Mechatronics at Colorado State University," *Journal of Mechatronics*, Mechatronics Education in the United States issue, Pergamon Press, May, 1995.
- Alciatore, D., and Hstand, M., "Mechatronics and Measurement Systems Course at Colorado State University," *Proceedings of the Workshop on Mechatronics Education*, pp. 7–11, Stanford, CA, July, 1994.
- Ashley, S., "Getting a Hold on Mechatronics," *Mechanical Engineering*, pp. 60–63, ASME, New York, May, 1997.
- Beckwith, T., Marangoni, R., and Lienhard, J., *Mechanical Measurements*, 6th edition, Pearson, New York, 2007.
- Craig, K., "Mechatronics System Design at Rensselaer," *Proceedings of the Workshop on Mechatronics Education*, pp. 24–27, Stanford, CA, July, 1994.
- Doebelin, E., *Measurement Systems Applications and Design*, 4th edition, McGraw-Hill, New York, 1990.
- Morley, D., "Mechatronics Explained," *Manufacturing Systems*, p. 104, November, 1996.
- Shoureshi, R., and Meckl, P., "Teaching MEs to Use Microprocessors," *Mechanical Engineering*, v. 166, n. 4, pp. 71–74, April, 1994.

Design elements: Internet Link (Pointing Hand): ©Marvid/iStockGetty Images; Lab Exercise (Flask): ©Marvid/iStockGetty Images; Mechanical System (Chart): ©McGraw-Hill Global Education Holdings, LLC; Video Demo (Video Play Symbol): ©Marvid/iStockGetty Images

Electric Circuits and Components

This chapter reviews the fundamentals of basic electrical components and discrete circuit analysis techniques. These topics are important in understanding and designing all elements in a mechatronic system, especially discrete circuits for signal conditioning and interfacing. ■



CHAPTER OBJECTIVES

After you read, discuss, study, and apply ideas in this chapter, you will:

1. Understand differences among resistance, capacitance, and inductance
2. Be able to define Kirchhoff's voltage and current laws and apply them to passive circuits that include resistors, capacitors, inductors, voltage sources, and current sources

3. Know how to apply models for ideal voltage and current sources
4. Be able to predict the steady-state behavior of circuits with sinusoidal inputs
5. Be able to characterize the power dissipated or generated by a circuit
6. Be able to predict the effects of mismatched impedances
7. Understand how to reduce noise and interference in electrical circuits
8. Appreciate the need to pay attention to electrical safety and to ground components properly
9. Be aware of several practical considerations that will help you assemble actual circuits and make them function properly and reliably
10. Know how to make reliable voltage and current measurements

2.1 INTRODUCTION

Practically all mechatronic and measurement systems contain electrical circuits and components. To understand how to design and analyze these systems, a firm grasp of the fundamentals of basic electrical components and circuit analysis techniques is a necessity. These topics are fundamental to understanding everything else that follows in this book.

When electrons move, they produce an electrical current, and we can do useful things with the energized electrons. The reason they move is that we impose an electrical field that imparts energy by doing work on the electrons. A measure of the electric field's potential is called **voltage**. It is analogous to potential energy in a gravitational field. We can think of voltage as an “across variable” between two points in the field. The resulting movement of electrons is the current, a “through variable,” that moves through the field. When we measure current through a circuit, we place a meter in the circuit and let the current flow through it. When we measure a voltage, we place two conducting probes on the points across which we want to measure the voltage. Voltage is sometimes referred to as **electromotive force**, or **emf**.

Current is defined as the time rate of flow of charge:

$$I(t) = \frac{dq}{dt} \quad (2.1)$$

where I denotes current and q denotes quantity of charge. The charge is provided by the negatively charged electrons. The SI unit for current is the **ampere** (A), and charge is measured in **coulombs** ($C = A \cdot s$). When voltage and current in a circuit are constant (i.e., independent of time), their values and the circuit are referred to as **direct current**, or DC. When the voltage and current vary with time, usually sinusoidally, we refer to their values and the circuit as **alternating current**, or AC.

An electrical circuit is a closed loop consisting of several conductors connecting electrical components. Conductors may be interrupted by components called switches. Some simple examples of valid circuits are shown in Figure 2.1.

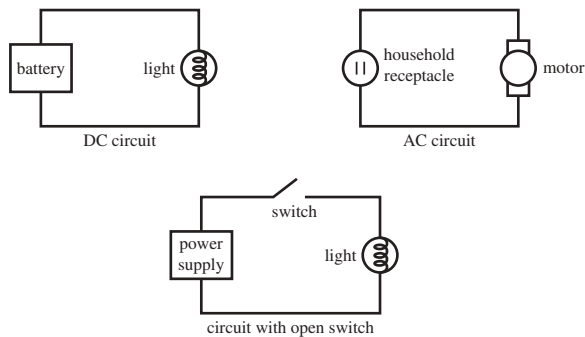


Figure 2.1 Electrical circuits.

The terminology and current flow convention used in the analysis of an electrical circuit are illustrated in Figure 2.2a. The voltage source, which provides energy to the circuit, can be a power supply, battery, or generator. The voltage source adds electrical energy to electrons, which flow from the negative terminal to the positive terminal, through the circuit. The positive side of the source attracts electrons, and the negative side releases electrons. The negative side is usually not labeled in a circuit schematic (e.g., with a minus sign) because it is implied by the positive side, which is labeled with a plus sign. Standard convention assumes that positive charge flows in a direction opposite from the electrons. **Current** describes the flow of this positive charge (not electrons). We owe this convention to Benjamin Franklin, who thought current was the result of the motion of positively charged particles. A **load** consists of a network of circuit elements that may dissipate or store electrical energy. Figure 2.2b shows two alternative ways to draw a circuit schematic. The **ground** indicates a reference point in the circuit where the voltage is assumed to be zero. Even though we do not show a connection between the ground symbols in the top circuit, it is implied that both ground symbols represent a single reference voltage (i.e., there is a “common ground”). This technique can be applied when drawing complicated circuits to reduce the number of lines. The bottom circuit is an equivalent representation.

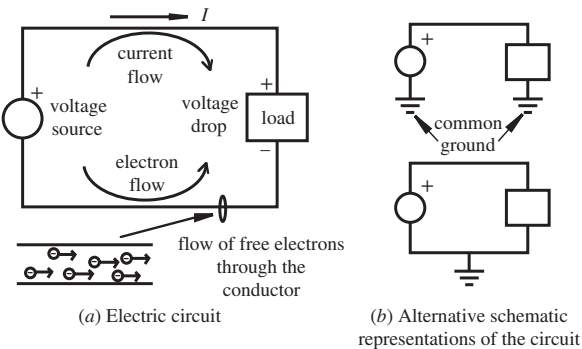


Figure 2.2 Electric circuit terminology.

■ CLASS DISCUSSION ITEM 2.1

Proper Car Jump Start

Draw an equivalent circuit and list the sequence of steps to connect jumper cables properly between two car batteries when trying to jump-start a car with a run-down battery. Be sure to label both the positive and negative terminals on each battery and the red and black cables of the jumper.

It is recommended that the last connection you make should be between the black jumper cable and the run-down car; and instead of connecting it to the negative terminal of the battery, you should connect it to the frame of the car at a point away from the battery. What is the rationale for this advice? Does it matter in what order the connections are removed after you have started the car?

Note - Hints and partial answers for many of the Class Discussion Items throughout the book (including this one) are provided on the book website at mechatronics.colostate.edu.

2.2 BASIC ELECTRICAL ELEMENTS

There are three basic passive electrical elements: the resistor (R), capacitor (C), and inductor (L). Passive elements require no additional power supply, unlike active devices such as integrated circuits. The passive elements are defined by their voltage–current relationships, as summarized below, and the symbols used to represent them in circuit schematics are shown in Figure 2.3.

There are two types of ideal energy sources: a **voltage source** (V) and a **current source** (I). These ideal sources contain no internal resistance, inductance, or capacitance. Figure 2.3 also illustrates the schematic symbols for ideal sources. Figure 2.4 shows some examples of actual components that correspond to the symbols in Figure 2.3. Video Demo 2.1 shows more examples and explains what they do and how they work.



Video Demo

2.1 A simple guide to electronic components

■ CLASS DISCUSSION ITEM 2.2

Hydraulic Analogies of Electrical Sources

An electrical voltage source is analogous to a hydraulic impeller-based centrifugal pump, and a current source is analogous to a positive-displacement gear or piston pump. Explain these analogies in detail by comparing variables of interest in both. Hint: See Sections 4.11 and 10.8.

2.2.1 Resistor

A **resistor** is a dissipative element that converts electrical energy into heat. As we will see throughout the book, resistors are used for many purposes in a variety of applications. The most common uses are to limit current through a device and to drop down or set a voltage value. Resistance is also present in all wires and cables, and the

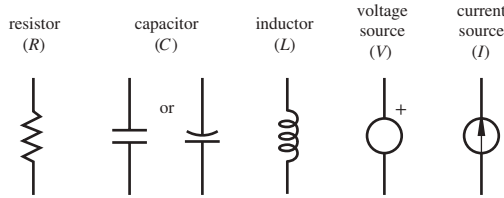


Figure 2.3 Schematic symbols for basic electrical elements.

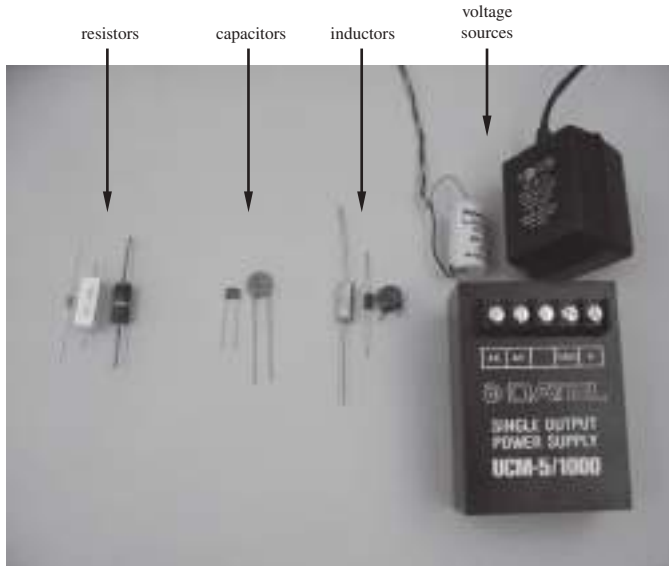


Figure 2.4 Examples of basic circuit elements.

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resulting voltage drops and power losses often create undesired consequences that we sometimes need to address. **Ohm's law** defines the voltage–current characteristic of an ideal resistor:

$$V = IR \quad (2.2)$$

The unit of resistance is the **ohm** (Ω). Resistance is a material property whose value is the slope of the resistor's voltage–current curve (see Figure 2.5). For an ideal resistor, the voltage–current relationship is linear, and the resistance is constant. However, real resistors are typically nonlinear due to temperature effects. As the current increases, temperature increases resulting in higher resistance. Also, a real resistor has a limited power dissipation capability designated in watts, and it may fail when this limit is exceeded.

If a resistor's material is homogeneous and has a constant cross-sectional area, such as the cylindrical wire illustrated in Figure 2.6, then the resistance is given by

$$R = \frac{\rho L}{A} \quad (2.3)$$

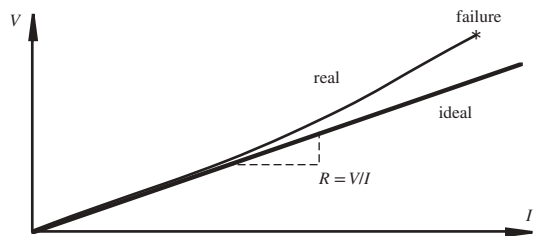


Figure 2.5 Voltage–current relation for an ideal resistor.

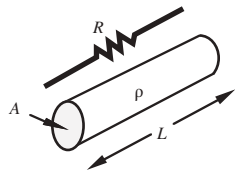


Figure 2.6 Wire resistance.

Table 2.1 Resistivities of common conductors

Material	Resistivity ($10^{-8} \Omega \cdot \text{m}$)
Aluminum	2.8
Carbon	4000
Constantan	44
Copper	1.7
Gold	2.4
Iron	10
Silver	1.6
Tungsten	5.5



Internet Link

2.1 Conductor sizes

2.2 Conductor current ratings

where ρ is the **resistivity**, or specific resistance of the material; L is the wire length; and A is the cross-sectional area. Resistivities for common conductors are given in Table 2.1. Example 2.1 demonstrates how to determine the resistance of a wire of given diameter and length. Internet Links 2.1 and 2.2 list the standard conductor diameters and current ratings.

EXAMPLE 2.1

Resistance of a Wire

As an example of the use of Equation 2.3, we will determine the resistance of a copper wire 1.0 mm in diameter and 10 m long.

From Table 2.1, the resistivity of copper is

$$\rho = 1.7 \times 10^{-8} \Omega \cdot \text{m}$$

Because the wire diameter, area, and length are

$$\begin{aligned} D &= 0.001 \text{ m} \\ A &= \pi D^2/4 = 7.8 \times 10^{-7} \text{ m}^2 \\ L &= 10 \text{ m} \end{aligned}$$

the total wire resistance is

$$R = \rho L/A = 0.218 \Omega$$

■ CLASS DISCUSSION ITEM 2.3
Hydraulic Analogy of an Electrical Resistor

An electrical resistor is analogous to piping friction or a flow-constriction valve in a hydraulic system. Explain these analogies in detail by comparing variables of interest in both. Hint: See Section 4.11.

Actual resistors used in assembling circuits are packaged in various forms including axial-lead components, surface mount components, and the **dual in-line package (DIP)** and the **single in-line package (SIP)**, which contain multiple resistors in a package that conveniently fits into circuit boards. These four types are illustrated in Figures 2.7 and 2.8. Video Demo 2.2 also shows several examples of resistor types and packages.

An axial-lead resistor’s value and tolerance are usually coded with four colored bands (*a, b, c, tol*) as illustrated in Figure 2.9. The colors used for the bands are listed with their respective values in Table 2.2 and at Internet Link 2.3 (for easy reference). A resistor’s value and tolerance are expressed as

$$R = ab \times 10^c \pm \text{tolerance } (\%) \tag{2.4}$$

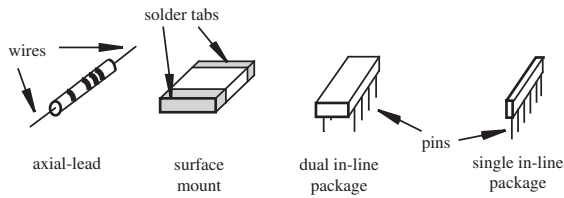


Figure 2.7 Resistor packaging.

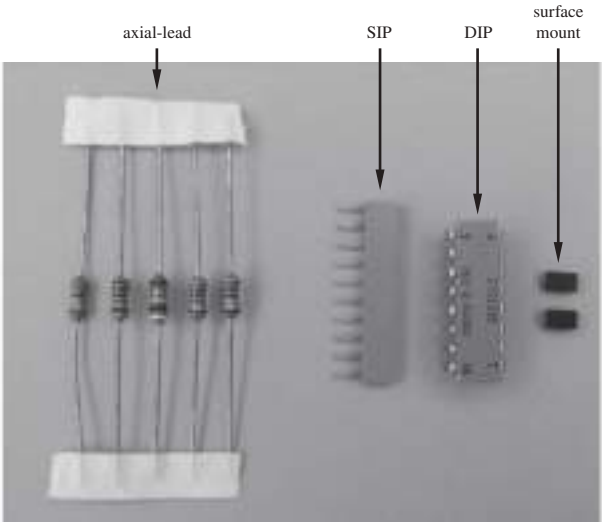


Figure 2.8 Examples of resistor packaging.
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Video Demo

2.2 Resistors



Internet Link

2.3 Resistor color codes

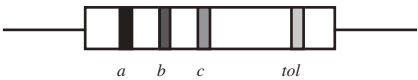


Figure 2.9 Axial-lead resistor color bands.

Table 2.2 Resistor color band codes

<i>a</i> , <i>b</i> , and <i>c</i> Bands		<i>tol</i> Band	
Color	Value	Color	Value
Black	0	Gold	±5%
Brown	1	Silver	±10%
Red	2	Nothing	±20%
Orange	3		
Yellow	4		
Green	5		
Blue	6		
Violet	7		
Gray	8		
White	9		

where the *a* band represents the tens digit, the *b* band represents the ones digit, the *c* band represents the power of 10, and the *tol* band represents the tolerance or uncertainty as a percentage of the coded resistance value. Here is a popular (and politically correct) mnemonic you can use to remember the resistor color codes when you don't have a table handy: “Bob BROWN Ran Over YELLOW Grass, But VIOLET Got Wet.” The capitalized letters identify the colors: black, brown, red, orange, yellow, green, blue, violet, gray, and white. The set of **standard values** for the first two digits (*ab*) are 10, 11, 12, 13, 14, 15, 16, 18, 20, 22, 24, 27, 30, 33, 36, 39, 43, 47, 51, 56, 62, 68, 75, 82, and 91. Often, resistance values are in the kΩ range and sometimes the unit is abbreviated as k instead of kΩ. For example, 10 k next to a resistor on an electrical schematic implies 10 kΩ. Precision resistors, with much tighter value tolerance, use a five-color-band code. For more info, see Internet Link 2.4.

The most common resistors you will use in ordinary electronic circuitry are 1/4 watt, 5% tolerance carbon or metal-film resistors. Resistor values of this type range in value between 1 Ω and 24 MΩ. Resistors with higher power ratings are also available. The 1/4 watt rating means the resistor can fail if it is required to dissipate more power than this.

Precision metal-film resistors have 1% or smaller uncertainties and are available in a wider range of values than the lower-tolerance resistors. They usually have a numerical four-digit code printed directly on the body of the resistor. The first three digits denote the value of the resistor, and the last digit indicates the power of 10 by which to multiply.



Internet Link

2.4 Precision resistor color codes

Resistance Color Codes

EXAMPLE 2.2

An axial-lead resistor has the following color bands:

a = green, b = brown, c = red, and tol = gold

From Equation 2.4 and Table 2.2, the range of possible resistance values is

$$R = 51 \times 10^2 \Omega \pm 5\% = 5100 \pm (0.05 \times 5100) \Omega$$

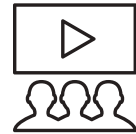
or (rounded down to the nearest 100)

$$4800 \Omega < R < 5300 \Omega$$

Resistors come in a variety of shapes and sizes. As with many electrical components, the size of the device often has little to do with the characteristic value (e.g., resistance) of the device. Capacitors are one exception, where a larger device usually implies a higher capacitance value and/or a higher voltage capacity. With most devices that carry continuous current, the physical size is usually related to the maximum current or power rating, both of which are related to the power dissipation capabilities. Video Demo 2.3 shows various types of components of various sizes to illustrate this principle. The best place to find detailed information on various components is online from vendor websites. Internet Link 2.5 points to a collection of links to the largest and most popular suppliers.

Variable resistors are available that provide a range of resistance values controlled by a mechanical screw, knob, or linear slide. The most common type is called a **potentiometer**, or **pot**. The various schematic symbols for a potentiometer are shown in Figure 2.10. A potentiometer that is included in a circuit to adjust or fine-tune the resistance in the circuit is called a **trim pot**. A trim pot is shown with a little symbol to denote the screw used to adjust (“trim”) its value. The direction to rotate the potentiometer for increasing resistance is usually indicated on the component. Standard potentiometers are discussed further in Sections 4.8 and 9.2.2. Another form of potentiometer is a digital potentiometer, or **digipot**. Its resistance can be controlled through a digital device like a microcontroller. The resistance can be set to a selected discrete value within a set range based on a binary number input. A digipot is a form of digital-to-analog (D/A) converter (see Section 8.5).

Conductance is defined as the reciprocal of resistance. It is sometimes used as an alternative to resistance to characterize a dissipative circuit element. It is a measure of how easily an element conducts current as opposed to how much it resists it. The unit of conductance is the **siemens** ($S = 1/\Omega = \text{mho}$).



Video Demo

2.3 Electronics components of various types and sizes



Internet Link

2.5 Electronic component online resources and vendors

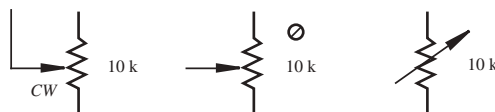


Figure 2.10 Potentiometer schematic symbols.

2.2.2 Capacitor

A **capacitor** is a passive element that stores energy in the form of an electric field. This field is the result of a separation of electric charge. The simplest capacitor consists of a pair of parallel conducting plates separated by a dielectric material as illustrated in Figure 2.11. The **dielectric material** is an insulator that increases the capacitance as a result of permanent or induced electric dipoles in the material. As we will see throughout the book, capacitors are used for many purposes in a variety of applications. Example uses include filtering and smoothing voltage signals, creating delays in timing circuits, and storing charge and energy for later use (like a battery).

Strictly, direct current (DC) does not flow through a capacitor; rather, charges are displaced from one side of the capacitor through the conducting circuit to the other side, establishing the electric field. The displacement of charge is called a **displacement current** because current appears to flow through the device as it charges or discharges. The capacitor's voltage–current relationship is defined as

$$V(t) = \frac{1}{C} \int_0^t I(\tau) d\tau = \frac{q(t)}{C} \quad (2.5)$$

where $q(t)$ is the amount of accumulated charge measured in coulombs, C is the capacitance measured in farad ($F = \text{coulomb/volt}$), and τ is a dummy variable of integration. By differentiating this equation, we can relate the displacement current to the rate of change of voltage:

$$I(t) = C \frac{dV}{dt} \quad (2.6)$$

Capacitance is a property of the dielectric material and the plate geometry and separation. Values for typical capacitors range from 1 pF ($1 \times 10^{-12} F$) to 1000 μF ($1000 \times 10^{-6} F = 1 \times 10^{-3} F = 1 \text{ mF}$), but they are also available with much larger values. Because the voltage across a capacitor is the integral of the displacement current (see Equation 2.5), the voltage cannot change instantaneously. As we will see several times throughout the book, this characteristic can be used for timing purposes in electrical circuits using a simple RC circuit, which is a resistor and capacitor in series.

The primary types of commercial capacitors are electrolytic capacitors, tantalum capacitors, ceramic disk capacitors, and mylar capacitors. Electrolytic capacitors are polarized, meaning they have a positive end and a negative end. The positive lead of a polarized capacitor must be held at a higher voltage than the negative side; otherwise, the device will usually be damaged (e.g., it will short and/or explode with a popping sound). Capacitors come in many sizes and shapes (see Video Demo 2.4).



Video Demo

2.4 Capacitors

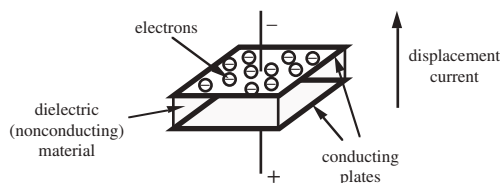


Figure 2.11 Parallel plate capacitor.

Often the capacitance is printed directly on the component, typically in μF or pF , but sometimes a three-digit code is used. The first two digits are the value and the third is the power of 10 multiplied times picofarad (e.g., 102 implies $10 \times 10^2 \text{ pF} = 1 \times 10^{-9} \text{ F} = 1 \text{ nF}$). If there are only two digits, the value reported is in picofarad (e.g., 22 implies 22 pF). Section 2.10.1 presents much more information about how capacitance values are labeled and read. It also provides more information about the different types of capacitors, explaining their properties and uses in different applications.

■ CLASS DISCUSSION ITEM 2.4

Hydraulic Analogy of an Electrical Capacitor

An electrical capacitor is analogous to a storage tank, an accumulator, a household expansion tank, or a flexible-wall pressure vessel (e.g., a balloon) in hydraulic and pneumatic systems. Explain these analogies in detail by comparing variables of interest in both. Hint: See Sections 4.11, 10.9, and 10.10, and look up these components online if necessary.

2.2.3 Inductor

An **inductor** is a passive energy storage element that stores energy in the form of a magnetic field. The simplest form of an inductor is a wire coil, which has a tendency to maintain a magnetic field once established. You will not see discrete inductor components used much in this book, but they are important in some filter, radio tuning, and power circuits. Regardless, understanding inductance is very important because many mechatronic system components, including relays, solenoids, transformers, and motors, contain coils which have inductance. The inductor's characteristics are a direct result of Faraday's law of induction, which states

$$V(t) = \frac{d\lambda}{dt} \quad (2.7)$$

where λ is the total **magnetic flux** through the coil windings due to the current. Magnetic flux is measured in webers (Wb). The magnetic field lines surrounding an inductor are illustrated in Figure 2.12. The south-to-north direction of the magnetic

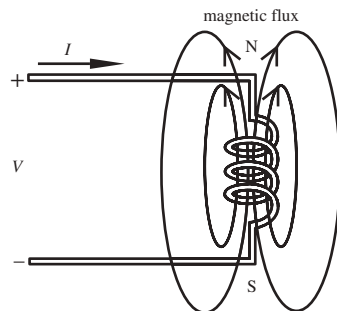


Figure 2.12 Inductor flux linkage.

field lines, shown with arrowheads in the figure, is found using the **right-hand rule** for a coil. The rule states that, if you curl the fingers of your right hand in the direction of current flow through the coil, your thumb will point in the direction of magnetic north. For an ideal coil, the flux is proportional to the current:

$$\lambda = LI \quad (2.8)$$

where L is the inductance of the coil, which is assumed to be constant. The unit of measure of inductance is the **henry** ($\text{H} = \text{Wb/A}$). Using Equations 2.7 and 2.8, an inductor's voltage–current relationship can be expressed as

$$V(t) = L \frac{dI}{dt} \quad (2.9)$$

The magnitude of the voltage across an inductor is proportional to the rate of change of the current through the inductor. If the current through the inductor is increasing ($dI/dt > 0$), the voltage polarity is as shown in Figure 2.12. If the current through the inductor is decreasing ($dI/dt < 0$), the voltage polarity is opposite to that shown.

Integrating Equation 2.9 results in an expression for current through an inductor given the voltage:

$$I(t) = \frac{1}{L} \int_0^t V(\tau) d\tau \quad (2.10)$$

where τ is a dummy variable of integration. From this we can infer that the current through an inductor cannot change instantaneously because it is the integral of the voltage. This is important in understanding the function or consequences of inductors in circuits. It takes time to increase or decrease the current flowing through an inductor, especially when there is resistance in series with the inductance (and there is always at least some resistance in circuits). An important mechatronic system component, the electric motor, has large inductance due to its internal coils, so it is difficult to start or stop the motor very quickly. This is true of electromagnetic relays and solenoids as well.

Typical inductor components range in value from $1 \mu\text{H}$ ($1 \times 10^{-6} \text{ H}$) to 100 mH ($100 \times 10^{-3} \text{ H} = 0.1 \text{ H}$). Inductance is important to consider in motors, relays, solenoids, some power supplies, and high-frequency circuits. Although some manufacturers have coding systems for inductors, there is no standard method. Often, the value is printed on the device directly, typically in μH or mH .

■ CLASS DISCUSSION ITEM 2.5

Hydraulic Analogy of an Electrical Inductor

An electrical inductor is analogous to the inertial properties (AKA “inertance”) of the fluid in a long pipe in a hydraulic system. Explain these analogies in detail by comparing variables of interest in both. Hint: See Section 4.11.

2.3 KIRCHHOFF'S LAWS

Now we are ready to put circuit elements and sources together in circuits and calculate voltages and currents anywhere in the circuit. Kirchhoff's laws are essential for the analysis and understanding of circuits, regardless of how simple or complex the circuit may be. In fact, these laws are the basis for even the most complex circuit analysis such as that involved with transistor circuits, operational amplifiers, or even integrated circuits with hundreds or many thousands of elements. **Kirchhoff's voltage law (KVL)** states that the sum of voltages around a closed loop or path is 0 (see Figure 2.13):

$$\sum_{i=1}^N V_i = 0 \quad (2.11)$$

Note that the loop must be closed, but the conductors themselves need not be closed (i.e., the loops can go through open circuits).

To apply KVL to a circuit, as illustrated in Figure 2.13, you first assume a current direction on each branch of the circuit. Next, assign the appropriate polarity to the voltage across each passive element assuming that the voltage drops across each element in the direction of the current. Where assumed current enters a passive element, a plus is shown, and where the assumed current leaves the element, a minus is shown. The polarity of voltage across a voltage source and the direction of current through a current source must always be maintained as given. Now, starting at any point in the circuit (such as node A in Figure 2.13) and following either a clockwise or counterclockwise loop direction (clockwise in Figure 2.13), form the sum of the voltages across each element, assigning to each voltage the first algebraic sign encountered at each element in the loop. For Figure 2.13, the result would be

$$-V_1 - V_2 + V_3 + \cdots - V_N = 0 \quad (2.12a)$$

Alternatively, you can assign the signs based on whether the voltage increases (from $-$ to $+$, assigning $+$) or drops (from $+$ to $-$, assigning $-$) across the element. Using this convention, the equation would be:

$$V_1 + V_2 - V_3 + \cdots + V_N = 0 \quad (2.12b)$$

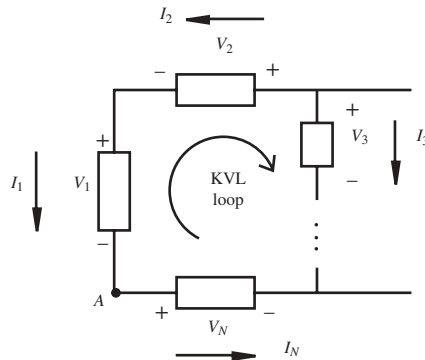
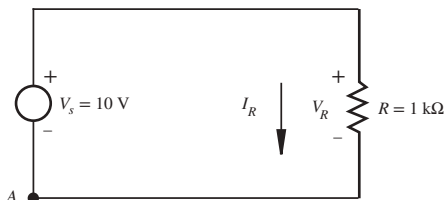


Figure 2.13 Kirchhoff's voltage law.

Equations 2.12a and 2.12b are equivalent, but the second convention is more intuitive because it represents what actually occurs in the circuit. However, the first convention is more common, probably because it involves less thought.

EXAMPLE 2.3**Kirchhoff's Voltage Law**

KVL will be used to find the current I_R in the following circuit.



The first step is to assume the current direction for I_R . The chosen direction is shown in the figure. With a circuit this simple, the current direction is obvious based on the polarity of the source; but in more complex circuits, current directions might not be so obvious. Then we use the current direction through the resistor to assign the voltage-drop polarity. If the current were assumed to flow in the opposite direction instead, the voltage polarity across the resistor would also have to be reversed. The polarity for the voltage source is fixed regardless of current direction. Starting at point A and progressing clockwise around the loop, we assign the first voltage sign we come to on each element yielding

$$-V_s + V_R = 0$$

Applying Ohm's law,

$$-V_s + I_R R = 0$$

Therefore,

$$I_R = V_s / R = 10 / 1000 \text{ A} = 10 \text{ mA}$$

Kirchhoff's current law (KCL) states that the sum of the currents flowing into a closed surface or node is 0. Referring to Figure 2.14a,

$$I_1 + I_2 - I_3 = 0 \quad (2.13)$$

More generally, referring to Figure 2.14b,

$$\sum_{i=1}^N I_i = 0 \quad (2.14)$$

Note that currents entering a node or surface are assigned a positive value, and currents leaving are assigned a negative value.

It is important to note that, when analyzing a circuit, you arbitrarily assume current directions and denote the directions with arrows on the schematic. If the calculated result for a current is negative, the current actually flows in the opposite direction. Also, assumed voltage drops must be consistent with the assumed current directions. If a calculated voltage is negative, its actual polarity is opposite to that shown.

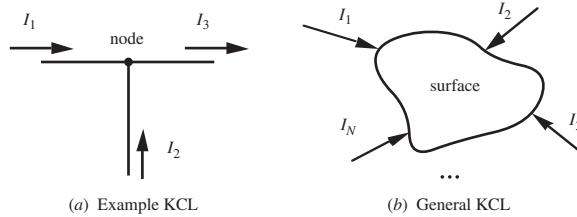


Figure 2.14 Kirchhoff's current law.

Lab Exercise 1 introduces many of the basic concepts presented so far in this chapter. The following practical skills are developed:

- Assembling basic circuits using a breadboard (see Video Demo 2.5)
- Making voltage and current measurements (see Video Demo 2.6)
- Reading resistor and capacitor values

More information and resources dealing with all of these topics can also be found in Section 2.10.

2.3.1 Series Resistance Circuit

Applying KVL to the simple series resistor circuit illustrated in Figure 2.15 yields some useful results. Assuming a current direction I , starting at node A , and following a clockwise direction yields

$$-V_s + V_{R_1} + V_{R_2} = 0 \quad (2.15)$$

From Ohm's law,

$$V_{R_1} = IR_1 \quad (2.16)$$

and

$$V_{R_2} = IR_2 \quad (2.17)$$

Substituting these two equations into Equation 2.15 gives

$$-V_s + IR_1 + IR_2 = 0 \quad (2.18)$$

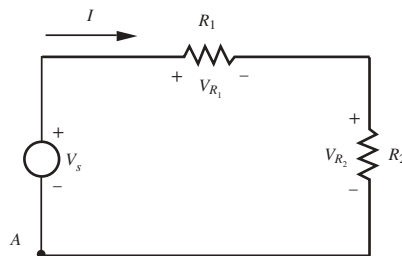


Figure 2.15 Series resistance circuit.



Lab Exercise

Lab 1

Introduction—
Resistor codes,
breadboard,
and basic
measurements



Video Demo

2.5 Breadboard
construction

2.6 Instrumentation
for powering
and making
measurements in
circuits

and solving for I yields

$$I = \frac{V_s}{(R_1 + R_2)} \quad (2.19)$$

Note that, if we had a single resistor of value $R_1 + R_2$, we would have the same result. Therefore resistors in series add, and the equivalent resistance of a series resistance circuit is

$$R_{\text{eq}} = R_1 + R_2 \quad (2.20)$$

In general, N resistors connected in series can be replaced by a single equivalent resistance given by

$$R_{\text{eq}} = \sum_{i=1}^N R_i \quad (2.21)$$

By applying KVL to capacitor and inductor circuits, it can be shown (Questions 2.13 and 2.14) that two capacitors in series combine as

$$C_{\text{eq}} = \frac{C_1 C_2}{C_1 + C_2} \quad (2.22)$$

and two inductors in series add:

$$L_{\text{eq}} = L_1 + L_2 \quad (2.23)$$

A circuit containing two resistors in series is referred to as a **voltage divider** because the source voltage V_s divides between each resistor. Expressions for the resistor voltages can be obtained by substituting Equation 2.19 into Equations 2.16 and 2.17 giving

$$V_{R_1} = \frac{R_1}{R_1 + R_2} V_s, \quad V_{R_2} = \frac{R_2}{R_1 + R_2} V_s \quad (2.24)$$

In general, for N resistors connected in series with a total applied voltage of V_s , the voltage V_{R_i} across any resistor R_i is

$$V_{R_i} = \frac{R_i}{R_{\text{eq}}} V_s = \frac{R_i}{\sum_{j=1}^N R_j} V_s \quad (2.25)$$

Voltage dividers are useful because they allow us to create different reference voltages in a circuit even if the circuit is energized only by a single output supply. However, care must be exercised that attached loads do not drain significant current and affect the voltage references produced with the dividers (see Class Discussion Item 2.6).

■ CLASS DISCUSSION ITEM 2.6

Improper Application of a Voltage Divider

Your car has a 12 V battery that powers some circuits in the car at lower voltage levels. Why is it inappropriate to use a simple voltage divider to create a lower voltage level for circuits that might draw variable current?

2.3.2 Parallel Resistance Circuit

Applying KCL to the simple parallel resistor circuit illustrated in Figure 2.16 also yields some useful results. Because each resistor experiences the same voltage V_s , as they are both in parallel with the source, Ohm's law gives

$$I_1 = \frac{V_s}{R_1} \quad (2.26)$$

and

$$I_2 = \frac{V_s}{R_2} \quad (2.27)$$

Applying KCL at node A gives

$$I - I_1 - I_2 = 0 \quad (2.28)$$

Substituting the currents from Equations 2.26 and 2.27 yields

$$I = \frac{V_s}{R_1} + \frac{V_s}{R_2} = V_s \left(\frac{1}{R_1} + \frac{1}{R_2} \right) \quad (2.29)$$

Replacing the resistance values R_1 and R_2 with their conductance equivalents $1/G_1$ and $1/G_2$ gives

$$I = V_s(G_1 + G_2) \quad (2.30)$$

A single resistor with a conductance of value $(G_1 + G_2)$ would have given the same result; therefore, conductances in parallel add. We can write Equation 2.30 as

$$I = V_s G_{\text{eq}} = \frac{V_s}{R_{\text{eq}}} \quad (2.31)$$

where G_{eq} is the equivalent conductance and R_{eq} is the equivalent resistance. By comparing the right-hand side of this equation to Equation 2.29, we get

$$\frac{1}{R_{\text{eq}}} = \frac{1}{R_1} + \frac{1}{R_2} \quad (2.32)$$

or

$$R_{\text{eq}} = \frac{R_1 R_2}{R_1 + R_2} \quad (2.33)$$

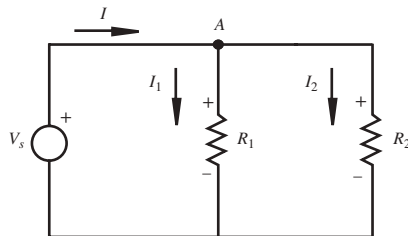


Figure 2.16 Parallel resistance circuit.

In general, N resistors connected in parallel can be replaced by a single equivalent resistance given by

$$\frac{1}{R_{\text{eq}}} = \sum_{i=1}^N \frac{1}{R_i} \quad (2.34)$$

or

$$R_{\text{eq}} = \frac{1}{\sum_{i=1}^N \frac{1}{R_i}} \quad (2.35)$$

By applying KCL to capacitor and inductor circuits, it can be shown (Questions 2.14 and 2.16) that two capacitors in parallel add:

$$C_{\text{eq}} = C_1 + C_2 \quad (2.36)$$

and two inductors in parallel combine as

$$L_{\text{eq}} = \frac{L_1 L_2}{L_1 + L_2} \quad (2.37)$$

A circuit containing two resistors connected in parallel is called a **current divider** because the source current I divides between each resistor. Expressions for the divided currents can be obtained by solving Equation 2.29 for V_s and substituting into Equation 2.26 and 2.27 giving

$$I_1 = \frac{R_2}{R_1 + R_2} I, \quad I_2 = \frac{R_1}{R_1 + R_2} I \quad (2.38)$$

Video Demo 2.7 illustrates the differences between parallel and series wiring of lighting. The demonstration illustrates voltage and current division and the effects on power output.

When drawing circuit schematics, by hand or with software tools, it is important to be consistent with how you show connections (or the lack thereof) at intersecting lines on the drawing. Figure 2.17 illustrates two conventions for doing this. The first convention (Figure 2.17a) is the most common and is what was used in Example 2.4. With this convention, a dot implies a connection, and the absence of a dot (at crossing lines only) implies no connection. Figure 2.17b shows an alternative convention where a dot is not required to indicate a connection as long as a crossing arc is used to indicate a nonconnection. Because the circuit diagrams in this chapter have been very simple, we really didn't need a convention—any crossing lines have been assumed to be connected. Even with the circuit in Example 2.4, the connection dots are not really required. People will assume there are connections at all intersecting lines in simple diagrams unless dot or arc features appear at one or more intersections. However, with more complicated circuits (e.g., those in Chapter 7 dealing with complicated microcontroller-based solutions), a clear and consistent convention is very important to present and interpret the intent of the designer.

Lab Exercise 2 provides experience with using various instruments including an oscilloscope, multimeter, power supply, and function generator (see Video Demo 2.6). The Lab also covers practical application of Ohm's law, KVL, and KCL, as applied for



Video Demo

2.7 Light bulb series and parallel circuit comparison



Lab Exercise

Lab 2 Instrument familiarization and basic electrical relations



Video Demo

2.6 Instrumentation for powering and making measurements in circuits

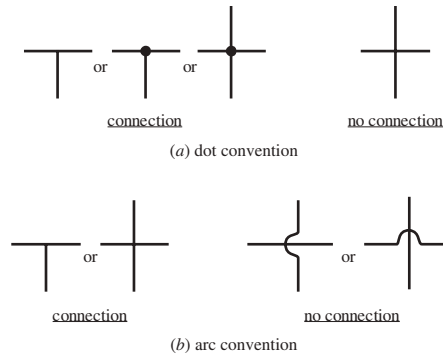
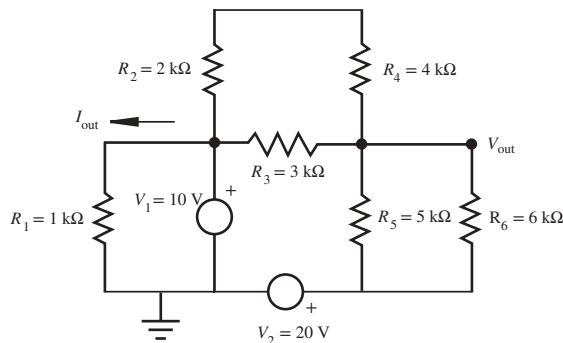


Figure 2.17 Circuit schematic connection conventions.

Circuit Analysis

EXAMPLE 2.4

As an example of how the tools presented in the previous sections apply to a nontrivial circuit, consider the following network, where the goal is to find I_{out} and V_{out} . At any node in the circuit, such as the one labeled by V_{out} , the voltage is defined with respect to the ground reference denoted by the ground symbol $\perp$. Voltage differences between any two points can be obtained by taking the difference between the ground-referenced values at the points.



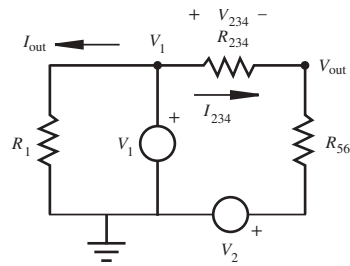
The first step is to combine resistor clusters between and around the sources (V_1 and V_2) and the branches of interest (those dealing with I_{out} and V_{out}) using the series and parallel resistance formulas (Equations 2.20 and 2.33). Resistors R_2 and R_4 are in series, with an equivalent resistance of $(R_2 + R_4)$, and this is in parallel with resistor R_3 . Resistors R_5 and R_6 are also in parallel. Therefore, the resultant resistances for the equivalent circuit that follows are

$$R_{234} = \frac{(R_2 + R_4)R_3}{(R_2 + R_4) + R_3} = 2.00 \text{ k}\Omega$$

$$R_{56} = \frac{R_5 R_6}{R_5 + R_6} = 2.73 \text{ k}\Omega$$

(continued)

(concluded)



Applying KVL to the left loop gives

$$V_1 = I_{\text{out}} R_1$$

so

$$I_{\text{out}} = V_1 / R_1 = 10 \text{ V} / 1 \text{ k}\Omega = 10 \text{ mA}$$

Applying KVL to the right loop tells us that the total voltage across R_{234} and R_{56} in the assumed direction of I_{234} is $(V_1 - V_2)$. Voltage division (Equation 2.24) can then be used to determine the voltage drop across R_{234} in the assumed direction of I_{234} :

$$V_{234} = \frac{R_{234}}{R_{234} + R_{56}} (V_1 - V_2) = -4.23 \text{ V}$$

Because V_1 is referenced to ground, the voltage on the left side of resistor R_{234} is V_1 ; and because the voltage drops by V_{234} across the resistor, the desired output voltage is

$$V_{\text{out}} = V_1 - V_{234} = 14.2 \text{ V}$$

Note that because V_{234} was found to be negative, the actual flow of current through R_{234} would be in the opposite direction from that assumed in this solution.

A myriad of methods may be used to solve this problem (e.g., see Question 2.26), and the one presented here is just an example solution, not necessarily the best method.



Video Demo

2.8 Connectors
(BNC, banana
plugs, alligator
clips)

making voltage and current measurements in circuits. Video Demo 2.8 shows the various types of cables and connectors that are used to connect instruments to each other and to circuits. Internet Link 2.6 is an excellent resource reviewing many topics related to electricity and DC circuit analysis.

2.4 VOLTAGE AND CURRENT SOURCES AND METERS

When we analyze electrical networks on paper, we usually assume that sources and meters are ideal. However, actual physical devices are not ideal, and it is sometimes necessary to account for their limitations when circuits contain these devices. The following ideal behavior is usually assumed:

- An **ideal voltage source** has zero output resistance and can supply infinite current.

- An **ideal current source** has infinite output resistance and can supply infinite voltage.
- An **ideal voltmeter** has infinite input resistance and draws no current.
- An **ideal ammeter** has zero input resistance and no voltage drop across it.

Unfortunately, real sources and meters have terminal characteristics that are somewhat different from the ideal cases. However, the terminal characteristics of the real sources and meters can be modeled using ideal sources and meters with their associated input and output resistances.

As shown in Figure 2.18, a “real” voltage source can be modeled as an ideal voltage source in series with a resistance called the **output impedance** of the device. When a load is attached to the source and current flows, the output voltage V_{out} will be different from the ideal source voltage V_s due to voltage division. The output impedance of most commercially available voltage sources (e.g., a power supply) is very small, usually a fraction of an ohm. For most applications, this impedance is small enough to be neglected. However, the output impedance can be important when driving a circuit with small resistance because the impedance adds to the resistance of the circuit. Figure 2.19 shows examples of two commercially available voltage sources.

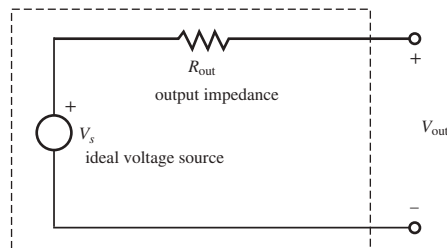


Figure 2.18 Real voltage source with output impedance.



Figure 2.19 Example of commercially available voltage sources.

©David Alciatore



Internet Link

2.6 All about circuits - Vol. I - DC

The top unit is a triple-output power supply that can provide three different voltages relative to ground, adjustable from 0 V, 20 V, and -20 V. The bottom unit is a programmable power supply that provides digitally controlled voltage sources.

As shown in Figure 2.20, a “real” current source can be modeled as an ideal current source in parallel with a resistance called the **output impedance**. When a load is attached to the source, the source current I_s divides between the output impedance and the load. The output impedance of most commercially available current sources is very large, minimizing the current division effect. However, this impedance can be important when driving a circuit with a large resistance.

As shown in Figure 2.21, a “real” ammeter can be modeled as an ideal ammeter in series with a resistance called the **input impedance** of the device. The input impedance of most commercially available ammeters is very small, minimizing the voltage drop V_R added in the circuit. However, this resistance can be important when making a current measurement through a circuit branch with small resistance because the output impedance adds to the resistance of the branch.

As shown in Figure 2.22, a “real” voltmeter can be modeled as an ideal voltmeter in parallel with an input impedance. The input impedance of most commercially

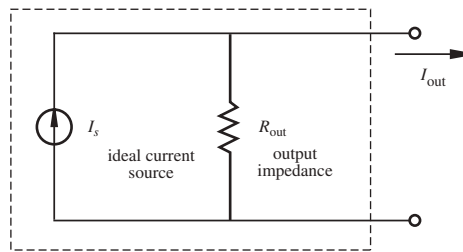


Figure 2.20 Real current source with output impedance.

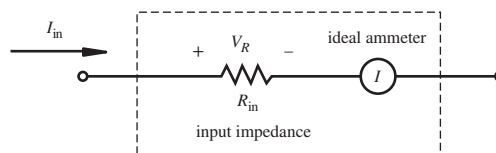


Figure 2.21 Real ammeter with input impedance.

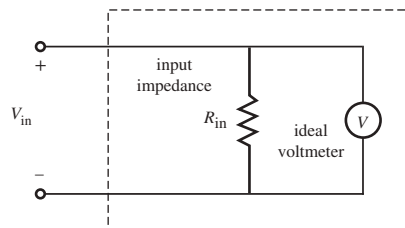


Figure 2.22 Real voltmeter with input impedance.

available voltmeters (e.g., an oscilloscope or multimeter) is very large, usually on the order of 1–10 M Ω . However, this resistance must be considered when making a voltage measurement across a circuit branch with large resistance because the parallel combination of the meter input impedance and the circuit branch would result in significant error in the measured value.

Figure 2.23 shows an example of a commercially available **digital multimeter** (DMM) that contains, among other things, an ammeter and a voltmeter. Figure 2.24 shows an example of a commercially available oscilloscope that contains a voltmeter capable of digitizing, displaying, and recording dynamic measurements. Internet Link 2.7 provides links to various online resources and vendors that offer an assortment of instrumentation (power supplies, function generators, multimeters, oscilloscopes, data acquisition equipment, and more).

Lab Exercise 2 provides experience with the effects of input and output impedance of various instruments. It is important to know how these instrument characteristics can affect voltage and current measurements. Section 2.10.3 has more information and resources on these topics. Lab Exercise 3 provides a complete overview of how to use an oscilloscope. Features and concepts covered include how to connect signals, grounding, coupling, and triggering. Video Demo 2.9 demonstrates how to use a typical analog oscilloscope. Many of the concepts involved with using an analog scope are also relevant with other scopes, even more sophisticated digital scopes and software-controlled virtual instruments (covered in Section 8.6). More information and resources dealing with how to use an oscilloscope properly can be found in Section 2.10.5.



Figure 2.23 Example of commercially available digital multimeters.
©Oleksiy Maksymenko/Alamy



Figure 2.24 Example of a commercially available oscilloscope.
©Huntstock/Getty Images



Internet Link

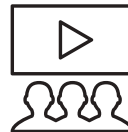
2.7 Instrumentation online resources and vendors



Lab Exercise

Lab 2 Instrument familiarization and basic electrical relations

Lab 3 The oscilloscope

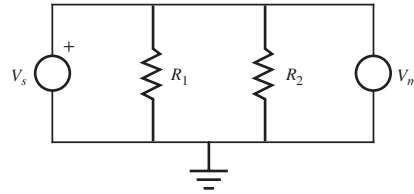


Video Demo

2.9 Oscilloscope demonstrations using the Tektronix 2215 analog scope

EXAMPLE 2.5**Input and Output Impedance**

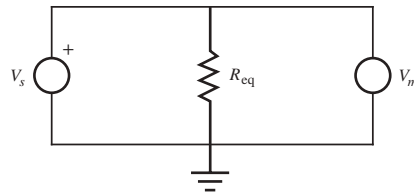
This example illustrates the effects of source and meter output and input impedance on making measurements in a circuit. Consider the following circuit with voltage source V_s and voltage meter V_m .



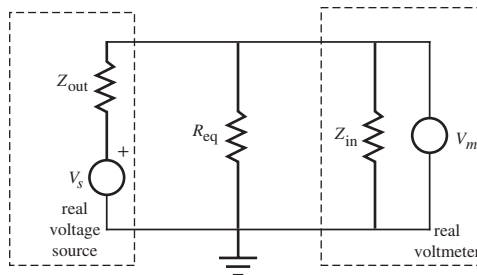
The equivalent resistance for this circuit is

$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2}$$

If the source and meter were both ideal, the measured voltage V_m would be equal to V_s , and the equivalent circuit would look like this:

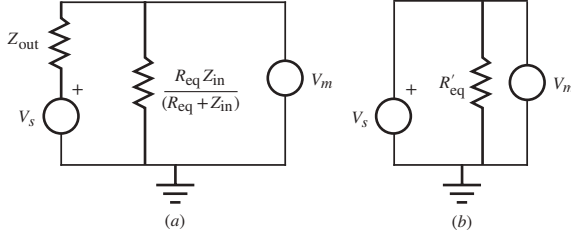


However, if the source has output impedance Z_{out} and the meter has input impedance Z_{in} , the “real” circuit actually looks like this:



The parallel combination of R_{eq} and Z_{in} yields the following circuit (a). Z_{out} and the parallel combination of R_{eq} and Z_{in} are now effectively in series because no current flows into the ideal meter V_m . Thus, the total equivalent resistance shown in circuit (b) is

$$R'_{eq} = \frac{R_{eq} Z_{in}}{R_{eq} + Z_{in}} + Z_{out}$$



Note that R'_{eq} defined in the previous equation approaches R_{eq} as Z_{in} approaches infinity and Z_{out} approaches 0. From voltage division in circuit (a), the voltage measured by the actual meter would be

$$V_m = \frac{\frac{R_{eq} Z_{in}}{(R_{eq} + Z_{in})}}{\frac{R_{eq} Z_{in}}{(R_{eq} + Z_{in})} + Z_{out}} V_s = \frac{R'_{eq} - Z_{out}}{R'_{eq}} V_s$$

The measured voltage V_m equals V_s for $Z_{in} = \infty$ and $Z_{out} = 0$, but with a real source and real meter, the measured voltage could differ appreciably from the expected ideal result. For example, if $R_1 = R_2 = 1 \text{ k}\Omega$,

$$R_{eq} = \frac{1 \cdot 1}{1 + 1} \text{ k}\Omega = 0.5 \text{ k}\Omega$$

and if $Z_{in} = 1 \text{ M}\Omega$ and $Z_{out} = 50 \text{ }\Omega$,

$$R'_{eq} = \frac{0.5 \cdot 1000}{0.5 + 1000} + 0.05 \text{ k}\Omega = 0.550 \text{ k}\Omega$$

Therefore, if $V_s = 10 \text{ V}$,

$$V_m = \left(\frac{0.550 - 0.05}{0.550} \right) 10 \text{ V} = 9.09 \text{ V}$$

This differs substantially from the result that would be expected (10 V) with an ideal source and meter.

2.5 THEVENIN AND NORTON EQUIVALENT CIRCUITS

Sometimes, to simplify the analysis of more complex circuits, we wish to replace voltage sources and resistor networks with an equivalent voltage source and series resistor. This is called a **Thevenin equivalent** of the circuit. Thevenin's theorem states that, given a pair of terminals in a linear network, the network may be replaced by an ideal voltage source V_{OC} in series with a resistance R_{TH} . V_{OC} is equal to the open circuit voltage across the terminals, and R_{TH} is the equivalent resistance across

the terminals when independent voltage sources are shorted and independent current sources are replaced with open circuits.

We will illustrate Thevenin's theorem with the circuit shown in Figure 2.25. The part of the circuit in the dashed box will be replaced by its Thevenin equivalent. The open circuit voltage V_{OC} is found by disconnecting the rest of the circuit and determining the voltage across the terminals of the remaining open circuit. For this example, the voltage divider rule gives

$$V_{OC} = \frac{R_2}{R_1 + R_2} V_s \quad (2.39)$$

To find R_{TH} , the supply V_s is shorted (i.e., $V_s = 0$), grounding the left end of R_1 . If there were current sources in the circuit, they would be replaced with open circuits. Because R_1 and R_2 are in parallel relative to the open terminals, the equivalent resistance is

$$R_{TH} = \frac{R_1 R_2}{R_1 + R_2} \quad (2.40)$$

The Thevenin equivalent circuit is shown in Figure 2.26.

Another equivalent circuit representation is the **Norton equivalent**, shown in Figure 2.27. Here the linear network is replaced by an ideal current source I_{SC} and the Thevenin resistance R_{TH} in parallel with this source. I_{SC} is found by calculating

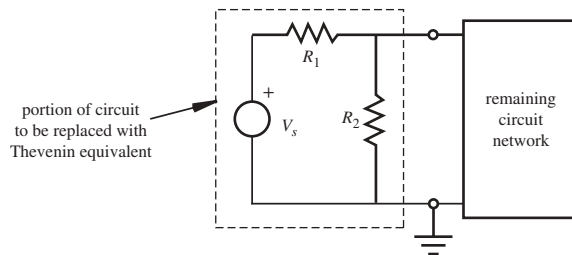


Figure 2.25 Example illustrating Thevenin's theorem.

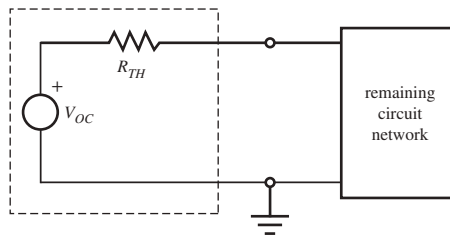


Figure 2.26 Thevenin equivalent circuit.

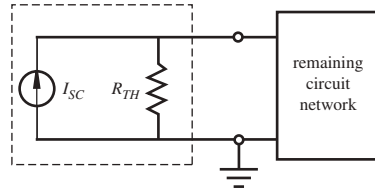


Figure 2.27 Norton equivalent circuit.

the current that would flow through the terminals if they were shorted together, having removed the remaining load circuit. It can be shown that the current I_{SC} flowing through R_{TH} produces the Thevenin voltage V_{OC} just discussed.

The Thevenin and Norton equivalents are independent of the remaining circuit network representing a load. This is useful because it is possible to make changes in the load without reanalyzing the Thevenin or Norton equivalent.

2.6 ALTERNATING CURRENT CIRCUIT ANALYSIS

When linear circuits are excited by alternating current (AC) signals of a given frequency, the current through and voltage across every element in the circuit are AC signals of the same frequency. A sinusoidal AC voltage $V(t)$ is illustrated in Figure 2.28 and can be expressed mathematically as

$$V(t) = V_m \sin(\omega t + \phi) \quad (2.41)$$

where V_m is the signal **amplitude**, ω is the **angular frequency** measured in radians per second, and ϕ is the **phase angle** relative to the reference sinusoid $V_m \sin(\omega t)$ measured in radians. The phase angle is related to the **time shift** (Δt) between the signal and reference:

$$\phi = \omega \Delta t \quad (2.42)$$

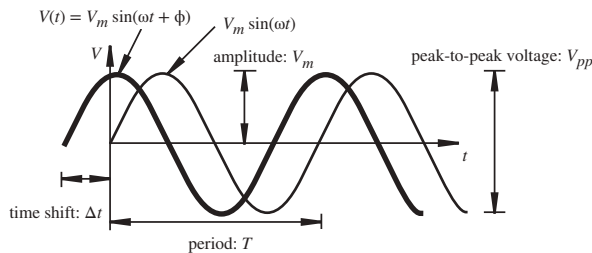


Figure 2.28 Sinusoidal waveform.

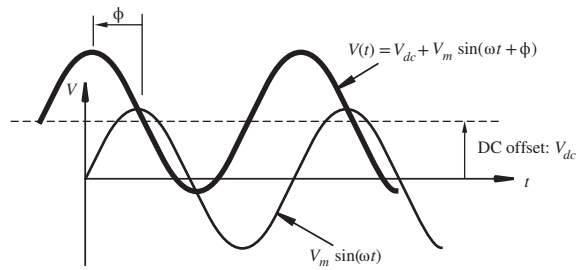


Figure 2.29 Sinusoidal signal DC offset.

A positive phase angle ϕ implies a **leading** waveform (i.e., it occurs earlier, or to the left, on the time axis), and a negative angle implies a **lagging** waveform (i.e., it occurs later, or to the right, on the time axis). The **period** T of the waveform is the time required for a full cycle. The frequency of the signal, measured in hertz (Hz = cycle/sec), is related to the period and angular frequency as

$$f = \frac{1}{T} = \frac{\omega}{2\pi} \quad (2.43)$$

Figure 2.29 illustrates another important sinusoidal waveform parameter called the **DC offset**. It represents the vertical shift of the signal from the reference sinusoid. Mathematically, the DC offset is represented by the term V_{dc} in the equation:

$$V(t) = V_{dc} + V_m \sin(\omega t + \phi) \quad (2.44)$$

Figures 2.28 and 2.29 illustrate a positive phase angle (ϕ), where the voltage signal $V(t)$ leads (i.e., occurs earlier in time relative to) the reference sine wave.

EXAMPLE 2.6

AC Signal Parameters

As an example of how the AC signal parameters are discerned in a signal equation, consider the following AC voltage:

$$V(t) = 5.00 \sin(t - 1) \text{ V}$$

The signal amplitude is

$$V_m = 5.00 \text{ V}$$

The signal angular frequency is

$$\omega = 1.00 \text{ rad/sec}$$

ω is the coefficient of the time variable t in the argument of the sinusoid. Similarly, the frequency in hertz is

$$f = \frac{\omega}{2\pi} = \frac{1}{2\pi} \text{ Hz} = 0.159 \text{ Hz}$$

and the phase angle is

$$\phi = -1 \text{ rad} = -57.3^\circ$$

The negative phase indicates the signal lags (i.e., occurs later in time relative to) the reference ($\sin(t)$). The arguments of the sinusoids are always assumed to be specified in radians for computational purposes.

Alternating current power is used in many applications where direct current (DC) power is impractical or infeasible. Principal reasons for using AC power include:

- AC power is more efficient to transmit over long distances because it is easily transformed to a high-voltage, low-current form, minimizing power losses (see Section 2.7) during transmission. In residential areas, it is easily transformed back to required levels. Note that the voltage drop in the transmission line is small compared to the voltage level at the source.
- AC power is easy to generate with rotating machinery (e.g., a generator).
- AC power is easy to use to drive rotating machinery (e.g., an AC electric motor).
- AC power provides a fixed frequency signal (60 Hz in the United States, 50 Hz in Europe) that can be used for timing purposes and synchronization.

■ CLASS DISCUSSION ITEM 2.7

Reasons for AC

Justify and fully explain the reasons why AC power is used in virtually all commercial and public utility systems. Refer to the reasons just listed.

The steady state analysis of AC circuits is simplified by the use of **phasor** analysis, which uses complex numbers to represent sinusoidal signals. **Euler's formula** forms the basis for this analysis:

$$e^{j(\omega t + \phi)} = \cos(\omega t + \phi) + j \sin(\omega t + \phi) \quad (2.45)$$

where j represents the imaginary number $\sqrt{-1}$. This implies that sinusoidal signals can be expressed as real and imaginary components of **complex exponentials**. Because of the mathematical ease of manipulating exponential expressions vs. trigonometric expressions, this form of analysis is convenient for making and interpreting calculations.

Once all transients have dissipated in an AC circuit after power is applied, the voltage across and current through each element will oscillate with the same frequency ω as the input. The amplitude of the voltage and current for each element

will be constant (for a constant-amplitude input) but may differ in phase from the input. This fact lets us treat circuit variables (voltages, currents, and impedances) as complex exponentials with given or calculated magnitudes and phases for a “steady state” analysis. A phasor (e.g., a voltage V of magnitude V_m and phase ϕ) is a vector representation of the complex exponential:

$$V = V_m e^{j(\omega t + \phi)} = V_m \langle \phi \rangle = V_m [\cos(\omega t + \phi) + j \sin(\omega t + \phi)] \quad (2.46)$$

where $V_m e^{j(\omega t + \phi)}$ is the complex exponential form, $V_m \langle \phi \rangle$ is the **polar form**, and $V_m [\cos(\omega t + \phi) + j \sin(\omega t + \phi)]$ is the complex **rectangular form** of the phasor. A graphical interpretation of these quantities is shown on the complex plane in Figure 2.30. Note that the phase angle ϕ is measured from the ωt reference.

Useful mathematical relations for manipulating complex numbers and phasors include

$$r = \sqrt{x^2 + y^2} \quad (2.47)$$

$$\phi = \tan^{-1}\left(\frac{y}{x}\right) \quad (2.48)$$

$$x = r \cos(\phi) \quad (2.49)$$

$$y = r \sin(\phi) \quad (2.50)$$

$$(x_1 + y_1 j) + (x_2 + y_2 j) = (x_1 + x_2) + (y_1 + y_2) j \quad (2.51)$$

$$r_1 \langle \phi_1 \rangle \cdot r_2 \langle \phi_2 \rangle = r_1 \cdot r_2 \langle \phi_1 + \phi_2 \rangle \quad (2.52)$$

$$r_1 \langle \phi_1 \rangle / r_2 \langle \phi_2 \rangle = r_1 / r_2 \langle \phi_1 - \phi_2 \rangle \quad (2.53)$$

where r is the phasor magnitude, ϕ is the phasor angle, x is the real component, and y is the imaginary component. Note that the quadrant determined by the arguments (x, y) of the arctangent function must be carefully considered when converting from rectangular to polar form. For example, if $x = y = -1$, $\phi = -135^\circ$, not 45° that you

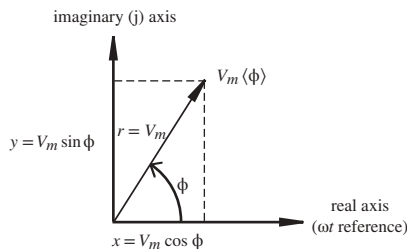


Figure 2.30 Phasor representation of a sinusoidal signal.

would get if you carelessly used a single argument $\tan^{-1}$ function on a calculator or in a computer program.

Ohm's law can be extended to the AC circuit analysis of resistor, capacitor, and inductor elements as

$$V = ZI \quad (2.54)$$

where Z is called the **impedance** of the element. This is a complex number, and you can imagine Z as a complex, frequency-dependent resistance. Impedances can be derived from the fundamental constitutive equations for the elements using complex exponentials. The unit of impedance is the ohm (Ω).

For the resistor, because $V = IR$,

$$Z_R = R \quad (2.55)$$

For the inductor, because $V = L \frac{dI}{dt}$, if $I = I_m e^{j(\omega t + \phi)}$, then

$$V = Lj\omega I_m e^{j(\omega t + \phi)} = (Lj\omega)I \quad (2.56)$$

Therefore, the impedance of an inductor is given by

$$Z_L = j\omega L = \omega L \langle 90^\circ \rangle \quad (2.57)$$

which implies that the voltage will lead the current by 90° . Note that because a DC signal can be considered an AC signal with zero frequency ($\omega = 0$), the impedance of an inductor in a DC circuit is 0. Therefore, it acts as a short in a DC circuit. At very high AC frequencies ($\omega = \infty$), the inductor has infinite impedance, so it behaves as an open circuit.

For the capacitor, because $I = C \frac{dV}{dt}$, if $V = V_m e^{j(\omega t + \phi)}$, then

$$I = Cj\omega V_m e^{j(\omega t + \phi)} = (Cj\omega)V \quad (2.58)$$

giving

$$V = \left(\frac{1}{Cj\omega} \right) I \quad (2.59)$$

Therefore, the impedance of a capacitor is given by

$$Z_C = \frac{1}{j\omega C} = \frac{-j}{\omega C} = \frac{1}{\omega C} \langle -90^\circ \rangle \quad (2.60)$$

which implies the voltage will lag the current by 90° . The impedance of a capacitor in a DC circuit ($\omega = 0$) is infinite, so it acts as an open circuit. At very high AC frequencies ($\omega = \infty$), the capacitor has zero impedance, so it acts as a short circuit.

As illustrated in Example 2.7, every result presented in previous sections for analyzing simple DC circuits, including Ohm's law, series and parallel resistance

**Internet Link**

2.8 All about
circuits - Vol. II - AC

combinations, voltage division, and current division, applies to the AC signals and impedances just presented. Internet Link 2.8 is an excellent resource that reviews AC electricity, circuit analysis, and devices.

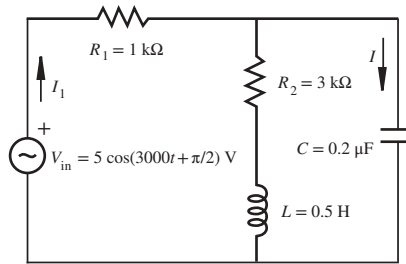
In circuits with multiple sources, it is important to express all of them in either their sine or cosine form consistently so that the phase relationships are relative to a consistent reference. The following trigonometric identities are useful in accomplishing this:

$$\sin(\omega t + \phi) = \cos(\omega t + \phi - \pi/2) \quad (2.61)$$

$$\cos(\omega t + \phi) = \sin(\omega t + \phi + \pi/2) \quad (2.62)$$

EXAMPLE 2.7**AC Circuit Analysis**

The following is an illustrative example of AC circuit analysis. The goal is to find the steady state AC current I through the capacitor in the circuit:



Because the input voltage source is

$$V_{in} = 5 \cos\left(3000t + \frac{\pi}{2}\right) \text{ V}$$

each element in the circuit will respond at the same angular frequency:

$$\omega = 3000 \text{ rad/sec}$$

Because the voltage source has a magnitude of 5 V and a phase of $\pi/2$, relative to $\cos(3000t)$, the phasor and complex form of the source is

$$V_{in} = 5\langle 90^\circ \rangle \text{ V} = (0 + 5j) \text{ V}$$

The complex and phasor form of the capacitor impedance is

$$Z_C = -j/\omega C = -1666.67j \, \Omega = 1666.67\langle -90^\circ \rangle \, \Omega$$

The complex and phasor form of the inductor impedance is

$$Z_L = j\omega L = 1500j \, \Omega = 1500\langle 90^\circ \rangle \, \Omega$$

To find the current (I) through the capacitor, we will first find the current through the entire circuit (I_1) and then use current division. Therefore, we need the impedance

of the middle branch of the circuit, along with the equivalent impedance of the entire circuit.

Resistor R_2 and inductor L are in series, so their combined impedance, in both rectangular and phasor form, using Equations 2.47 and 2.48, is:

$$R_2 + Z_L = (3000 + 1500j) \Omega = 3354.1 \angle 26.57^\circ \Omega$$

This impedance is in parallel with capacitor C , and the combined impedance of this parallel combination, using Equation 2.33, is:

$$\frac{(R_2 + Z_L)Z_C}{(R_2 + Z_L) + Z_C}$$

The numerator of this expression can be calculated using Equation 2.52:

$$(R_2 + Z_L)Z_C = 3354.1 \angle 26.57^\circ \cdot 1666.67 \angle -90^\circ \Omega = 5,590,180 \angle -63.43^\circ \Omega$$

The denominator can be found using Equation 2.51:

$$(R_2 + Z_L) + Z_C = [(3000 + 1500j) - 1666.67j] \Omega = (3000 - 166.67j) \Omega$$

Using Equations 2.47 and 2.48, the phasor form of this impedance, which is required to perform the division, is:

$$(R_2 + Z_L) + Z_C = (3000 - 166.67j) \Omega = 3004.63 \angle -3.18^\circ \Omega$$

Therefore, the parallel combination of $(R_2 + Z_L)$ and Z_C , using Equation 2.53, is:

$$\frac{(R_2 + Z_L)Z_C}{(R_2 + Z_L) + Z_C} = \frac{5,590,180 \angle -63.43^\circ}{3004.63 \angle -3.18^\circ} \Omega = 1860.52 \angle -60.25^\circ \Omega$$

The rectangular form of this impedance, using Equations 2.49 and 2.50, is:

$$\frac{(R_2 + Z_L)Z_C}{(R_2 + Z_L) + Z_C} = 1860.52 \angle -60.25^\circ \Omega = (923.22 - 1615.30j) \Omega$$

This impedance is in series with resistor R_1 , so the equivalent impedance of the entire circuit is:

$$Z_{eq} = R_1 + \frac{(R_2 + Z_L)Z_C}{(R_2 + Z_L) + Z_C} = 1000 + (923.22 - 1615.30j) \Omega = 1923.22 - 1615.30j \Omega$$

From Equations 2.47 and 2.48, the phasor form of this impedance is:

$$Z_{eq} = (1923.22 - 1615.30j) \Omega = 2511.57 \angle -40.03^\circ \Omega$$

We can now find I_1 from Ohm's law:

$$I_1 = \frac{V_{in}}{Z_{eq}} = \frac{5 \angle 90^\circ}{2511.57 \angle -40.03^\circ} = 1.991 \angle 130.03^\circ \text{ mA}$$

Current division is used to find I

$$I = \frac{(R_2 + Z_L)}{(R_2 + Z_L) + Z_C} I_1 = \frac{3354.1 \angle 26.57^\circ}{3004.63 \angle -3.18^\circ} 1.991 \angle 130.03^\circ \text{ mA}$$

(continued)

(concluded)

which, using Equations 2.52 and 2.53, gives

$$I = 2.22 \angle 159.8^\circ \text{ mA}$$

so the capacitor current leads the input reference by 159.8° or 2.789 rad, and the resulting current is

$$I(t) = 2.22 \cos(3000t + 2.789) \text{ mA}$$

Note that if the input voltage were $V_{in} = 5 \sin(3000t + \pi/2) \text{ V}$ instead, the resulting current would be $I(t) = 2.22 \sin(3000t + 2.789) \text{ mA}$. But in this example, the reference voltage was $\cos(3000t)$.

Mathcad/Matlab Example 2.1 executes all of the analyses above using a software. Phasors can be entered or displayed in polar or rectangular form, and all calculations are performed with ease. If you are not familiar with Mathcad, you might want to watch Video Demo 2.10, which describes and demonstrates the software and its capabilities.

MATLAB®
examples

2.1 AC circuit analysis

2.7 POWER IN ELECTRICAL CIRCUITS

All circuit elements dissipate, store, or deliver power through the physical interaction between charges and electromagnetic fields. An expression for power can be derived by first looking at the infinitesimal work (dW) done when an infinitesimal charge (dq) moves through an electric field resulting in a change in potential represented by a voltage V . This infinitesimal work is given by

$$dW = Vdq \quad (2.63)$$

Because **power** is the rate of work done,

$$P = \frac{dW}{dt} = V \frac{dq}{dt} = VI \quad (2.64)$$

Therefore, the power consumed or generated by an element is simply the product of the voltage across and the current through the element. If the current flows in the direction of decreasing voltage as shown in Figure 2.31, P is negative, implying that the element is dissipating or storing energy. If the current flows in the direction of increasing voltage, P is positive, implying that the element is generating or releasing energy. The instantaneous power in a resistive circuit can be expressed as

$$P = VI = I^2R = V^2/R \quad (2.65)$$

For AC signals, because $V = V_m \sin(\omega t + \phi_V)$ and $I = I_m \sin(\omega t + \phi_I)$, the power changes continuously over a period of the AC waveform. Instantaneous power is not a useful quantity by itself, but if we look at the average power delivered over a period, we get a good measure of the circuit's or component's overall power



Video Demo

2.10 Mathcad analysis software demo

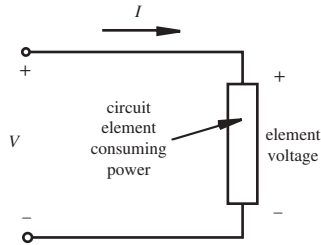


Figure 2.31 Power in a circuit element.

characteristics. It can be shown (Question 2.46) that the average power over a period is

$$P_{\text{avg}} = \frac{V_m I_m}{2} \cos(\theta) \quad (2.66)$$

where θ is the difference between the voltage and current phase angles ($\phi_V - \phi_I$), which is the phase angle of the complex impedance $Z = V/I$.

If we use the rms, or **root-mean-square** values of the voltage and current defined, respectively, by

$$I_{\text{rms}} = \sqrt{\frac{1}{T} \int_0^T I^2 dt} = \frac{I_m}{\sqrt{2}} \quad \text{and} \quad V_{\text{rms}} = \sqrt{\frac{1}{T} \int_0^T V^2 dt} = \frac{V_m}{\sqrt{2}} \quad (2.67)$$

the average AC power consumed by a resistor can be expressed in the same form as with DC circuits (see Question 2.49):

$$P_{\text{avg}} = V_{\text{rms}} I_{\text{rms}} = R I_{\text{rms}}^2 = V_{\text{rms}}^2 / R \quad (2.68)$$

■ CLASS DISCUSSION ITEM 2.8

Transmission Line Losses

When power is transmitted from power plants over large distances, high-voltage lines are used. Transformers (see Section 2.8) are used to change voltage levels both before and after transmission. Because current is lower at the higher voltage, less power is lost during the transmission, based on the middle expression ($I^2 R$) for power in Equation 2.65. But doesn't the last expression (V^2/R) imply that more power is lost at a higher voltage? How do you explain this apparent discrepancy?

■ CLASS DISCUSSION ITEM 2.9

International AC

In European countries, the household AC signal is 220 V_{rms} at 50 Hz. What effect does this have on electrical devices such as an electric razor purchased in the United States but used in these countries without an appropriate power adapter?

For AC networks with inductance and capacitance in addition to resistance, the average power consumed by the network can be expressed, using Equations 2.66 and 2.67, as

$$P_{\text{avg}} = I_{\text{rms}} V_{\text{rms}} \cos \theta = I_{\text{rms}}^2 |Z| \cos \theta = (V_{\text{rms}}^2 / |Z|) \cos \theta \quad (2.69)$$

where $|Z|$ is the magnitude of the complex impedance. $\cos \theta$ is called the **power factor**, because the average power dissipated by the network is dependent on this term.

■ CLASS DISCUSSION ITEM 2.10

AC Line Waveform

Draw a figure that represents one cycle of the AC voltage signal present at a typical household wall receptacle. What is the amplitude, frequency, period, and rms value for the voltage? Also, what is a typical rms current capacity for a household circuit?

2.8 TRANSFORMERS

A transformer is a device used to change the relative amplitudes of voltage and current in an AC circuit. As illustrated in Figure 2.32, it consists of primary and secondary windings whose magnetic fluxes are linked by a ferromagnetic core.

Video Demo 2.11 shows an example of an actual transformer, in this case a laminated core, shell-type power transformer.

Using Faraday's law of induction and neglecting magnetic losses, the voltage per turn of wire is the same for both the primary and secondary windings, because the windings experience the same alternating magnetic flux. Therefore, the primary and secondary voltages (V_P and V_S) are related by

$$\frac{V_P}{N_P} = \frac{V_S}{N_S} = -\frac{d\phi}{dt} \quad (2.70)$$

where N_P is the number of turns in the primary winding, N_S is the number of turns in the secondary winding, and ϕ is the magnetic flux linked between the two coils. Thus, the secondary voltage is related to the primary voltage by

$$V_S = \frac{N_S}{N_P} V_P \quad (2.71)$$



Video Demo

2.11 Power transformer with laminated core

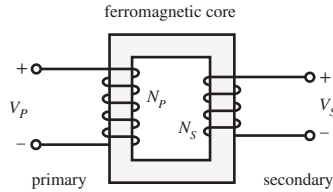


Figure 2.32 Transformer.

where N_S/N_P is the ratio of the number of turns of the transformer. If $N_S > N_P$, the transformer is called a **step-up transformer** because the voltage increases. If $N_S < N_P$, it is called a **step-down transformer** because the voltage decreases. If $N_S = N_P$, it is called an **isolation transformer**, and the output voltage is the same as the input voltage. All transformers electrically isolate the output circuit from the input circuit.

If we neglect losses in the transformer due to winding resistance and magnetic effects, the power in the primary and secondary circuits is equal:

$$I_P V_P = I_S V_S \quad (2.72)$$

Using Equation 2.71 we obtain following relation between the secondary and primary currents:

$$I_S = \frac{N_P}{N_S} I_P \quad (2.73)$$

Thus, a step-up transformer results in lower current in the secondary and a step-down transformer results in higher current. An isolation transformer has equal alternating currents in both the primary and secondary. Note that any DC component of voltage or current in a transformer primary will not appear in the secondary. Only alternating currents add “and voltages”? are transformed.

■ CLASS DISCUSSION ITEM 2.11

DC Transformer

Can a transformer be used to increase voltage in a DC circuit? Why or why not?

2.9 IMPEDANCE MATCHING

Often we must be careful when connecting different devices and circuits together. For example, when using certain function generators to drive a circuit, proper **signal termination**, or loading, may be required as illustrated in Figure 2.33. Placing the $50\ \Omega$ termination resistance in parallel with a higher impedance network helps match the receiving network input impedance to the function generator output

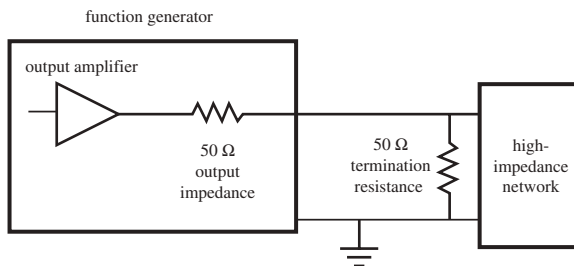


Figure 2.33 Signal termination.

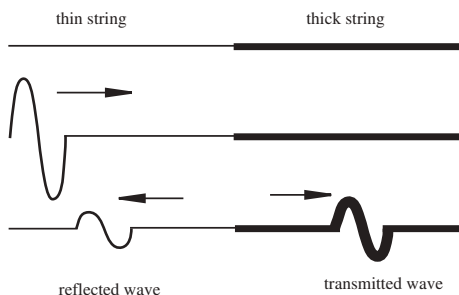


Figure 2.34 Impedance matching—string analogy.

impedance. This is called **impedance matching**. If we do not match impedances, a high-impedance network will reflect frequency components of the driving circuit (e.g., the function generator), especially the high-frequency components. A good analogy to this effect is a thin string attached to a thicker string. As illustrated in Figure 2.34, if we propagate transverse vibrations along the thin string, there will be partial transmission to the thick string and partial reflection back to the source. This is a result of the mismatch of the properties at the interface between the two strings.

In addition to signal termination concerns, impedance matching is important in applications where it is desired to transmit maximum power to a load from a source. This concept is easily illustrated with the simple resistive circuit shown in Figure 2.35 with source voltage V_s , source output impedance R_s , and load resistance R_L . The voltage across the load is given by voltage division:

$$V_L = \frac{R_L}{R_L + R_s} V_s \quad (2.74)$$

Therefore, the power transmitted to the load is

$$P_L = \frac{V_L^2}{R_L} = \frac{R_L}{(R_L + R_s)^2} V_s^2 \quad (2.75)$$

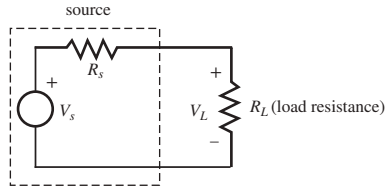


Figure 2.35 Impedance matching.

To find the load resistance that maximizes this power, we set the derivative of the power equal to 0 and solve for the load resistance:

$$\frac{dP_L}{dR_L} = V_s^2 \frac{(R_L + R_s)^2 - 2R_L(R_L + R_s)}{(R_L + R_s)^4} = 0 \quad (2.76)$$

The derivative is 0 only when the numerator is 0, so

$$(R_L + R_s)^2 = 2R_L(R_L + R_s) \quad (2.77)$$

Solving for R_L gives

$$R_L = R_s \quad (2.78)$$

The second derivative of power can be checked to verify that this solution results in a maximum and not a minimum. The result of this analysis is as follows: To maximize power transmission to a load, the load's impedance should match the source's impedance.

■ CLASS DISCUSSION ITEM 2.12

Audio Stereo Amplifier Impedances

Why are audio stereo amplifier output impedances important specifications when selecting speakers?

■ CLASS DISCUSSION ITEM 2.13

Common Usage of Electrical Components

Cite specific examples in your experience where and how each of the following electrical components is used:

- Battery
- Resistor
- Capacitor
- Inductor
- Voltage divider
- Transformer

2.10 PRACTICAL CONSIDERATIONS

This chapter has presented all of the fundamentals and theory of basic electrical circuits. This final section presents various practical considerations that come up when trying to assemble actual circuits that function properly and reliably. The Laboratory Exercises book (see mechatronics.colostate.edu/lab_book.html) that accompanies this textbook provides some useful exercises to help you develop prototyping and measurement skills, and the sections below provide some additional supporting information.

2.10.1 Capacitor Information

As we saw in Section 2.2.1, determining resistance values from a discrete resistor component is very easy—a simple matter of looking up color values in a table. Unfortunately, capacitor labeling is not nearly as straightforward.

A capacitor is sometimes referred to as a “cap.” Large caps are usually the electrolytic type that must be attached to a circuit with an indicated polarity. Because large capacitors have a large package size, the manufacturer usually prints the value clearly on the package, including the unit prefix. The only thing you need to be careful with is the capital letter M, which is often used to indicate micro, not mega. For example, an electrolytic capacitor labeled “+500MF” indicates a 500 μF capacitor.

It is very important to be careful with electrolytic-capacitor polarity. The capacitor’s internal construction is not symmetrical, and you can destroy the cap if you apply the wrong polarity to the terminals: the terminal marked + must be at a higher voltage than the other terminal. Sometimes, violating this rule will result in gas formation internally that can cause the cap to explode. Improper polarity can also cause the cap to become shorted.

As the caps get smaller, determining the value becomes more difficult. Tantalum caps are silver-colored cylinders. They are polarized: a + mark and/or a metal nipple mark the positive end. An example label is +4R7m. This is fairly clear as long as you know that the “R” marks the decimal place: A +4R7m is a 4.7 mF (millifarad) cap. The same cap could also be labeled +475K, which you might think is 475 kilofarads, but you would be wrong. Here, the “K” is a tolerance indicator, not a unit prefix. “K” means $\pm 10\%$ (see more below). Capacitance values are usually quite small on the Farad scale. The values are usually in the microfarad ($\mu\text{F} = 10^{-6} \text{ F}$) to picofarad ($\text{pF} = 10^{-12} \text{ F}$) range. Labeling on tantalum caps mimics the resistor code system: 475 indicates 47 times ten to the fifth power, and the unit prefix pF is assumed. In general, if a cap’s numerical value is indicated as a fraction (e.g., 0.01), the unit prefix will almost always be micro (μ); and if the value is a large integer (e.g., 47×10^5), pF will apply. The prefix nano ($\text{n} = 10^{-9}$) is usually not used for capacitance values. Returning to the example, a tantalum cap labeled “475” must be $47 \times 10^5 \text{ pF}$, which is $4.7 \times 10^6 \text{ pF}$, which is $4.7 \times 10^{-6} \text{ F}$ or 4.7 μF .

Mylar capacitors are usually yellow cylinders that are rather clearly marked. For example, “.01M” is just 0.01 μF . Mylar caps are not polarized, so you can orient them at random in your circuits. Because they are fabricated as long coils of metal foil (separated by a thin dielectric—the “mylar” that gives them their name), mylar

caps betray their function at very high frequencies where the inductance of the coil become significant, blocking the very high frequencies you would expect a cap to pass. Ceramic caps, described next, are better in this respect, although they are very poor in other characteristics.

Ceramic caps have a flat, round shape (like pancakes) and are usually orange-colored. Because of their shape and construction (in contrast to the coiled mylars), they act like capacitors even at high frequencies. The trick in reading these is to ignore the markings that might accidentally be interpreted as units. For example, a ceramic cap labeled “Z5U .02M 1kV” is a 0.02 μF cap with a maximum voltage rating of 1kV. The M is a tolerance marking, in this case $\pm 20\%$.

CK05 caps have a small box shape, with their leads 0.2 inches apart so they can be easily inserted in prototyping or printed circuit boards. Therefore, they are common and useful. An example marking is 101K, which is 100 pF (10×10^1 pF), as described above.

The tolerance codes that often appear on capacitors are listed in Table 2.3. These codes apply to both capacitors and resistors with printed labels. Note that the Z tolerance code indicates a very tight tolerance if on a resistor, but a very large tolerance if on a capacitor!

Table 2.3 Capacitor and resistor tolerance codes

Code Letter	Meaning
Z	+80%, –20% for caps, $\pm 0.025\%$ for precision resistors
M	$\pm 20\%$
K	$\pm 10\%$
J	$\pm 5\%$
G	$\pm 2\%$
F	$\pm 1\%$
D	$\pm 0.5\%$
C	$\pm 0.25\%$
B	$\pm 0.1\%$
N	$\pm 0.02\%$
A	$\pm 0.005\%$

More information dealing with practical considerations concerning capacitors can be found at Internet Link 2.9.

2.10.2 Breadboard and Prototyping Advice

A **breadboard** is a convenient device for prototyping circuits in a form that can be easily tested and modified. Figure 2.36 illustrates a typical breadboard layout consisting of a rectangular matrix of insertion points spaced 0.1 inches apart. As shown in the figure, each column a through e, and f through j, is internally connected, as illustrated by the arrows in the diagram. The + and – rows that lie along



Internet Link

2.9 Capacitor practical considerations

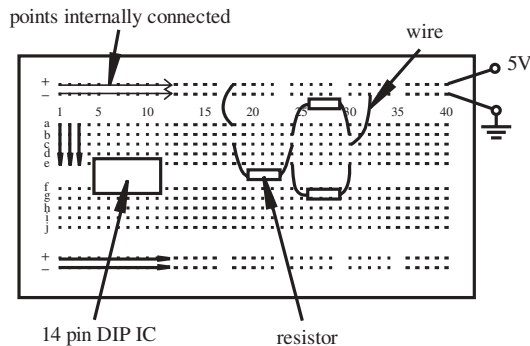


Figure 2.36 Breadboard.

the top and bottom edges of the breadboard are also internally connected to provide convenient DC voltage and ground busses. As illustrated in the figure, integrated circuits (ICs or “chips”) are usually inserted across the gap between columns a through e, and f through j. A 14-pin dual in-line package (DIP) IC is shown here. When the IC is placed across the gap, each pin of the IC is connected to a separate numbered column, making it easy to connect wires to and from the IC pins. The figure also shows an example of how to construct a simple resistor circuit. The schematic for this circuit is shown in Figure 2.37. The techniques for measuring voltage V_1 and current I_3 are described in Section 2.10.3. Figure 2.38 shows an example of a wired breadboard including resistors, an integrated circuit, and a push-button switch. When constructing such circuits, care should be exercised in trimming leads so the components lie on top of the breadboard in an organized geometric pattern. This will make it easier to see connections and find potential problems and errors later.

Video Demo 2.12 shows how a breadboard is constructed, and Video Demo 2.13 provides “rules of thumb” for how to properly assemble circuits on the board. Internet Link 2.10 is an excellent resource, providing useful tips when prototyping with breadboards (solderless protoboards), perf boards (soldered protoboards), and printed circuit boards (PCBs) for when a design is finalized.



Video Demo

2.12 Breadboard construction

2.13 Breadboard advice and rules of thumb



Internet Link

2.10 Prototyping tips

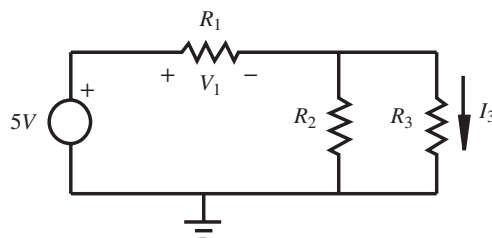


Figure 2.37 Example resistor circuit schematic.

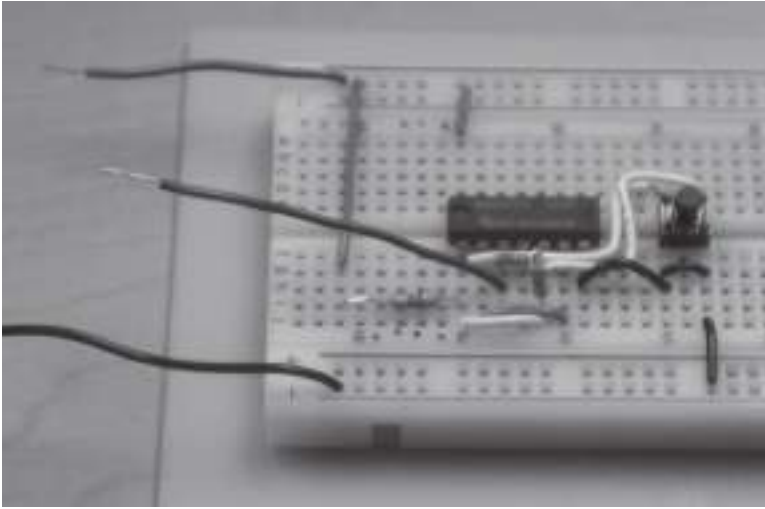


Figure 2.38 Example Breadboard Circuit.

©David Alciatore

Below is a set of basic guidelines you should follow when using breadboards to prototype circuits involving integrated circuits. Generally, if you carefully follow this protocol, you will save a lot of time and avoid a lot of frustration:

- a. Start with a clearly drawn schematic illustrating all components, inputs, outputs, and connections.
- b. Draw a detailed wiring diagram, using the information from datasheets regarding device pin-outs (diagrams showing pin functions and numbering). Label and number each pin used on each IC and fully specify each component (i.e., include the IC identifying numbers) on your wiring diagram. This will be your wiring guide.
- c. Double-check the functions you want to perform with each device and test them individually.
- d. Insert the ICs into your breadboard.
- e. Wire all connections carefully, checking off or highlighting each line on your wiring diagram as you insert each wire. Select wire colors in a consistent and meaningful way (e.g., red for +5V, black for ground, other colors for signals), and use appropriate lengths (~ 1/4 in) for exposed wire ends. If the ends are too short, you might not establish good connections; and if too long, you might damage the breadboard or risk shorts. Also, be careful to not insert component (e.g., resistor and capacitor) leads too far into the breadboard holes. This can also result in breadboard damage or shorting problems.
- f. Be very gentle with the breadboards. Don't force wires into or out of the holes. If you do this, the breadboard might be damaged, and you will no longer be able to create reliable connections in the damaged holes or rows. Use a "chip puller" (small tool) to remove ICs from the breadboard to prevent bent or broken pins.

- g. Make sure your wiring is very neat (i.e., not a “rat’s nest”), and keep all of your wires as short as possible to minimize electrical magnetic interference (EMI) and added resistance, inductance, and capacitance.
- h. Make sure all components and wires are firmly seated in the breadboard, establishing good connections. This is especially important with large ICs like microcontrollers.
- i. Double check the +5V and ground connections to each IC.
- j. Before connecting the power supply, set the output to +5V and turn it off.
- k. Connect the power supply to your breadboard and then turn it on.
- l. Measure signals at inputs and outputs to verify proper functionality.
- m. If your circuit is not functioning properly, go back through the above steps in reverse order checking everything carefully.
- n. When prototyping with a soldered protoboard or PCB, use IC sockets to allow easy installation and removal of ICs.

And anytime your circuits are not working properly after they are built, always go through the following set of checks to help diagnose and fix any problems:

- a. Verify that your breadboard circuit is constructed properly based on the circuit schematic or wiring diagram by checking each connection, making sure the breadboard is being used properly per Figure 2.36.
- b. Use the beep continuity-check feature on a multimeter to verify all connections and to check for shorts (see Video Demo 2.14).
- c. Make sure power and ground are available where needed on the breadboard, and include jumper wires between the top and bottom power and ground rows if necessary.
- d. Make sure you have common grounds among your circuit and all instrumentation being used (power supply, function generator, multimeter, oscilloscope).
- e. Check the power supply voltage with the multimeter to make sure it is at the correct level.
- f. Take voltage measurements in different parts of the circuit to make sure values match what is expected.

And for additional troubleshooting advice, especially for more-complicated circuits, see Section 2.10.6 dealing with how to limit and address electromagnetic interference, and Sections 7.12.1 and 7.12.4 dealing with debugging and troubleshooting software and circuits in microcontroller projects.

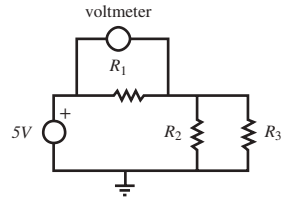
2.10.3 Voltage and Current Measurement

It is very important that you know how to measure voltage and current, especially when prototyping a circuit. Figure 2.39 illustrates how you measure voltage across an element in a circuit, in this case a resistor. To measure voltage, the leads of the

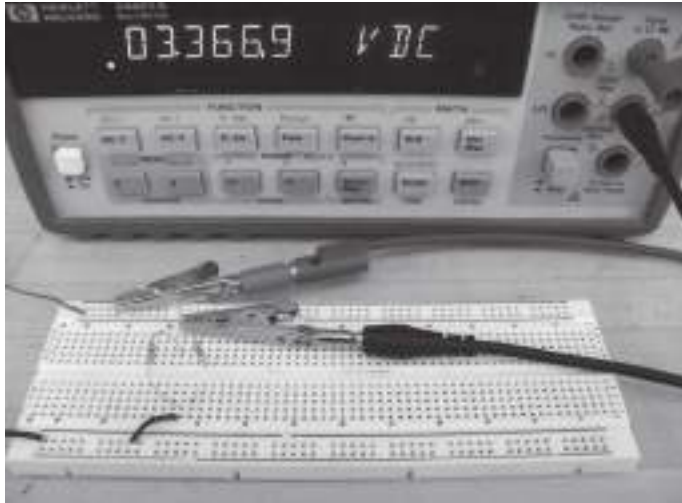


Video Demo

2.14 Current measurement and checking continuity



(a) circuit schematic



(b) photograph

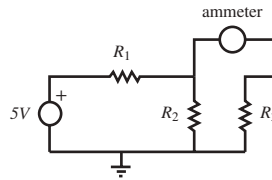
Figure 2.39 Measuring voltage.

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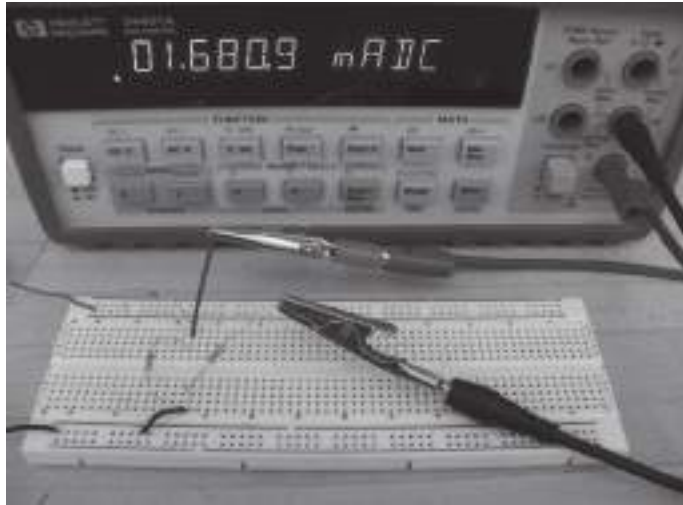
voltmeter are simply placed across the element. However, as shown in Figure 2.40, when measuring current through an element, the ammeter must be connected in series with the element. This requires physically altering the circuit to insert the ammeter in series. For the example in the figure, the top lead of resistor R_3 is removed from the breadboard to make the necessary connections to the ammeter. A demonstration of these techniques can be found in Video Demo 2.13. It is also important to be aware of input impedance effects, especially when measuring voltage across a large resistance or measuring current through a circuit branch with low resistance (see Section 2.4 for more information).

2.10.4 Soldering

Once a prototype circuit has been tested on a breadboard, a permanent prototype can be created by soldering components and connections using a **proto-board** (also called a perf board, perforated board, or vector board). These boards are manufactured with a regular square matrix of holes spaced 0.1 inch apart as with the insertion points in a breadboard. Unlike with the breadboard, there are no prewired connections between the holes. All connections must be completed with external wire and solder joints. The result is a prototype that is more robust and reliable.



(a) circuit schematic



(b) photograph

Figure 2.40 Measuring current.

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**Internet Link**

2.11 ExpressPCB
free PCB layout
software and
inexpensive
manufacturing

2.12 Printed circuit
board information
resource

For multiple versions of a prototype or production version of a circuit, a **printed circuit board (PCB)** is usually manufactured. Here, components are inserted and soldered to perforations in the board and all connections between the components are “printed” on the board with a conducting medium. For more information about PCBs and how to make them, see Internet Links 2.11 and 2.12.

Solder is a metallic alloy of tin, lead, and other elements that has a low melting point (approximately 375°F). The solder usually is supplied in wire form, often with a core of flux that facilitates melting, helps enhance wetting of the metal surfaces, and helps prevent oxidation. Solder is applied using a soldering iron consisting of a heated tip and support handle (see Figure 2.41). Some soldering irons also include a rheostat to control tip temperature. When using a soldering iron, be sure the tip is securely installed. Also, after heating, make sure the tip is clean and shiny, wiping it on a wet sponge or steel wool if necessary.

Here is a helpful list of steps you should follow to create a good solder connection:

- (1) Before soldering, make sure you have everything you need: hot soldering iron, solder, components, wire, protoboard or PCB, tip-cleaning pad, and magnifying glass.

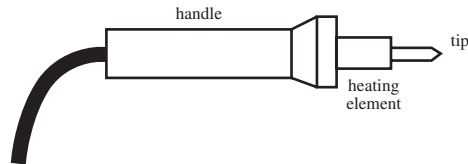


Figure 2.41 Soldering iron.

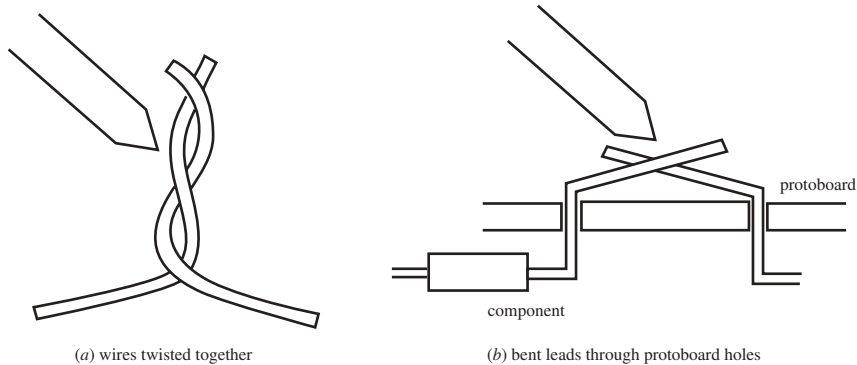


Figure 2.42 Preparing a soldered joint.

- (2) Clean any surfaces that are to be joined. You can use fine emery paper, steel wool, or a metal brush to remove oxide layers and dirt so that the solder can easily wet the surface. Rosin core (flux) solder will enhance the wetting process.
- (3) Make a mechanical connection between the wires to be joined, either by bending or twisting, and ensure the components are secure so that they will not move when you apply the iron. Figure 2.42 illustrates two wires twisted together and a component inserted into a protoboard in preparation for soldering.
- (4) Heating the wires and metal surfaces to be joined is necessary so that the solder properly wets the metal for a strong bond to result. When soldering electronic components, practice in heating is necessary so that the process is swift enough to not damage components. Soldering irons with sharper tips are convenient for joining small electronic components, because they can deliver the heat very locally.
- (5) When the surfaces have been heated momentarily, apply the solder to the work (not the soldering iron) and it should flow fluidly over the surfaces. Feed enough solder to provide a robust but not blobby joint. (If the solder balls up on the work, the iron is not hot enough.) Smoothly remove the iron and allow the joint to solidify momentarily. You should see a slight change in surface texture of the solder when it solidifies. If the joint is ragged or dull, you may have a “cold” joint, one where the solder has not properly wetted the surfaces. Such a joint will not have adequate or reliable conductivity and must be repaired by resoldering. Figure 2.43 illustrates a successful solder joint where the solder has wet both surfaces, in this case a component lead in a metal-rim-hole perforated board.

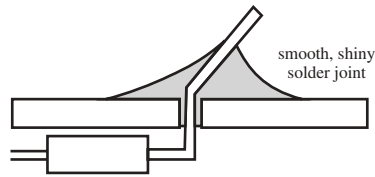


Figure 2.43 Successful solder joint.

- (6) If flux solvent is available, wipe the joint clean.
- (7) Inspect your work with a magnifying glass to make sure the joint looks good.



Internet Link

2.13 Electronics Club “Guide to Soldering”

2.14 Curious Inventor—“How to Solder”



Video Demo

2.15 How and why to solder correctly

Often you may have a small component or IC that you do not want to heat excessively. To avoid excessive heat, you can use a heat sink. A heat sink is a piece of metal like an alligator clip connected to the wire between the component and the connection to help absorb some of the heat that would be conducted to the component. However, if the heat sink is too close to the connection, it will be difficult to heat the wires. When using an IC, a socket can be soldered into the protoboard first, and then the IC can be later inserted, thereby avoiding any thermal stress on the IC.

When using hook-up wire, be sure to use solid (nonbraided) wire on a protoboard, because it will be easy to manipulate and join. Wire must be stripped of its insulating cover before soldering. When using hook-up wire in a circuit, tinning the wire first (covering the end with a thin layer of solder) facilitates the joining process.

Often you might make mistakes in attaching components and need to remove one or more soldered joints. A solder sucker makes this a lot easier. To use a solder sucker (see Figure 2.44), cock it first, heat the joint with the soldering iron, then trigger the solder sucker to vacuum up the molten solder. Then the component can easily be removed, because very little solder will be left to hold it.

For more information and advice on how to solder properly, see Internet Links 2.13 and 2.14. Video Demo 2.15 is also an excellent resource.

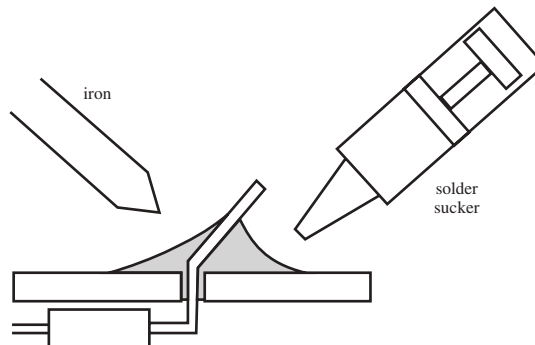


Figure 2.44 Removing a soldered joint.

2.10.5 The Oscilloscope

The oscilloscope, or o-scope for short, is probably one of the most widely used electrical instruments and is one of the most misunderstood. Lab Exercise 3 provides experiences to become familiar with the proper methods for connecting inputs, grounding, coupling, and triggering the oscilloscope. Video Demo 2.9 provides a demonstration of typical oscilloscope functionality, and this section provides information on some important oscilloscope concepts.

Most oscilloscopes are provided with a switch to select between AC or DC coupling of a signal to the oscilloscope input amplifier. When AC coupling is selected, the DC component of the signal is blocked by a capacitor inside the oscilloscope that is connected between the input terminal and the amplifier stage. Both AC and DC coupling configurations are illustrated in Figure 2.45. R_{in} is the input resistance (impedance) and C_{in} is the input capacitance. C_c is the coupling capacitor, which is present only when AC coupling is selected.

AC coupling must be selected when the intent is to block any DC component of a signal. This is important, for example, when measuring small AC spikes and transients on a 5 V digital supply voltage. However, it must be kept in mind that with AC coupling:

- One is not aware of the presence of any DC level with respect to ground.
- The lower-frequency components of a signal are attenuated.
- When the oscilloscope is switched from DC to AC coupling, it takes a little time before the display stabilizes. This is due to the time required to charge the coupling capacitor C_c to the value of the DC component (average value) of the signal.
- Sometimes the input time constant ($\tau = R_{in}C_c$, from Chapter 4) is quoted among the oscilloscope specifications. This number is useful, because after about five time constants (5τ), the displayed signal is stable.

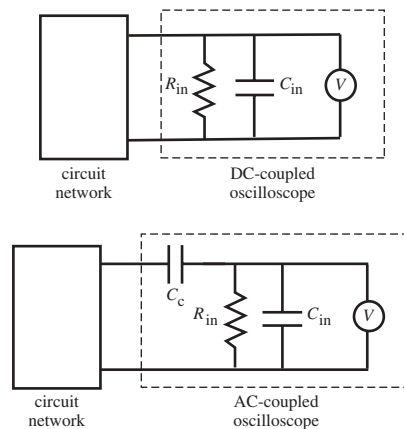


Figure 2.45 Oscilloscope coupling.



Lab Exercise

Lab 3 The oscilloscope



Video Demo

2.9 Oscilloscope demonstrations using the Tektronix 2215 analog scope

AC coupling can be explained by considering the impedance of the coupling capacitor as a function of frequency: $Z_C = 1/(j\omega C)$. With a DC voltage ($\omega = 0$) the impedance of the capacitor is infinite, and all of the DC voltage at the input is blocked by the capacitor. For AC signals, the impedance is less than infinite, resulting in attenuation of the input signal dependent upon the frequency. As the input frequency increases, the attenuation decreases to zero.

Triggering is another important concept when attempting to display a signal on an oscilloscope. A trigger is an event that causes the signal to sweep across the display. If the signal being measured is periodic, and the trigger is consistent with each sweep, the signal will appear static on the display, which is desirable. The oscilloscope may be level triggered, where the sweep starts when the signal reaches a selectable voltage level, or slope triggered, where a certain rate of signal change triggers the sweep. Another triggering option available is line triggering, where the AC power input is used to synchronize the sweep. Thus, any terminal voltage synchronized with the line frequency of 60 Hz or multiples of 60 Hz can be triggered in this mode. This is useful to detect if 60 Hz noise from various line-related sources is superimposed on a signal.

Normally all measurement instruments, power sources, and signal sources in a circuit must be referenced to a **common ground**, as shown in Figure 2.46. However, to measure a differential voltage ΔV , it is correct to connect the scope as shown in Figure 2.47. Note that the oscilloscope signal ground and external network ground are not common, allowing measurement of a potential difference anywhere in a circuit. However, in some oscilloscopes, each channel's “—” signal reference is attached

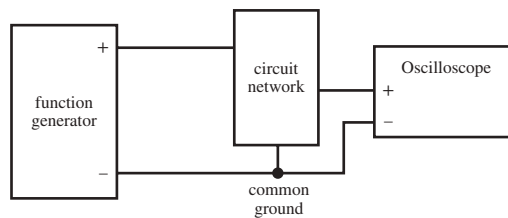


Figure 2.46 Common ground connection.

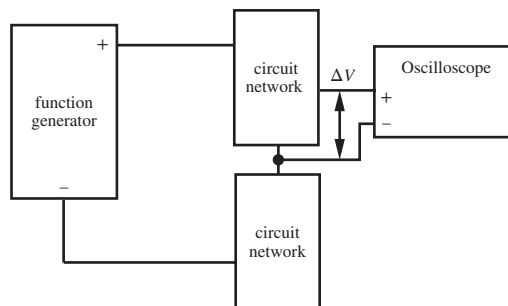


Figure 2.47 Relative ground connection.

to chassis ground, which is attached to the AC line ground. Therefore, to make a differential voltage measurement, you must use a two-channel signal difference feature, using the “+” leads of each channel for the measurement. An alternative for DC circuits is to measure the voltage at each node separately, relative to ground, and then manually subtract the voltage readings.

The **input impedance** of an oscilloscope is typically in the $1\text{ M}\Omega$ range, which is fairly large. However, as described in Section 2.4, when measuring the voltage drop across an element whose impedance is of similar or greater magnitude than the input impedance, serious errors can result. One approach to avoid this problem is to increase the input impedance of the oscilloscope using an attenuator probe, which increases the input impedance by some known factor, at the same time decreasing the amplitude of the input signal by the same factor. Thus a 10x probe will increase the magnitude of the input impedance of the oscilloscope by a factor of 10, but the displayed voltage will be only 1/10 of the amplitude of the actual terminal voltage. Most oscilloscopes offer an alternative scale to be used with a 10x probe.

2.10.6 Grounding and Electrical Interference

It is important to provide a common ground defining a common voltage reference among all instruments and power sources used in a circuit or system. As illustrated in Figure 2.48, many power supplies have both a positive DC output (+ output) and a negative DC output (– output). These outputs produce both positive and negative voltages referenced to a common ground, usually labeled COM. On other instruments and circuits that may be connected to the power supply, all input and output voltages must be referenced to the same common ground. It is wise to double-check the integrity of each signal ground connection when assembling a group of devices.

It is important not to confuse the signal ground with the chassis ground. The **chassis ground** is internally connected to the ground wire on the power cord and may not be connected to the signal ground (COM). The chassis ground is attached to the metal case enclosing an instrument to provide user safety if there is an internal fault in the instrument (see Section 2.10.7).

Figure 2.49 illustrates an interference problem where high-frequency electrical **noise** can be induced in a signal by magnetic induction in the measurement leads.

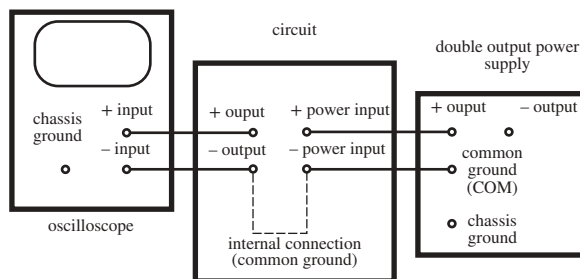


Figure 2.48 Common ground.

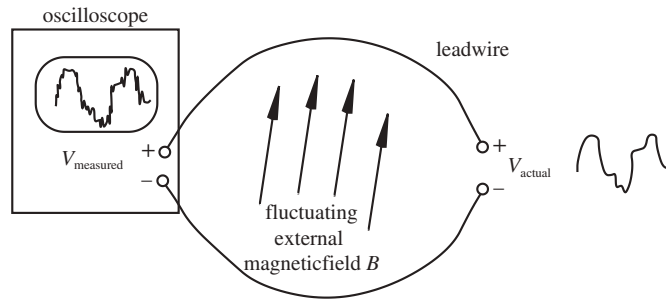


Figure 2.49 Inductive coupling.

The area circumscribed by the leads encloses external magnetic fields from any AC magnetic sources in the environment, such as AC power lines or electric machinery. This would result in an undesirable magnetically induced AC voltage, as a result of Faraday's law of induction, given by

$$V_{\text{noise}} = A \cdot \frac{dB}{dt} \quad (2.79)$$

where A is the area enclosed by the leads and B is the external magnetic field. The measured voltage differs from the actual value according to

$$V_{\text{measured}} = V_{\text{actual}} + V_{\text{noise}} \quad (2.80)$$

■ CLASS DISCUSSION ITEM 2.14

Automotive Circuits

Often, electrical components in an automobile such as the alternator or starter motor are grounded to the frame. Explain how this results in an electrical circuit.

Many types of **electromagnetic interference** (EMI) can reduce the effectiveness and reliability of a circuit or system. Also, poorly designed connections within a circuit can cause noise and unwanted signals. These effects can be mitigated using a number of standard methods. The first approach is to eliminate or move the source of the interference, if possible. The source may be a switch, motor, or AC power line in close proximity to the circuit. It may be possible to remove, relocate, shield, or improve grounding of the interference source. However, this is not usually possible, and standard methods to reduce external EMI or internal coupling may be applied. Some standard methods are

- Keep sensitive circuits and wiring (e.g., those supporting controllers and sensors) as far away as possible from high-voltage and large-current circuits and wiring (e.g., those supporting power supplies, amplifiers, and actuators). This will help limit noise induced in the low-power circuits from the high-power circuits.

- Keep wire pairs going to and from large-current devices (e.g., power supplies, amplifiers, and actuators) close together and twisted if possible to minimize EMI effects. With the wires close, magnetic field created by large current in one wire will be mostly canceled by the magnetic field created by the equal current flowing in the opposite direction in the other wire.
- Eliminate potential differences caused by **multiple point grounding**. A common ground bus (large conductor, plate, or solder plane) should have a resistance small enough that voltage drops between grounding points are negligibly small. Also, make the multiple point connections close to ensure that each ground point is at approximately the same potential.
- Isolate sensitive signal circuits from high-power circuits using **optoisolators** or transformer couplings. Optoisolators are LED-phototransistor pairs (described in Chapter 3) that electrically decouple two sides of a circuit by transmitting a signal as light rather than through a solid electrical connection. One advantage is that the sensitive signal circuits are isolated from current spikes in the high-power circuit.
- Minimize inductive coupling and multiple-point grounding issues caused by **ground loops**. When the distance between multiple ground points is large, noise can be inductively coupled to the circuit through the conducting loops created by the multiple ground points. Figure 2.50 illustrates how you should be careful to not create large ground loops when wiring a circuit on a breadboard. Both circuits shown are providing power (5V and ground) to an integrated circuit. The wiring on the left, connected at points *A* and *B* via wires *a* and *b* creates a large ground loop area which can pick up induced voltages in the presence of fluctuating magnetic fields, as described above. The wiring on the right, connected to points *C* and *D* via wires *c* and *d* creates very little area in the resulting circuit; therefore, very little induced voltage will occur even in the presence of external fields.
- Shield sensitive circuits with earth-grounded metal covers to block external electric and magnetic fields.
- Use short leads in connecting all circuits to reduce capacitive and inductive coupling between leads.

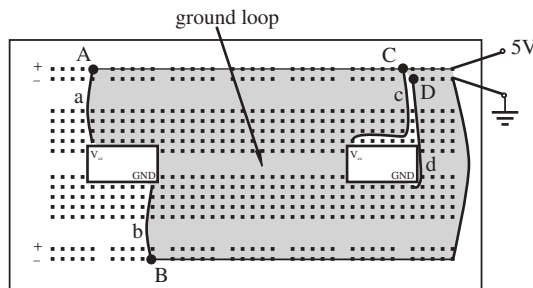


Figure 2.50 Ground loop.

- Use “**decoupling**” or “**bypass**” capacitors (e.g., 0.1 μF ceramic type) between the power and ground pins of integrated circuits to provide a short circuit for high-frequency noise.
- Use coaxial cable or twisted pair cable for high-frequency signal lines to minimize the effects of external magnetic fields.
- Use multiple-conductor shielded cable instead of ribbon cable for signal lines in the presence of power circuits (where large currents produce large magnetic fields) to help maintain signal integrity. Also, ground the metal shield to eliminate capacitive coupling to surrounding noise sources, but do so only at one end to prevent introduction of a ground loop.
- If printed circuit boards are being designed, ensure that adequate **ground planes** are provided. A ground plane is a large surface conductor that minimizes potential differences among ground points.
- If using an AC power plug in your system, do not connect the ground prong to the signal ground of your circuits. The ground prong is for equipment safety only (see Section 2.10.7), and is not appropriate as a signal ground (mostly because the ground prong conductor routes through the same cable or conduits as the AC power lines, which can introduce EMI).

Much more information and advice concerning how to prototype and troubleshoot circuits properly and carefully can be found in Section 2.10.2 dealing with general breadboard, circuit and prototyping advice, and Sections 7.12.1 and 7.12.4 dealing with debugging and troubleshooting software and circuits in microcontroller projects.

2.10.7 Electrical Safety

When using and designing electrical systems, safety should always be a major concern. In the United States, electrical codes require outlets with three terminals: hot, neutral, and ground. Figure 2.51 illustrates the prongs on a plug that is inserted into an outlet. The wires in the plug cable include a black wire connected to the hot prong, a white wire connected to the neutral prong, and a bare or green wire connected to the ground prong. The two flat prongs (hot and neutral) of a plug complete the active circuit, allowing alternating current (nominally at 120 V_{rms} at 60 Hz) to flow from the wall outlet through an electrical device. The round ground prong is connected only to the chassis of the device and not to the power circuit ground in the device. The chassis ground provides an alternative path to earth ground, reducing the danger to a person who may contact the chassis when

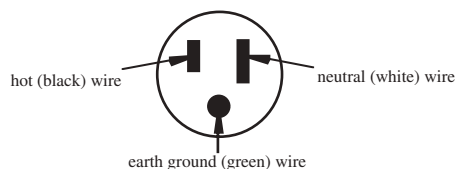


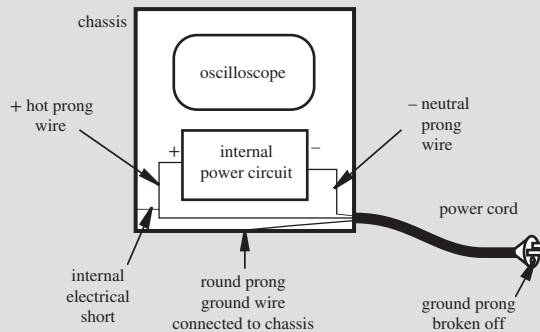
Figure 2.51 Three-prong AC power plug.

there is a fault in the power circuit. Without a separation between chassis and power ground, a high voltage can exist on the chassis, creating a safety hazard for the user because he or she can complete a path to ground. Removing the ground prong or using a three-prong-to-two-prong adapter carelessly creates a hazard (see Class Discussion Items 2.15 and 2.16). Some power plugs have only two prongs

■ CLASS DISCUSSION ITEM 2.15

Safe Grounding

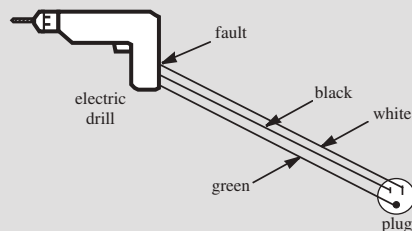
Consider the following oscilloscope whose power cord ground prong has been broken so that the chassis is not connected to ground. If you use this instrument, describe the possible danger you face.



■ CLASS DISCUSSION ITEM 2.16

Electric Drill Bathtub Experience

The following electric drill runs on household power and has a metal housing. You use a three-prong-to-two-prong adapter to plug the drill into the wall socket. You are standing in a wet bathtub drilling a hole in the wall. You are unaware that the black wire's insulation has worn thin and the bare copper black wire is contacting the metal housing of the drill. How have you created a lethal situation for yourself? How could it have been prevented or mitigated?

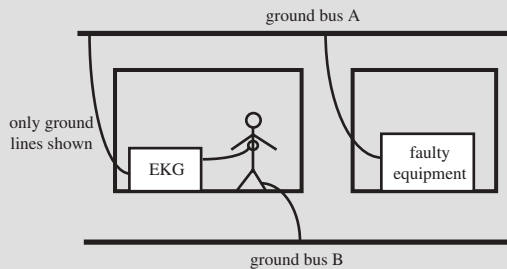


(hot and neutral), with no ground prong. As with three-prong plugs, the neutral prong is usually larger than the hot prong (see Figure 2.51), creating a **polarized** plug. This forces the plug (either a two-prong plug, or a three-prong plug with the ground prong removed) to be inserted into a polarized socket in only one orientation. This is a safety feature allowing a device to be switched off by interrupting the connection to the hot side of the plug instead of to the neutral side. That way, if the device is plugged in but switched off, the device will not be connected to hot side. If this were not the case (e.g., with a non-polarized plug or socket), a hazard can result in the case of an internal short or if the device is being serviced while plugged in.

■ CLASS DISCUSSION ITEM 2.17

Dangerous EKG

A cardiac patient is lying in his hospital bed with electrocardiograph (EKG) leads attached to his chest to monitor his cardiac rhythm. An electrical short occurs in the next room, and our patient experiences a cardiac arrest. You and the hospital facilities engineer have determined that there were multiple grounding points in the patient's room (see the illustration), and a fault in electrical equipment in the next room caused current to flow in the ground wire from the piece of the equipment. You are on the scene to determine if there could have been a lethal current through the patient. Consider the fact that ground lines have finite resistance per unit length and that a few microamps through the heart can cause ventricular fibrillation (a fatal malfunction).



■ CLASS DISCUSSION ITEM 2.18

High-Voltage Measurement Pose

When performing a high-voltage test, a creative electrical technician claims that standing on your right foot and using your right hand to hold the probe is the safest posture for making the measurement. What possible logic could support this claim?

■ CLASS DISCUSSION ITEM 2.19

Lightning Storm Pose

A park ranger at Rocky Mountain National Park recommends that if your hair rises when hiking in an open area during a lightning storm, it is imperative to crouch down low to the ground keeping your feet together. Explain why this might be life-saving advice.

Electricity passing through a person can cause discomfort, injury, and even death. The human body, electrically speaking, is roughly composed of a low-resistance core (on the order of $500\ \Omega$ across the abdomen) surrounded by high-resistance skin (on the order of $10\ \text{k}\Omega$ through the skin when dry). When the skin is wet, its resistance drops dramatically. Currents through the body below $1\ \text{mA}$ are usually not perceived. Currents as low as $10\ \text{mA}$ can cause tingling and muscle contractions. Currents through the thorax as low as $100\ \text{mA}$ can affect normal heart rhythm. Currents above $5\ \text{A}$ can cause tissue burning. Video Demo 2.16 shows an electronic toy that illustrates how current can flow through human skin. In this case a person's hand is being used to complete a circuit to control a blinking LED. Video Demos 2.17 and 2.18 graphically illustrate what can happen to animals and humans when they are not careful around high-voltage lines, and Video Demo 2.19 dispels a myth commonly associated with statements like: "It's not the volts that kill you, it's the amps."



Video Demo

2.16 Human circuit toy ball

2.17 Squirrel zapped by power lines

2.18 Stupid man zapped by power lines

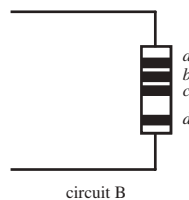
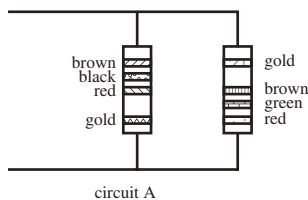
2.19 It's not the volts that kill you, it's the amps

QUESTIONS AND EXERCISES

Section 2.2 Basic Electrical Elements

- 2.1.** What is the resistance of a kilometer-long piece of 14-gage (0.06408 inch diameter) copper wire?
- 2.2.** Determine the possible range of resistance values for each of the following:
 - a. Resistor R_1 with color bands: red, brown, yellow.
 - b. Resistor R_2 with color bands: black, violet, orange.
 - c. The series combination of R_1 and R_2 .
 - d. The parallel combination of R_1 and R_2 .

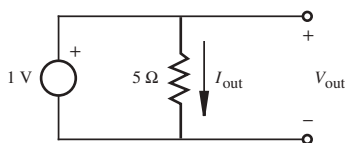
Note: the color bands are listed in order, starting with the first.
- 2.3.** What colors should bands a , b , c , and d be for the following circuit B to have the equivalent resistance of circuit A?



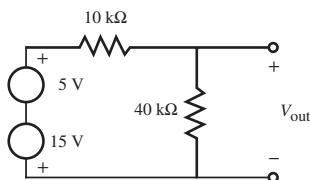
- 2.4. When using a trim pot in a circuit, it is usually placed in series with another fixed value resistor. Why is it not placed in parallel instead? Support your conclusions with analysis.
- 2.5. Document a complete and thorough answer to Class Discussion Item 2.1.

Section 2.3 Kirchhoff's Laws

- 2.6. Does it matter in which direction you assume the current flows when applying Kirchhoff's laws to a circuit? Why?
- 2.7. You quickly need a $50\ \Omega$ resistor but have a store of only $100\ \Omega$ resistors. What can you do?
- 2.8. You quickly need a $100\ \Omega$ resistor but have a store of only $50\ \Omega$ resistors. What can you do?
- 2.9. You quickly need a $150\ \Omega$ resistor but have a store of only $100\ \Omega$ resistors. What can you do?
- 2.10. Using Ohm's law, KVL, and KCL, derive an expression for the equivalent resistance of three parallel resistors (R_1 , R_2 , and R_3).
- 2.11. Derive current division formulas, similar to Equation 2.38, for three resistors in parallel.
- 2.12. Given two resistors R_1 and R_2 , where R_1 is much greater than R_2 , prove that the parallel combination is approximately equal to R_2 .
- 2.13. Derive an expression for the equivalent capacitance of two capacitors attached in series.
- 2.14. Derive an expression for the equivalent capacitance of two capacitors attached in parallel.
- 2.15. Derive an expression for the equivalent inductance of two inductors attached in series.
- 2.16. Derive an expression for the equivalent inductance of two inductors attached in parallel.
- 2.17. Find I_{out} and V_{out} in the following circuit:



- 2.18. Find V_{out} in the following circuit:



2.19. For the circuit in Question 2.30, with $R_1 = 1 \text{ k}\Omega$, $R_2 = 2 \text{ k}\Omega$, $R_3 = 3 \text{ k}\Omega$, and $V_{\text{in}} = 5 \text{ V}$, find

- the current through R_1
- the current through R_3
- the voltage across R_2

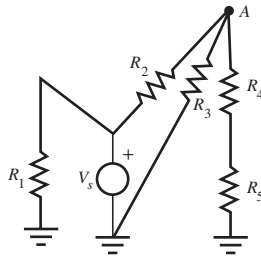
2.20. For the circuit in Example 2.4, find

- the current through R_4
- the voltage across R_5

You can use results from the example to help with your calculations.

2.21. Given the following circuit with $R_1 = 1 \text{ k}\Omega$, $R_2 = 2 \text{ k}\Omega$, $R_3 = 3 \text{ k}\Omega$, $R_4 = 4 \text{ k}\Omega$, $R_5 = 1 \text{ k}\Omega$, and $V_s = 10 \text{ V}$, determine

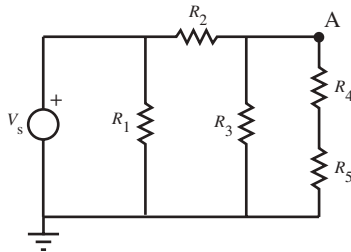
- the total equivalent resistance seen by V_s
- the voltage at node A
- the current through resistor R_5



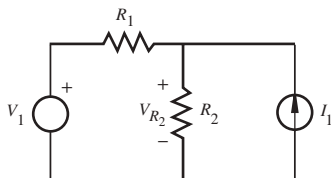
2.22. Given the following circuit with $R_1 = 2 \text{ k}\Omega$, $R_2 = 4 \text{ k}\Omega$, $R_3 = 5 \text{ k}\Omega$, $R_4 = 3 \text{ k}\Omega$, $R_5 = 1 \text{ k}\Omega$, and $V_s = 10 \text{ V}$, determine

- the total equivalent resistance seen by V_s
- the voltage at node A
- the current through resistor R_5

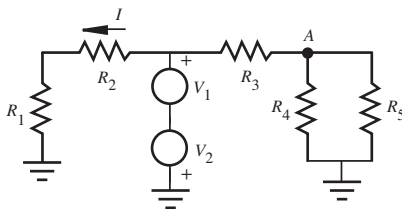
Also, how is this circuit different from the circuit in Question 2.21? If the resistance values were the same, would the circuits be identical? If not, what parts are different?



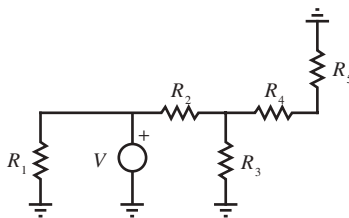
- 2.23. For the following circuit with $V_1 = 1\text{ V}$, $I_1 = 1\text{ A}$, $R_1 = 10\ \Omega$, and $R_2 = 100\ \Omega$, what is V_{R_2} ?



- 2.24. For the following circuit with $R_1 = 1\text{ k}\Omega$, $R_2 = 9\text{ k}\Omega$, $R_3 = 10\text{ k}\Omega$, $R_4 = 1\text{ k}\Omega$, $R_5 = 1\text{ k}\Omega$, $V_1 = 5\text{ V}$, and $V_2 = 10\text{ V}$, find I and the voltage at node A.



- 2.25. Find the equivalent resistance of the circuit below, as seen by voltage source V . Use the following values for the resistors: $R_1 = 1\text{ k}\Omega$, $R_2 = 2\text{ k}\Omega$, $R_3 = 3\text{ k}\Omega$, $R_4 = 4\text{ k}\Omega$, and $R_5 = 5\text{ k}\Omega$.

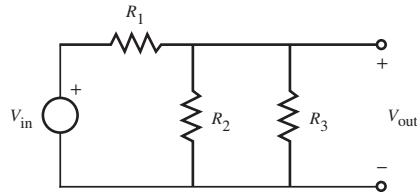


- 2.26. Solve for I_{out} and V_{out} in Example 2.4 by writing and solving KVL and KCL equations for all loops and nodes in the original circuit.
- 2.27. Given the values for V_{234} and V_{out} calculated in Example 2.4, also calculate the current up through resistor R_4 and the voltage across resistor R_5 , with the plus side of the voltage polarity on the V_{out} side of R_5 .

Section 2.4 Voltage and Current Sources and Meters

- 2.28. What is the output impedance of your laboratory DC power supply? What is the input impedance of your laboratory oscilloscope when DC coupled?

- 2.29.** Explain why measuring voltages with an oscilloscope across impedances on the order of $1\text{ M}\Omega$ may result in significant errors. Document your conclusions with analysis.
- 2.30.** For the following circuit, what is V_{out} in terms of V_{in} for
- $R_1 = 50\ \Omega$, $R_2 = 10\text{ k}\Omega$, $R_3 = 1.0\text{ M}\Omega$?
 - $R_1 = 50\ \Omega$, $R_2 = 500\text{ k}\Omega$, $R_3 = 1.0\text{ M}\Omega$?



- If R_3 represents the input impedance associated with a device measuring the voltage across R_2 , what conclusions can you make about the two voltage measurements?
- 2.31.** For the circuit in Question 2.30, if R_1 represents the output impedance of a voltage source and R_3 is assumed to be infinite (representing an ideal voltmeter), what effect does R_1 have on the voltage measurement being made? Also, what would the effect be for each of the R_2 values in Question 2.30? Please comment on the results.
- 2.32.** If a voltmeter is used to measure the voltage across one of the resistors of an equal-resistance voltage divider, what will be the percent error in the measurement if the input impedance of the meter is only five times the resistance measured across?

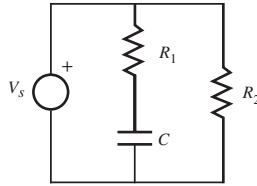
Section 2.5 Thevenin and Norton Equivalent Circuits

- 2.33.** What is the Thevenin equivalent of your laboratory DC power supply?
- 2.34.** What is the Thevenin equivalent of the circuit in Question 2.30 for the resistance values in part “a”?

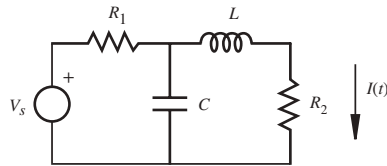
Section 2.6 Alternating Current Circuit Analysis

- 2.35.** For the circuit in Example 2.7, find the steady state voltage across the capacitor as a function of time. You can use results from the example to help with your calculations.

- 2.36. For the following circuit, what are the steady state voltages across R_1 , R_2 , and C , if $V_s = 10$ V DC, $R_1 = 1$ k Ω , $R_2 = 1$ k Ω , and $C = 0.01$ μ F?



- 2.37. Find the steady state current $I(t)$ in the following circuit, where $R_1 = R_2 = 100$ k Ω , $C = 1$ μ F, and $L = 20$ H for
- $V_s = 5$ V DC
 - $V_s = 5 \cos(\pi t)$ V

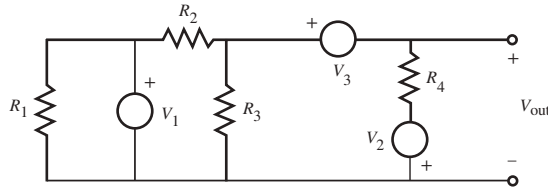


- 2.38. For each of these waveforms, what is the frequency in Hz and in rad/sec, the peak-to-peak amplitude, and the DC offset?
- $2.0 \sin(\pi t)$
 - $10.0 + \cos(2\pi t)$
 - $3.0 \sin(2\pi t + \pi)$
 - $\sin(\pi) + \cos(\pi)$

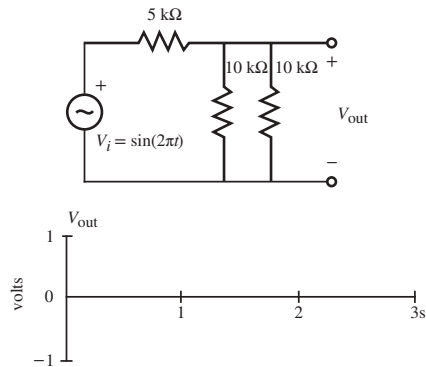
Section 2.7 Power in Electrical Circuits

- 2.39. If 100 volt rms is applied across a 100 Ω power resistor, what is the power dissipated in watts?
- 2.40. If 100 volt peak-to-peak is applied across a 100 Ω power resistor, what is the power dissipated in watt?
- 2.41. If standard U.S. household voltage is 120 volt rms, what is the peak voltage that would be observed on an oscilloscope?
- 2.42. Write a function to represent a typical household voltage signal.
- 2.43. A circuit designer needs to choose an appropriate size resistor to be used in series with a light emitting diode (LED). The LED manufacturer claims that the LED requires 2 V to keep it on and 10 mA to generate bright light. Also, the current should not exceed 100 mA. Assuming that a 5 V source is being used to drive the LED circuit, what range of resistance values would be appropriate for the job? Also, what resistor power rating would be required?

- 2.44.** For the following circuit with $R_1 = 1 \text{ k}\Omega$, $R_2 = 2 \text{ k}\Omega$, $R_3 = 3 \text{ k}\Omega$, $R_4 = 4 \text{ k}\Omega$, $V_1 = 10 \text{ V}$, $V_2 = 5 \text{ V}$, and $V_3 = 10 \text{ V}$, find
- V_{out}
 - the power produced by each voltage source



- 2.45.** Solve the previous question with $R_3 = 2 \text{ k}\Omega$ and $R_4 = 1 \text{ k}\Omega$, keeping everything else the same.
- 2.46.** Prove Equation 2.66.
- 2.47.** Derive the rms expressions in Equation 2.67 and show that Equation 2.68 is correct.
- 2.48.** Sketch the output waveform for V_{out} in the following circuit on the axes as shown:



- 2.49.** Document a complete and thorough answer to Class Discussion Item 2.10.

Section 2.8 Transformer

- 2.50.** If you were to design a transformer for $24 V_{\text{rms}}$ low-voltage lighting in a new kitchen, what should the turns ratio of the primary to secondary windings be to provide a satisfactory voltage source?

Section 2.9 Impedance Matching

- 2.51.** If your audio stereo amplifier has an output impedance of 8Ω , what resistance should your speaker coils have to maximize the generated sound power?

Section 2.10 Grounding and Electrical Interference

- 2.52.** When making high-frequency voltage measurements with an oscilloscope, why is it good practice to use BNC (coaxial) cable rather than two separate wires to the probe?

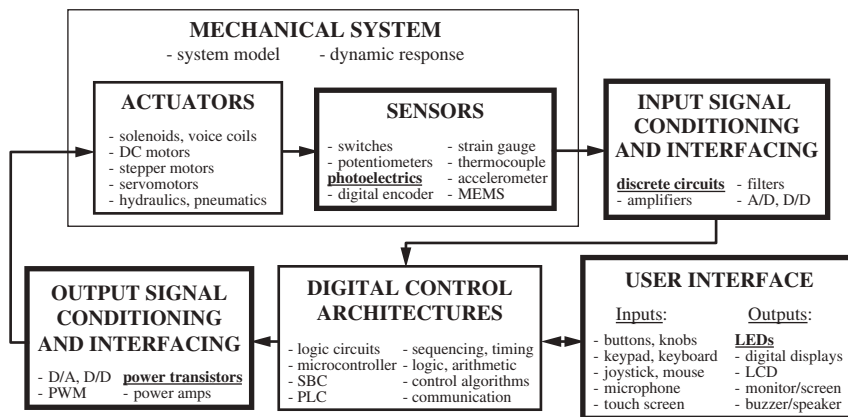
BIBLIOGRAPHY

- Horowitz, P. and Hill, W., *The Art of Electronics*, 3rd Edition, Cambridge University Press, New York, 2015.
- Johnson, D., Hilburn, J., and Johnson, J., *Basic Electric Circuit Analysis*, 5th Edition, Prentice-Hall, Englewood Cliffs, NJ, 1995.
- Lerner, R. and Trigg, G., *Encyclopedia of Physics*, VCH Publishers, New York, 1991.
- McWhorter, G. and Evans, A., *Basic Electronics*, Master Publishing, Richardson, TX, 2004.
- Mims, F., *Getting Started in Electronics*, 3rd Edition, Master Publishing, Richardson, TX, 2003.

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Semiconductor Electronics

This chapter presents semiconductor diodes and transistors, important for sensing, interfacing, and display in mechatronic systems. ■



CHAPTER OBJECTIVES

After you read, discuss, study, and apply ideas in this chapter, you will:

1. Comprehend the basic physics of semiconductor devices
2. Be aware of the different types of diodes and how they are used
3. Know the similarities and differences between bipolar junction transistors and field-effect transistors
4. Understand how a transistor can be used to switch current to a load
5. Be able to design circuits using diodes, voltage regulators, bipolar transistors, and field-effect transistors
6. Be able to select semiconductor components for your designs

3.1 INTRODUCTION

We will examine some extraordinary materials that scientists and engineers have transformed into inventions that affect all aspects of life in the 21st century and beyond. To understand these inventions, we need to understand the physical characteristics of a class of materials known as semiconductors, which are used extensively in electronic circuits today. We examine the physics of semiconductors, discuss how electronic components are designed using different types of semiconductor materials, learn the circuit schematic symbols for different semiconductor diodes and transistors, and use the devices in circuit design.

3.2 SEMICONDUCTOR PHYSICS AS THE BASIS FOR UNDERSTANDING ELECTRONIC DEVICES

Metals have a large number of weakly bound electrons in what is called their conduction band. When an electric field is applied to a metal, the electrons migrate freely producing a current through the metal. Because of the ease by which large currents can flow in metals, they are called **conductors**. In contrast, other materials have atoms with valence electrons that are tightly bound, and when an electric field is applied, the electrons do not move easily. These materials are called **insulators** and do not normally sustain large electric currents. In addition, a very useful class of materials, elements in group IV of the periodic table, have properties somewhere between conductors and insulators. They are called **semiconductors**. Semiconductors such as silicon and germanium have current-carrying characteristics that depend on temperature or the amount of light falling on them. As illustrated in Figure 3.1, when a voltage is applied across a semiconductor, some of the valence electrons easily jump to the conduction band and then move in the electric field to produce a current, although smaller than that which would be produced in a conductor.

In a semiconductor crystal, a valence electron can jump to the conduction band, and its absence in the valence band is called a hole. A valence electron from a nearby atom can move to the hole, leaving another hole in its former place. This chain of events can continue, resulting in a current that can be thought of as the movement of holes in one direction or electrons in the other. The net effect is the same, so perhaps Ben Franklin wasn't completely wrong when he thought currents were the movement of positive charges, the common convention used today.

The properties of pure semiconductor crystals can be significantly changed by inserting small quantities of elements from group III or group V of the periodic table into the crystal lattice of the semiconductor. These elements, known as **dopants**, can be diffused or implanted into semiconductors. A thin crystal of silicon, often called a chip, can have a minute pattern of dopants deposited on and diffused into its surface, resulting in devices that are the basis of all modern electronics.

When different amounts and different types of atoms are added to the crystal lattice of silicon, interesting electrical property changes occur. Silicon has four

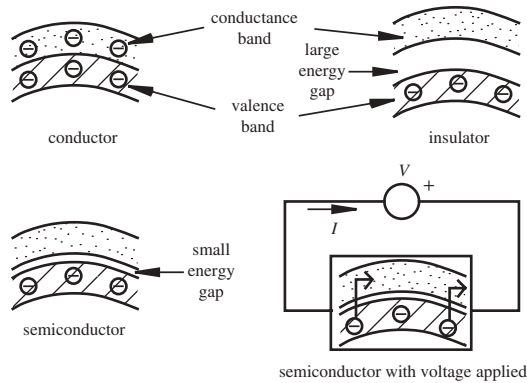


Figure 3.1 Valence and conduction bands of materials.

valence electrons that form symmetrical covalent bonds with the surrounding atoms in the crystal lattice. However, if antimony, arsenic, or phosphorous from group V is added to the crystal lattice, one of the five valence electrons in each dopant atom remains free to move around, because only four of the valence electrons participate in covalent bonds with surrounding silicon atoms. In this case, the dopant is called a **donor** element because it enhances the electron conductivity of the semiconductor. The resulting semiconductor is called **n-type** silicon due to the “free” electrons available in the crystal lattice as charge carriers (“n” stands for “negative”). Conversely, if the silicon is doped with boron, aluminum, or gallium from group III, **holes** form due to missing electrons in the lattice where the so-called **acceptor** dopant atoms have replaced silicon atoms. This is because the dopant atom only has three valence electrons to participate in surrounding covalent bonds, leaving a covalent bond “hole” that a valence electron can “fill.” A hole can jump from atom to atom, effectively producing a positive current. What really happens is that electrons move to occupy the holes, and this effectively looks like holes moving. The resulting semiconductor is called **p-type** silicon due to the holes, which are effectively positive charge carriers (“p” stands for “positive”).

In summary, the purpose for doping a semiconductor such as silicon is to increase? and control the number of charge carriers in the semiconductor. In an n-type semiconductor, the charge carriers are electrons, and in a p-type semiconductor, they are holes. It is important to note that a doped semiconductor is electrically neutral since there are still equal numbers of electrons and protons. What is changed is the conductivity of the material. As we will see shortly, the interaction between n-type and p-type semiconductor materials is the basis for most semiconductor electronic devices. Video Demo 3.1 provides an excellent overview and illustration of all of the concepts in this section and explains how semiconductor physics applies in the design of a transistor, a very important semiconductor device that will be presented in detail in Sections 3.4 and 3.5. If you found the concepts in this section a little confusing, be sure to watch the video, which is very well done.



Video Demo

3.1 How does a transistor work?

3.3 JUNCTION DIODE

Contemporary electronic devices are produced by creating microscopic interfaces between differently doped areas within semiconductor material. If a p-type region of silicon is created adjacent to an n-type region, a **pn junction** is the result. The p-type side of the diode is referred to as the **anode**, and the n-type side is called the **cathode**. As illustrated in the top of Figure 3.2, at the pn junction, electrons from the n-type silicon can diffuse to occupy the holes in the p-type silicon, creating what is called a **depletion region**. A small electric field develops across this thin depletion region due to the diffusion of electrons. This results in a voltage difference across the depletion region called the **contact potential**. For silicon, the contact potential is in the order of 0.6–0.7 V. The positive side of the contact potential is in the n-type region, and the negative side is in the p-type region due to the diffusion of the electrons. Note that we still have not connected the junction to an external circuit.

Now, as shown in the bottom left of Figure 3.2, if a voltage source is connected to the pn junction with the positive side of the source connected to the anode (p side) and the negative side connected to the cathode (n side), forming a complete circuit, the diode is said to be **forward biased**. The applied voltage overcomes the contact potential and shrinks the depletion region. The anode in effect becomes a source of holes and the cathode becomes a source of electrons so that holes and electrons are continuously replenished at the junction. As the applied voltage approaches the value of the contact potential (0.6–0.7 V for silicon), the current increases exponentially. This effect is quantitatively described by the **diode equation**:

$$I_D = I_0 \left(e^{\frac{qV_D}{kT}} - 1 \right) \quad (3.1)$$

where I_D is the current through the junction, I_0 is the reverse saturation current (described in the next paragraph), q is the charge of one electron (1.60×10^{-19} C), k is Boltzmann's constant (1.381×10^{-23} J/K), V_D is the forward bias voltage across the junction, and T is the absolute temperature of the junction in kelvin.

As shown in the bottom right of Figure 3.2, if the positive side of the voltage source is connected to the cathode (n side) and the negative side is connected to

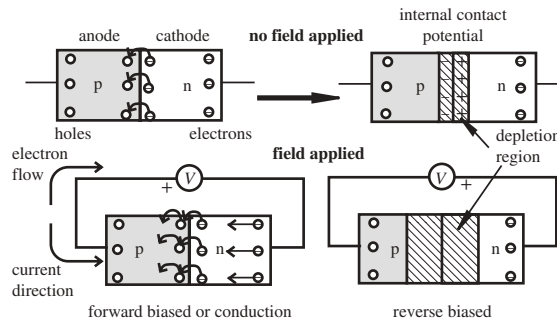
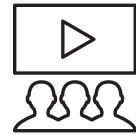


Figure 3.2 pn Junction characteristics.

the anode (p side), the depletion region is enlarged, inhibiting diffusion of electrons and thus current; and we say the junction is **reverse biased**. A **reverse saturation current** (I_0) does flow, but it is extremely small (in the order of 10^{-9} to 10^{-15} A).

Therefore, a pn junction passes current in one direction only. It is known as a silicon **diode** and is sometimes referred to as a **rectifier**. The schematic symbol for the silicon diode is shown in Figure 3.3. Figure 3.4 and Video Demo 3.2 show examples of various common diodes, including a small-signal diode, a small power diode, and various types of light-emitting diodes. LEDs are described more in Section 3.3.2, and seven-segment displays are presented in Section 6.12.1. The diode is analogous to a fluid check (nonreturn) valve, which allows fluid to flow only in one direction as illustrated in Figure 3.5. We will soon see that pn junctions also occur in more advanced devices like transistors and integrated circuits. As we will see, the on-off action of the pn junction provides the basis for all digital devices.



Video Demo

3.2 Diodes

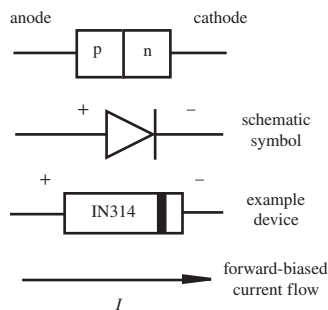


Figure 3.3 Silicon diode.

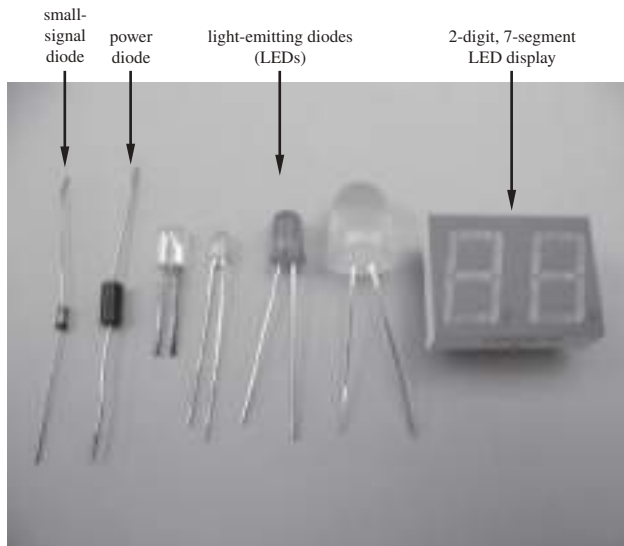


Figure 3.4 Examples of common diodes.

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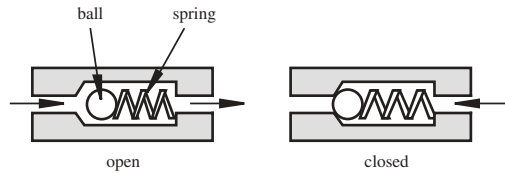


Figure 3.5 Diode check valve analogy.

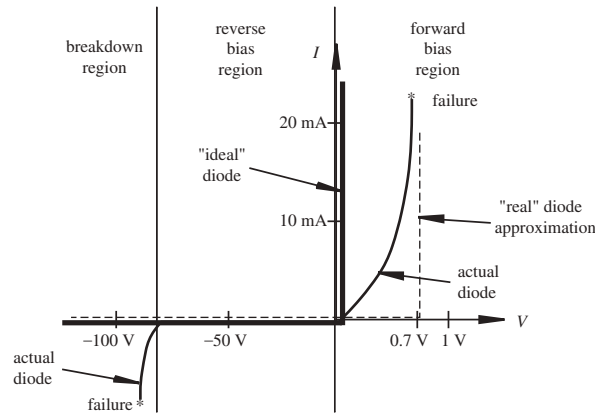


Figure 3.6 Ideal, actual, and approximate diode curves.

As described by Equation 3.1, the current–voltage characteristic curve for a semiconductor diode is exponential and is shown graphically in the first quadrant of Figure 3.6 (the curve labeled “actual diode”). There is a dramatic nonlinear increase in current as the forward bias voltage approaches 0.7 V. Note the different scales used on the positive and negative sides of the voltage axis. Sometimes we will approximate the behavior of the semiconductor diode using what we call an **“ideal” diode** model. The current–voltage characteristic curve for the “ideal” diode is shown by the dark solid lines in Figure 3.6. This model implies that the diode is fully on when forward biased, with no voltage drop across the diode. Also, when reverse biased, the reverse saturation current is assumed to be 0. So an “ideal” diode has zero resistance when forward biased and infinite resistance when reverse biased.

A good approximation for a **“real” diode** is shown by the dashed lines in Figure 3.6. We assume that a “real” diode requires 0.7 V of forward bias voltage to enable significant current flow. The “ideal” and “real” simplified models are used to make diode circuit analysis easier, while still capturing the important features of the device.

When an actual diode is reverse biased, it can withstand a reverse voltage up to a limit known as the **breakdown voltage**, where the diode will fail as the reverse current increases precipitously. We will see in Section 3.3.4 that there is a class of diodes, called zener diodes, designed for use in the reverse bias region for special applications.

When analyzing diode circuits, we need to be clear whether we are assuming an “ideal” model or the approximate model of a “real” diode. In this book, we will never use the “actual” diode exponential current–voltage equation when doing basic circuit

analysis. If we assume an “ideal” diode, we will replace the diode with a short circuit when forward biased (i.e., when current is flowing in the “on” direction of the diode) and an open circuit when reverse biased. If we assume a “real” diode approximation, we will replace the diode with a 0.7 V voltage drop when forward biased and an open circuit when reverse biased. If we do not mention which model is being used, always assume the “real” diode model, which is a close approximation to actual diode function.

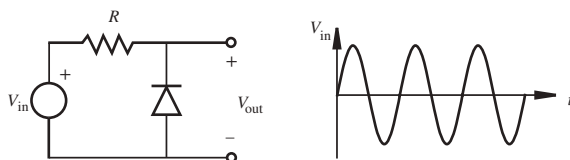
A diode is useful as a rectifier, where it passes only the positive half or the negative half of an AC signal. Example 3.1 illustrates how to analyze a simple ideal diode circuit called a half-wave rectifier. Rectifier circuits are used in the design of power supplies, where AC power must be transformed into DC power for use in electronic devices and digital circuits.

The important specifications that differentiate diodes are the maximum forward current and the maximum reverse bias voltage where breakdown occurs. The instantaneous surge current and average current are usually both specified, and the values calculated for a circuit must not exceed these limits. You must also confirm that reverse bias voltages in your circuit do not exceed the specified breakdown value. Rectifier and power diodes are capable of carrying very large currents. They are designed to be attached to heat sinks in order to efficiently dissipate heat produced in the junction. Diodes require nanoseconds to switch between their on and off states. This switching time is fast enough for most applications, but when designing high-speed circuits it may pose a constraint.

Half-Wave Rectifier Circuit Assuming an Ideal Diode

EXAMPLE 3.1

Given the following circuit containing a diode, we will illustrate how to determine the output voltage V_{out} given a sinusoidal input V_{in} , assuming an “ideal” diode.



A good approach to solving this problem is to analyze separately the response when $V_{\text{in}} > 0$ and then when $V_{\text{in}} < 0$. When V_{in} is positive, the diode is reverse biased and therefore equivalent to an open circuit. No current flows through the resistor, and the output V_{out} equals V_{in} . When V_{in} is negative, the diode is forward biased, and it is equivalent to a short circuit. Therefore, there is no voltage drop across the diode and V_{out} is 0 V. Combining these two cases, the resulting output waveform retains the positive peaks in the sine wave and loses the negative peaks (see the following figure). Because only the positive half of the wave remains, this circuit is known as a **half-wave rectifier**. Section 3.3.1 presents a full-wave rectifier.



■ CLASS DISCUSSION ITEM 3.1

Real Silicon Diode in a Half-Wave Rectifier

In Example 3.1, we assumed that the diode was ideal. The “real” diode approximation assumes that 0.7 V is required to forward bias the diode. Using the current-voltage relation shown by the dashed curve in Figure 3.6, show how the output of the half-wave rectifier would be different.

3.3.1 Diode Circuit Applications

This section presents a variety of common and useful diode circuits. The first is called a **full-wave bridge rectifier**. It is used to help convert AC power into DC as illustrated in Figure 3.7. A rectifier is an extremely important circuit because it is used in many digital and battery-powered devices such as computers, phones, electric toothbrushes, and razors, and any AC-powered mechatronic systems containing digital circuits and microcontrollers. All of these devices require DC voltages to operate, but power in our homes and workplaces is often provided only in AC form. AC adaptors, DC power supplies, battery charges, and all AC-powered DC devices include a full-wave bridge rectifier.

In Figure 3.7, the AC line input voltage (e.g., 120 V_{rms} at 60 Hz in the United States, and 220–230 V_{rms} at 50Hz in Europe) is first stepped down to a smaller-amplitude AC signal using a transformer (see Section 2.8). This is necessary since the desired DC voltage has a magnitude (e.g., 5 V or 12 V) lower than the amplitude of the AC line input. Unlike the half-wave rectifier presented in Example 3.1, which used only a single diode and blocked the negative halves of the AC signal, the full-wave rectifier uses four diodes to retain the entire signal while inverting the negative halves of the wave (described more below). The entire AC-to-DC process, including rectification, is illustrated by the signal plots at the bottom of Figure 3.7. A filter and voltage regulator is used to smooth out the rectified signal to give a cleaner and more-stable DC voltage reference. Filter basics are presented in Section 4.4, and voltage regulator basics are covered in Sections 3.3.4 and 3.3.5.

Figure 3.8 illustrates how the full-wave bridge rectifier functions. Assuming ideal diodes in Figure 3.8a, when the AC input to the bridge is positive (the upper halves of the wave), the current flows through the top-left and bottom-right diodes

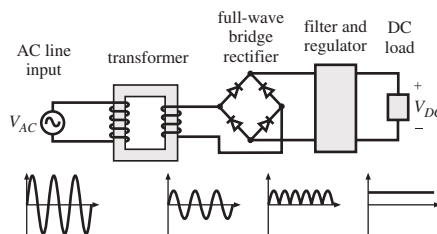


Figure 3.7 AC-to-DC converter with full-bridge rectifier.

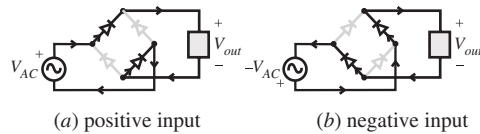


Figure 3.8 Full-bridge rectifier action.

as shown and the output voltage matches the AC input ($V_{\text{out}} = V_{\text{AC}}$). As shown in Figure 3.8b, when the AC input goes negative (the bottom halves of the wave), the other pair of diodes conduct causing the current through the output circuit to remain in the same direction. In this case, the output voltage is the negative of the input ($V_{\text{out}} = -V_{\text{AC}}$), so the output is an inverted version of the input (i.e., the negative halves of the input wave are flipped positive).

Figure 3.9 illustrates another extremely important diode circuit, where the diode provides protection against switch arcing and voltage/current spikes that can result when an inductive load is switched off. In this application, the diode is called a **flyback, kickback, or snubber diode**. The switch in the figure could be a transistor or a relay instead, and the inductive load could be an inductor, a motor coil, a solenoid, a relay, or anything containing a coil of wire that has inductance. Figure 3.10 illustrates how the circuit functions and justifies the need for the diode. As shown in Figure 3.10a, when the switch is in the closed position, a steady state current ($I_{\text{ss}} = V_s/R$) is established. Remember that in steady state, an inductor is equivalent to a short (zero resistance). An inductor generates a voltage only when the current changes ($V = L \, di/dt$), and this voltage opposes the change in current. So when the switch is opened, the current does not stop immediately because the inductor generates a voltage that forward biases the diode allowing the current to keep flowing in the flyback loop, as shown in Figure 3.10b. The current then dissipates gradually and fairly quickly (based on the resistor and inductor values, per first-order-system response theory in Chapter 4).

Figure 3.10c shows what would happen if the flyback diode were not included in the circuit. When the switch is first opened, the current attempts to decrease very rapidly because there is no longer a closed conducting path. However, the magnetic-field energy stored in the inductor must go somewhere, and the inductor generates a very large voltage to oppose the change in current. This effect is

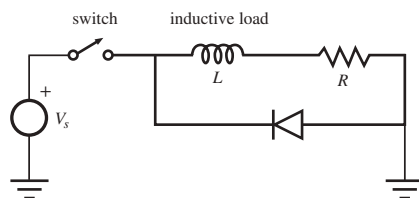


Figure 3.9 Inductive load flyback protection.

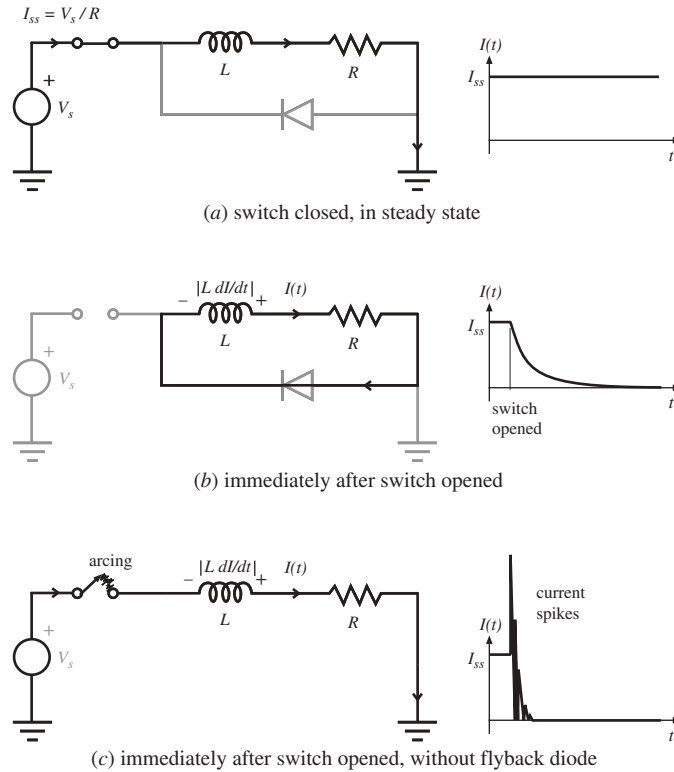


Figure 3.10 Flyback action.

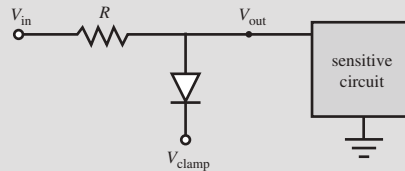
sometimes called “**inductive kick.**” The large voltage results in arcing across the switch contacts (while the contacts are still close together, immediately after the switch is opened). As illustrated in the plot on the right side of Figure 3.10c, the arcing can be a somewhat random process, with the current varying wildly over a very short amount of time. The resulting current spikes can be of very large magnitude, many times larger than the steady state current. Arcing is bad because it can damage the switch contacts, especially over many on–off cycles. Current spikes are bad because they can damage sensitive components in the circuit. They also generate fast-changing magnetic fields that can create electromagnetic interference (EMI), which can adversely affect surrounding circuits (see Section 2.10.6 for more information). The current spikes can also cause disturbances in the supply voltage and ground references.

When selecting a diode to be used for flyback protection, you just need to make sure the current rating is large enough to handle the steady-state-current magnitude that occurs at the beginning of the flyback period. It also helps to have a diode with a fast switching time between reverse and forward bias conditions so the flyback protection can activate as quickly as possible.

■ CLASS DISCUSSION ITEM 3.2

Diode Clamp

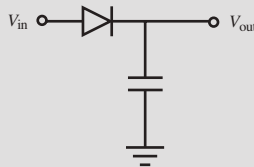
The circuit below is called a **diode clamp** because it limits (“clamps”) the voltage going to a sensitive circuit. If the circuit has very high input impedance, discuss how the voltage applied to the circuit (V_{out}) varies when the input voltage (V_{in}) changes, based on the clamp voltage (V_{clamp}). Consider both “real” and “ideal” models of the diode.



■ CLASS DISCUSSION ITEM 3.3

Peak Detector

The following circuit is known as a **peak detector**. When a time-varying signal V_{in} is applied at the input, the output V_{out} retains the maximum positive value of the input signal. Under what condition does the capacitor charge? Sketch an arbitrary input signal and the resulting ideal output. What behavior would you expect from an actual circuit where the capacitor is “leaky”; that is, the capacitor’s charge gradually dissipates? Draw the resulting V_{out} for the “real” (nonideal) capacitor.



Lab Exercise 4 introduces diodes and how they are used in basic circuits. The Lab also shows the differences between signal diodes and LEDs.

3.3.2 Optoelectronic Diodes

Light-emitting diodes are diodes that emit photons when forward biased. The typical LED and its schematic symbol are illustrated in Figure 3.11. The positive lead, or anode, is usually the longer of the two leads. The LED is usually encased in a colored plastic material that enhances the wavelength generated by the diode and sometimes helps focus the light into a beam. If the leads of an LED have been trimmed (e.g., to insert the LED in a breadboard), it might not be obvious which lead is the anode or cathode. If this is the case, there are two simple ways to distinguish the

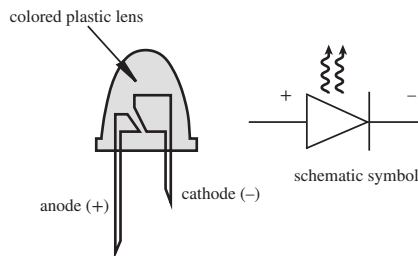


Figure 3.11 Light-emitting diode.

leads (without using an LED polarity-testing device or circuit). The internal construction of many LEDs look like the illustration in Figure 3.11. The lead attached to the smaller internal component is the plus side. Also, the plastic casing on some LEDs has a flat side on the lip at the base of the plastic casing. If so, that side is the negative side. This is easy to remember because the flat side corresponds to the vertical line in the schematic symbol in Figure 3.11.

The intensity of light of an LED is related to the amount of current flowing through the device. LEDs are manufactured to produce a variety of colors, but red, yellow, and green are usually the most common and least expensive. It is important to remember that an LED has a voltage drop of 1.5 to 2.5 V when forward biased, somewhat more than small-signal silicon diodes. Generally, the forward bias voltage is higher for LEDs that emit higher frequencies of light (e.g., a blue LED typically requires a higher bias voltage than a red LED).

It takes only a few milliamperes of current to dimly light an LED. It is important to include a series current-limiting resistor in the circuit to prevent excess forward current, which can quickly destroy the diode. Usually a $330\ \Omega$ resistor is included in series with an LED when used in digital (5 V) circuit designs. Figure 3.12 shows a typical LED circuit. Note that the current is limited to about 9 mA ($3\text{ V}/330\ \Omega$), which is enough to fully light a typical LED and is well within the current limit reported by manufacturers for many LEDs. However, different types and sizes of LEDs will require different amounts of current to achieve full brightness, so always check the manufacturer data sheet to determine how much series resistance you need to create the desired brightness. Lab Exercise 4 demonstrates how to build LED circuits properly and shows how much forward bias voltage and current is required

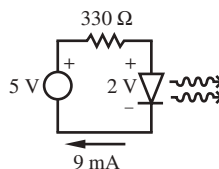


Figure 3.12 Typical LED circuit in digital systems.

to fully light an LED. LEDs are used ubiquitously as indicator signals on electrical devices and products, but they are also becoming increasingly important in lighting applications due to their high efficiency in converting electrical energy into light. The first lighting applications in which LEDs appeared were truck brake lights, traffic signal lights, flashlights, and bicycle headlights, but they are also being used more and more in home, office, and exterior lighting as economical replacements for older incandescent and fluorescent lighting.

Earlier we said that a pn junction is sensitive to light. Special diodes, called **photodiodes**, are designed to detect photons and can be used in circuits to sense light as shown in Figure 3.13. Note that it is the reverse current that flows through the diode when sensing light. The phototransistor (see Section 3.4.6) can be a more sensitive device, although it is slower to respond. The photodiode is based on quantum effects. If photons excite carriers in a reverse-biased pn junction, a very small current proportional to the light intensity flows. The sensitivity depends on the wavelength of the light. In addition to being used for light detection, photodiodes are also the basis of solar cells, where sunlight is converted to electrical energy.



Lab Exercise

Lab 4 Band-width, filters, and diodes

3.3.3 Analysis of Diode Circuits

Although most of your analyses include single isolated diodes in circuits, there are situations when you design a circuit containing multiple diodes. Because the diode is a nonlinear device, one has to be careful not to naively apply the linear circuit analysis methods discussed so far.

DC circuits that contain many diodes may not be easy to analyze by inspection. The following procedure is a straightforward method to determine voltages and currents in these circuits. First, assume current directions for each circuit element. Next, replace each diode with an equivalent open circuit if the assumed current is in a reverse bias direction or a short circuit if it is in the forward bias direction. Then compute the voltage drops and currents in the circuit loops using KVL and KCL. If the sign on a resulting current is opposite to the assumed direction through an element, you have made the wrong assumption and must change its direction and reanalyze the circuit. Repeat this procedure with different combinations of current directions until there are no inconsistencies between assumed and calculated voltage drops and currents.

The procedure and example above assumed that when a diode is forward biased, it can be replaced by a short circuit, which implies a 0 V forward bias voltage. The

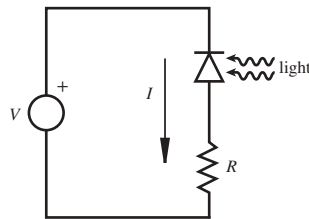
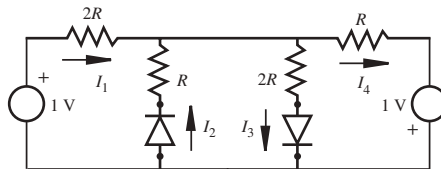


Figure 3.13 Photodiode light detector circuit.

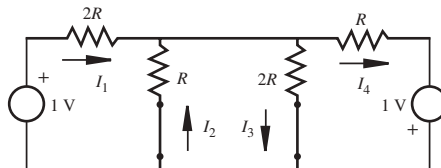
procedure has to be modified to model “real” diodes accurately. To account for the forward bias voltage, instead of replacing the diode with a short, it must be replaced by a small voltage source whose voltage is equal to the forward bias value of the diode (e.g., 0.7 V for signal silicon diodes).

EXAMPLE 3.2**Analysis of Circuit with More Than One Diode**

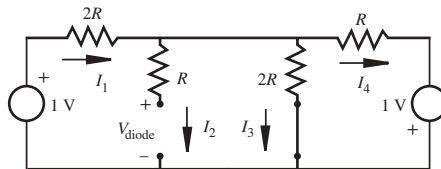
This example illustrates the application of the procedure just outlined to a circuit containing two diodes assumed to be ideal. In the following circuit, we want to determine all currents and voltages. We begin by arbitrarily assuming the current directions as shown.



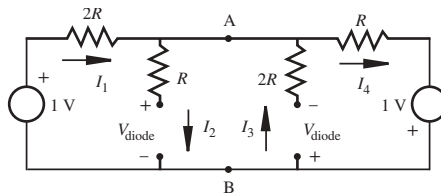
Having assumed the current directions, we replace each diode with a short, because each is assumed to be forward biased. The equivalent circuit follows.



By applying KVL to the loop containing I_2 and I_3 , we find that $I_2 = -2I_3$. We conclude that one of the current directions was assumed incorrectly (i.e., in the wrong direction). Therefore, we need to change one of our initial assumptions. Assume I_2 is in the direction opposite to that first chosen. With this assumption, the diode must be replaced with an open circuit because it is reverse biased. The equivalent circuit is shown next.

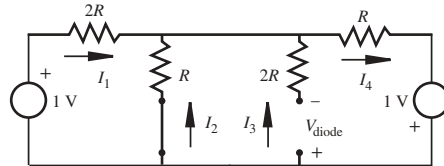


Note that $I_2 = 0$ in this circuit and V_{diode} is the voltage across the reverse-biased diode. By applying KVL to the loop containing I_3 and I_4 , the result is that $I_3 < 0$. Therefore, our assumed direction for I_3 is incorrect (since the calculated value is negative). We must reverse I_3 and replace the diode with an open circuit. The resulting circuit is shown.



Note that I_2 and I_3 are both 0 in this circuit and each reverse-biased diode has a nonzero voltage across its terminals. The diode branches are in parallel, so they must have the same voltage across them, which is the voltage across nodes A and B. Because the diode currents are assumed to be zero, there would be no drops across the diode-branch resistors. Therefore, the voltage across each diode would need to be the same (magnitude and polarity). This is not the case for this circuit (the voltages have opposite polarity), so the assumed current directions are again incorrect.

The next choice for assumed current directions, which is the only combination we have not investigated, follows.



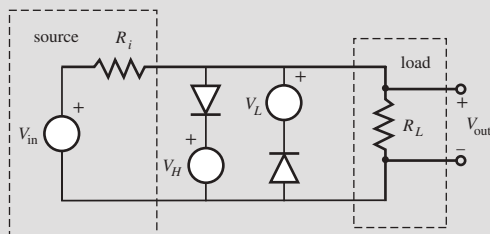
If we analyze this circuit (Question 3.10), we find that $I_2 > 0$ and $V_{\text{diode}} > 0$ as assumed. Therefore, there are no inconsistencies, and our results are correct.

In this example, we performed an exhaustive search to check every possible combination of diode biasing. If we had chosen the correct combination earlier in the procedure, by luck or by an educated guess, the exhaustive search would not have been required.

■ CLASS DISCUSSION ITEM 3.4

Voltage Limiter

The diode portion of the following circuit is called a **voltage limiter**. Explain why. Sketch some input and output waveforms that illustrate the circuit's behavior. Note: $V_H > V_L$.



3.3.4 Zener Diode

Reflect back on the current–voltage relationship for a diode shown in Figure 3.6 in Section 3.3. Note that when a diode is reverse biased with a large enough voltage, the diode allows a large reverse current to flow. This is called diode **breakdown**. For most diodes the breakdown value is at least 50 V and may extend to kilovolts. A

special class of diodes is designed to exploit this characteristic. They are known as **zener**, avalanche, or voltage regulator **diodes**. This family of diodes exhibits steep breakdown curves with well-defined breakdown voltages; thus, they can maintain a nearly constant voltage over a wide range of currents (see Figure 3.14). This characteristic makes them good candidates for building simple voltage regulators, because they can maintain a stable DC voltage in the presence of a variable supply voltage and variable load resistance.

To properly use the zener diode in a circuit, the zener should be reverse biased with a voltage kept in excess of its breakdown or **zener voltage** V_z . Using a zener diode in series with a resistor as shown in Figure 3.15 results in a simple circuit known as a **voltage regulator**. The output voltage of the circuit V_{out} is maintained or regulated by the zener diode at the zener voltage V_z . Even when the current through the zener diode changes (ΔI_z in the figure), the output voltage remains relatively constant (i.e., ΔV_z is small). The narrowness of the voltage range for a given current change is a measure of the voltage regulation of the circuit. If the input voltage and load do not change much, this circuit is effective in obtaining steady and lower DC voltage values from a source, even if the source is not well regulated.

Because the load applied to the voltage regulator will change with time in most applications and the voltage source will exhibit fluctuations, careful consideration

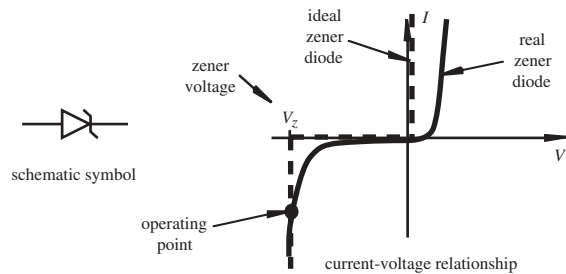


Figure 3.14 Zener diode symbol and current–voltage relationship.

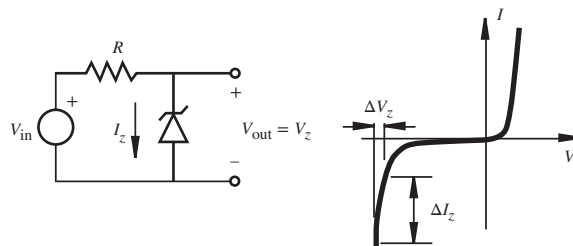


Figure 3.15 Zener diode voltage regulator.

must be paid to the effect on the regulated voltage V_z . For the circuit shown in Figure 3.15, the zener current is related to the circuit voltages according to

$$I_z = \frac{(V_{in} - V_z)}{R} \quad (3.2)$$

To determine how changes in current are related to changes in voltage, we take the finite differential of Equation 3.2, which yields

$$\Delta I_z = \frac{1}{R}(\Delta V_{in} - \Delta V_z) \quad (3.3)$$

The zener diode is a nonlinear circuit element, and therefore, ΔV_z is not directly proportional to ΔI_z . However, it is useful to define a dynamic resistance R_d that is the slope of the zener characteristic curve at a particular operating point. This allows us to express the zener current change in terms of the zener voltage change:

$$\Delta I_z = \frac{\Delta V_z}{R_d} \quad (3.4)$$

Normally a manufacturer specifies the nominal zener current I_{zt} and the maximum dynamic impedance (R_d) at the nominal zener current. In a circuit design using a zener diode, the zener current must exceed I_{zt} ; otherwise, the zener may operate near the “knee” of the characteristic curve where regulation is poor (i.e., where there is a large change in voltage with a small change in zener current).

By substituting Equation 3.4 into Equation 3.3 and solving for ΔV_z , we can express changes in the regulator output voltage ΔV_{out} in terms of fluctuations in the source voltage ΔV_{in} :

$$\Delta V_{out} = \Delta V_z = \frac{R_d}{R_d + R} \Delta V_{in} \quad (3.5)$$

Therefore, the circuit acts like a voltage divider (for a change in voltage) with the zener diode represented by its dynamic resistance at the operating current of the circuit.

Zener Regulation Performance

EXAMPLE 3.3

We wish to determine the regulation performance of the zener diode circuit shown in Figure 3.15 for a voltage source V_{in} whose value ranges between 20 and 30 V. For the zener diode, we select a 1N4744A manufactured by National Semiconductor from the family 1N4728A to 1N4752A (having different zener voltage values). It is a 15 V, 1 W zener diode. We select a value of R based on the specifications of this diode.

To limit the maximum power dissipation to less than 1 W, the current through the diode must be limited to

$$I_{z_{max}} = 1 \text{ W} / 15 \text{ V} = 66.7 \text{ mA}$$

(continued)

(concluded)

Therefore, using Equation 3.2, the value for resistance R should be chosen to be at least

$$R_{\min} = (V_{\text{in}_{\max}} - V_z)/I_{z_{\max}} = (30 \text{ V} - 15 \text{ V})/66.7 \text{ mA} = 225 \Omega$$

The closest acceptable standard resistance value is 240Ω . From the manufacturer's specifications for this zener diode, its dynamic resistance R_d is 14Ω at 17 mA . The current I_z in this example is larger than this value, so the operating point of the zener diode is on the well-regulated portion of the characteristic curve. Using the given value for R_d in Equation 3.5, we can approximate the resulting output voltage range:

$$\Delta V_{\text{out}} = \Delta V_z = \frac{R_d}{R_d + R} \Delta V_{\text{in}} = \frac{14}{14 + 240} (30 - 20) \text{ V} = 0.55 \text{ V}$$

which is a measure of regulation of this circuit. This can be expressed as a percentage of the output voltage for a relative measure:

$$\frac{\Delta V_{\text{out}}}{V_{\text{out}}} 100\% = \frac{0.55 \text{ V}}{15 \text{ V}} 100\% = 3.7\%$$

■ CLASS DISCUSSION ITEM 3.5

Effects of Load on Voltage Regulator Design

Example 3.2 ignored the current that would be drawn by a load. What effect would a load have on the results of the analysis?

Figure 3.16 illustrates a simple voltage regulator circuit where R_L is a load resistance and V_{in} is an unregulated source whose value exceeds the zener voltage V_z . The purpose of this circuit is to provide a constant DC voltage V_z across the load with a corresponding constant current through the load. Providing a stable regulated voltage to a system containing digital integrated circuits is a common application.

If we assume the zener diode is ideal (i.e., its breakdown current–voltage curve is vertical), we can draw some conclusions about the regulator circuit. First, the load

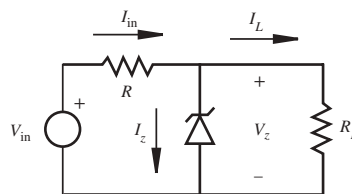


Figure 3.16 Zener diode voltage regulator circuit.

voltage will be V_z as long as the zener diode is subject to reverse breakdown. Therefore, the load current I_L is

$$I_L = \frac{V_z}{R_L} \quad (3.6)$$

Second, the load current will be the difference between the unregulated input current I_{in} and the zener diode current I_z :

$$I_L = I_{in} - I_z \quad (3.7)$$

As long as V_z is constant and the load does not change, I_L remains constant. This means that the diode current changes to absorb changes from the unregulated source.

Third, the unregulated source current I_{in} is given by

$$I_{in} = \frac{(V_{in} - V_z)}{R} \quad (3.8)$$

R is known as a current-limiting resistor because it limits the power dissipated by the zener diode. If I_z gets too large, the zener diode fails.

Zener Diode Voltage Regulator Design

DESIGN EXAMPLE 3.1

Suppose we need to design a regulated 15 V DC source to power a mechatronic system, and we would like to use the voltage regulator circuit shown in Figure 3.16. Furthermore, suppose we have access to only a poorly regulated DC source V_{in} whose nominal value is 24 V.

As the load R_L changes, the zener current I_z increases for larger R_L and decreases for smaller R_L . If we know the maximum possible load resistance (assuming that the output never is an open circuit), we can size the zener diode with regard to its power dissipation characteristics and select a current-limiting resistor. Combining Equations 3.6 and 3.7 and using the maximum value of the load $R_{L_{max}}$ gives

$$I_{z_{max}} = \left(I_{in} - \frac{V_z}{R_{L_{max}}} \right)$$

This is the largest current the zener experiences. The power dissipated by the zener diode is

$$P_{z_{max}} = I_{z_{max}} V_z = \left(I_{in} - \frac{V_z}{R_{L_{max}}} \right) V_z$$

I_{in} is controlled by the current-limiting resistor R . Substituting Equation 3.8 yields

$$P_{z_{max}} = \left(\frac{V_{in} - V_z}{R} \right) V_z - \frac{V_z^2}{R_{L_{max}}}$$

Furthermore, for this design problem, we assume that $R_{L_{max}}$ is 240 Ω , and we wish to select a 1 W zener. Therefore,

$$1 \text{ W} = \frac{24 \text{ V} - 15 \text{ V}}{R_{min}} (15 \text{ V}) - \frac{225 \text{ V}^2}{240 \Omega}$$

(continued)

(concluded)

We can now solve for the minimum required current-limiting resistance R :

$$R_{\min} = 69.7\Omega$$

The closest acceptable standard resistance value is 75 Ω .

In summary, zener diodes are useful in circuits where it is necessary to derive smaller regulated voltages from a single higher-voltage source. When designing zener diode circuits, one must select appropriate current-limiting resistors given the power limitations of the diodes. In simple mechatronic designs that may be powered by a 9 V battery and require good 5 V DC supplies for digital devices, a well-designed zener regulator is a cheap and effective solution if the current requirements are modest.

3.3.5 Voltage Regulators

Although the zener diode voltage regulator is cheap and simple to use, it has some drawbacks: The output voltage cannot be set to a precise value, and regulation against source ripple and changes in load is limited. Special semiconductor devices are designed to serve as voltage regulators, some for fixed positive or negative values and others easy to adjust to a desired, nonstandard value. One group of regulators that is easy to use is the three-terminal regulator designated as the 78XX, where the last two digits (XX) specify a voltage with standard values: 5 (05), 12, or 15 V. Using a regulator such as the LM7815C, a well-regulated 15 V source is easy to create, as shown in Figure 3.17 (see Section 7.10.2 for more information).

We could use this design instead of the zener regulator shown in Design Example 3.1 (see Class Discussion Item 3.6). The 78XX can deliver up to 1 A of current and is internally protected from overload. Using this device, the designer need not perform the design calculations shown with the zener diode regulator. The 78XX series of regulators have complementary 79XX series values for providing $\pm$ voltage supplies.

■ CLASS DISCUSSION ITEM 3.6

78XX Series Voltage Regulator

In Design Example 3.1, we used a zener diode to provide a desired DC voltage. Now show how a 78XX voltage regulator can do the same job. Specify the regulator and describe its characteristics.

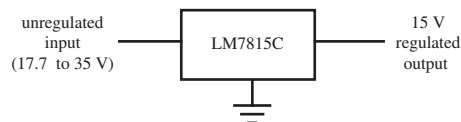


Figure 3.17 Fifteen-volt regulated DC supply.

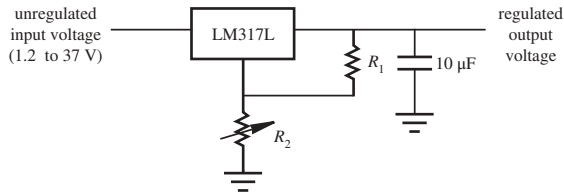


Figure 3.18 1.2 to 37 V adjustable regulator.

In some cases, you may need a regulated voltage source with a value not provided in a manufacturer's standard sequence. Then you may use a three-terminal regulator designed to be adjustable by the addition of external resistors. The LM317L can provide an adjustable output with the addition of two external resistors as shown in Figure 3.18. The output voltage is given by

$$V_{\text{out}} = 1.25 \left(1 + \frac{R_2}{R_1} \right) \text{V} \quad (3.9)$$

These adjustable regulators are available in higher current and voltage ratings.

Three-terminal voltage regulators are accurate, reject ripple on the input, reject voltage spikes, have roughly a 0.1% regulation, and are quite stable, making them useful in mechatronic system design.

■ CLASS DISCUSSION ITEM 3.7

Automobile Charging System

The typical automobile has a 12 V DC electrical system where a lead-acid battery is charged by a belt-driven AC alternator whose frequency and voltage vary with engine speed. What type of signal conditioning must be performed between the alternator and the battery, and how can this be done?

3.4 BIPOLAR JUNCTION TRANSISTOR

The bipolar junction transistor was the salient invention that led to the electronic age, integrated circuits, and ultimately the entire digital world. The transistor has truly revolutionized human existence by impacting practically everything in our everyday lives. We begin this section by providing the physical foundations necessary to understand the function of the transistor. Then we show how it can be used to build some important circuits.

3.4.1 Bipolar Transistor Physics

We saw earlier that a semiconductor diode consists of adjacent regions of p-type and n-type silicon, each connected to a lead. A **bipolar junction transistor** (BJT), in contrast, consists of three adjacent regions of doped silicon, each of which is

connected to an external lead. There are two types of BJTs: npn and pnp transistors. The most common type is the npn BJT, which we discuss in detail and use in our examples. As shown in Figure 3.19, it consists of a thin region or layer of p-type silicon sandwiched between two regions or layers of n-type silicon. Three leads are connected to the three regions, and they are called the **collector**, **base**, and **emitter**. As we will see, the *collector* “collects” current into the device and the *emitter* “emits” current from the device, and current flow is controlled by the *base* which serves as the “base” of operations. As denoted by the bold **n** in Figure 3.19, the n-type silicon in the emitter is more heavily doped than the collector, so the collector and emitter are not interchangeable. The corresponding circuit schematic symbol is also shown in the figure with currents and voltages defined and labeled. The construction, schematic, and notation for the pnp BJT is shown in Figure 3.20. The remainder of this section focuses on the npn bipolar junction transistor in Figure 3.19.

V_{CE} is the voltage between the collector and emitter, and V_{BE} is the voltage between the base and emitter. The relationships involving the transistor currents and voltages follow:

$$I_E = I_C + I_B \quad (3.10)$$

$$V_{BE} = V_B - V_E \quad (3.11)$$

$$V_{CE} = V_C - V_E \quad (3.12)$$

For an npn transistor to be on, the base-to-emitter pn junction must be forward biased ($V_{BE} = 0.7\text{V}$, so $V_B = V_E + 0.7\text{V}$). When this is the case, a large collector current can flow ($I_C > 0$) with a small base current ($I_B \ll I_C$), and there will be a small voltage drop (V_{CE}) in the collector-to-emitter circuit ($V_E = V_C - V_{CE}$). For an npn transistor

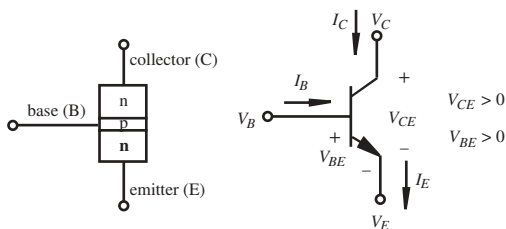


Figure 3.19 npn Bipolar junction transistor.

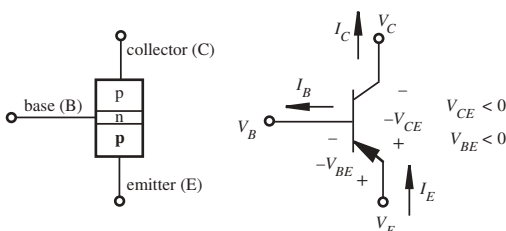


Figure 3.20 pnp Bipolar junction transistor.

to be on, the emitter-to-base pn junction must be forward biased ($V_{BE} = -0.7$ V, so $V_B = V_E - 0.7$ V). As with the npn transistor, this allows a large collector current to flow with a small base current.

To understand how the npn BJT functions, we begin by considering the base-to-emitter junction. When this junction is forward biased ($V_B = V_E + 0.7$ V), electrons diffuse from the emitter n-type region to the base p-type region. Because the base-to-collector junction is reverse biased ($V_B < V_C + 0.7$ V), there is a depletion region that would ordinarily prevent the flow of electrons from the base region into the collector region. However, because the base region is manufactured to be very thin and the emitter n-type region is more heavily doped than the base, most of the electrons from the emitter accelerate through the base region with enough momentum to cross the depletion region into the collector region without recombining with holes in the base region. Remembering that conventional current is in the opposite direction of electron motion, the result is that a small base current I_B flows from the base to the emitter and a larger current I_C flows from the collector to the emitter. The small base current controls a larger collector current, and therefore, the BJT functions as a current amplifier. This characteristic can be approximated with the following equation:

$$I_C = \beta I_B \quad (3.13)$$

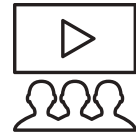
which states that the collector current is proportional to the base current with an amplification factor known as the **beta** (β) for the transistor. Manufacturers often use the symbol h_{FE} instead of β . For typical BJTs, beta is on the order of 100, but it can vary significantly among transistors. Beta is also temperature and voltage dependent; therefore, a precise relationship should not be assumed when designing specific transistor circuits.

Video Demo 3.3 does an excellent job explaining and illustrating the semiconductor physics behind how a diode (p–n junction) and BJT functions. If the explanations above were unclear, you might want to view the video.

Because of the BJT's base-collector current characteristics, it can be used to amplify current or to simply switch current on and off. This on–off switching is the basis for most digital computers because it allows easy implementation of a two-state binary representation. We focus on switch design and not amplifier design in our mechatronic applications. Amplifier design requires a more in-depth study of BJTs and is covered thoroughly in electrical engineering microelectronics textbooks.

3.4.2 Common Emitter Transistor Circuit

If a BJT's emitter is grounded and an input voltage is applied to the base, the result is the **common emitter** circuit shown in Figure 3.21. As the base current is gradually increased, the base-to-emitter diode of the transistor begins to conduct when V_{BE} is about 0.6 V. At this point I_C begins to flow and is roughly proportional to I_B ($I_C = \beta I_B$). As I_B is further increased, V_{BE} slowly increases only to about 0.7 V while I_C rises exponentially. As I_C rises, the voltage drop across R_C increases and V_{CE} drops toward ground. The collector cannot drop completely to ground; otherwise, the base-to-collector pn junction would also be forward biased. When V_{CE} reaches its minimum, the transistor is said to go into saturation. In this mode, the collector current is determined by R_C , and the linear relation between I_C and I_B no longer holds.



Video Demo

3.3 Transistor, How does it work?

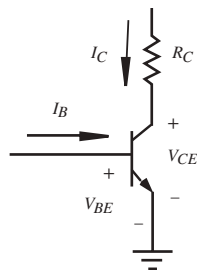


Figure 3.21 Common emitter circuit.

The characteristics of the common emitter transistor circuit can be summarized by plotting the collector current I_C versus the collector-emitter voltage V_{CE} for different values of base current I_B . The resulting family of curves (see Figure 3.22) describes the **common emitter characteristics** for the transistor. The transistor has a **cutoff region** (where no collector current flows), an **active region** (where collector current is proportional to base current), and a **saturation region** (where collector current is strictly controlled by the collector circuit, assuming sufficient base current).

When designing a transistor switch, we need to guarantee that the transistor is fully saturated when it is on. In full saturation, V_{CE} is at its minimum, which is about 0.2 V for a BJT. So in saturation, the base-to-emitter junction is forward biased ($V_{BE} = 0.7$ V), there is a small drop from the collector to the emitter ($V_{CE} = 0.2$ V), and the voltages at the leads of the transistor are related as:

$$V_B = V_E + 0.7 \text{ V} \quad (3.14)$$

$$V_C = V_E + 0.2 \text{ V} \quad (3.15)$$

Example 3.4 shows how to determine how much base current and input voltage are required to saturate a transistor. The power dissipated by the transistor ($I_C V_{CE}$) is smallest, for a given collector current, when it is fully saturated. If the transistor is not fully saturated, it gets hot faster and can fail.

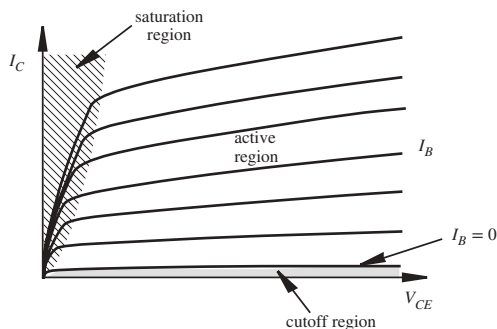


Figure 3.22 Common emitter characteristics for a transistor.

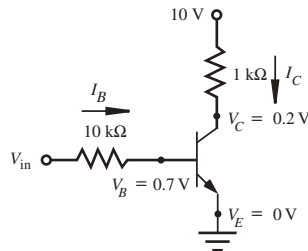
Guaranteeing a Transistor Is in Saturation

EXAMPLE 3.4

The 2N3904 is a small-signal transistor manufactured by many companies as a general purpose amplifier and switch. If you examine the specifications online or in a discrete transistor handbook, you can find a complete list of ratings and electrical characteristics. Here is some of the information provided:

- Maximum collector current (continuous) = 200 mA
- $V_{CE}(\text{sat}) = 0.2 \text{ V}$
- $h_{FE} = \beta = 100$ (depending on collector current and many other things)

In the following circuit, what minimum input voltage V_{in} is necessary to saturate the transistor?



Because $V_{CE}(\text{sat})$ for the 2N3904 is 0.2 V, when the transistor is fully saturated the collector current is

$$I_C = (10 \text{ V} - 0.2 \text{ V}) / 1 \text{ k}\Omega = 9.8 \text{ mA}$$

Because the DC current gain h_{FE} is about 100, I_B must be at least $I_C / 100$ or 0.098 mA. Because $V_{BE} = 0.7 \text{ V}$, the base current can be related to the input voltage with

$$I_B = 0.098 \text{ mA} = (V_{in} - 0.7 \text{ V}) / 10 \text{ k}\Omega$$

Therefore, the minimum required input voltage for saturation is

$$V_{in_{\min}} = 0.98 \text{ V} + 0.7 \text{ V} = 1.68 \text{ V}$$

Normally you would use a voltage larger than this (e.g., 2 to 5 times larger) to ensure that the transistor is fully saturated, even with variances in parameters.

Probably the best way to understand the function of the BJT is to perform voltage and current measurements on actual circuits and plot the results. We have done just that for the two circuits shown in Figure 3.23, using a 2N3904 small-signal transistor. Lab Exercise 5 also includes some experiences to help develop an understanding of how transistor circuits function. The first circuit (Figure 3.23a) is the common emitter configuration that has been the topic of this section. The second circuit (Figure 3.23b) has an additional resistor in the emitter circuit that results in what is called emitter degeneration.

Figure 3.24 shows the results for the common emitter circuit (Figure 3.23a). In Figure 3.24a, notice how the base-to-emitter forward bias voltage V_{BE} and the



Lab Exercise

Lab 5 Transistors and photoelectric circuits

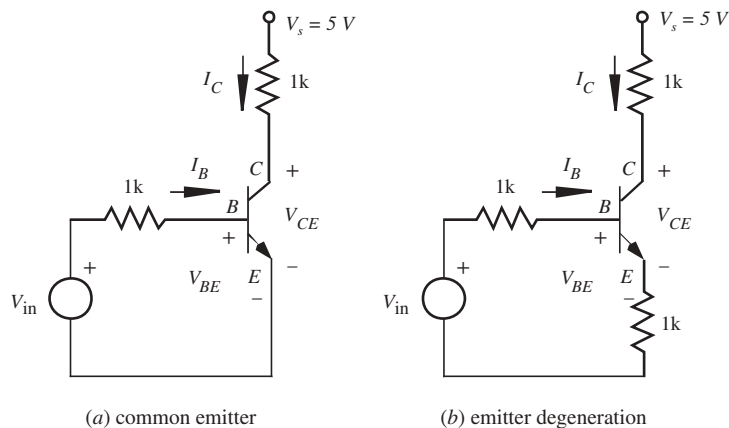
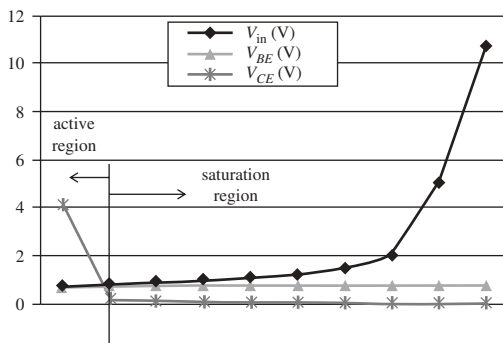
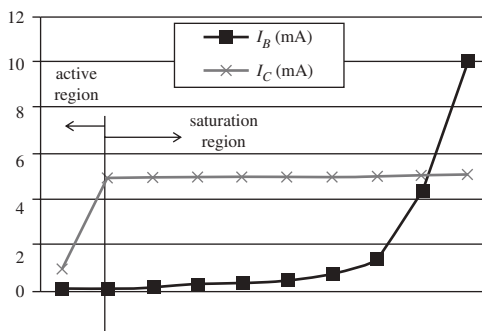


Figure 3.23 Transistor experiments.

collector-to-emitter voltage drop V_{CE} do not change much after the transistor is saturated, even when input voltage V_{in} is increased well above the minimum required for saturation. In Figure 3.24b, notice how the collector current I_C does not increase in the saturation region as the base current I_B is increased above what is required for



(a) voltages



(b) currents

Figure 3.24 Common emitter experimental results.

saturation. As demonstrated in Example 3.4, it is important to fully saturate a transistor by ensuring enough base current flows (by choosing an appropriate base resistor for the available input voltage). However, it is also clear that increasing the input voltage and base current significantly above the minimum required for saturation does not provide any meaningful increase in collector current and will only result in extra heat and energy loss in the base-to-emitter circuit.

Figure 3.25 shows the results for the emitter degeneration circuit (Figure 3.23b). In Figure 3.25a, notice how, just as with the common emitter circuit, the base-to-emitter forward bias voltage V_{BE} and the collector-to-emitter voltage drop V_{CE} do not change much after the transistor is saturated, even when input voltage V_{in} is increased well above the minimum required for saturation. In Figure 3.25b, notice how the collector current I_C response is very different from the response in the common emitter circuit. As before, saturation and maximum collector current occur at a fairly low base current. However, as the base current is increased, the collector current drops. This effect is called **emitter degeneration**. The reason for this is that the base current adds to the collector current, causing an increase in the emitter current ($I_E = I_B + I_C$), creating a larger voltage drop across the emitter resistor ($I_E R_E$). This reduces the voltage difference across the collector resistor, resulting in

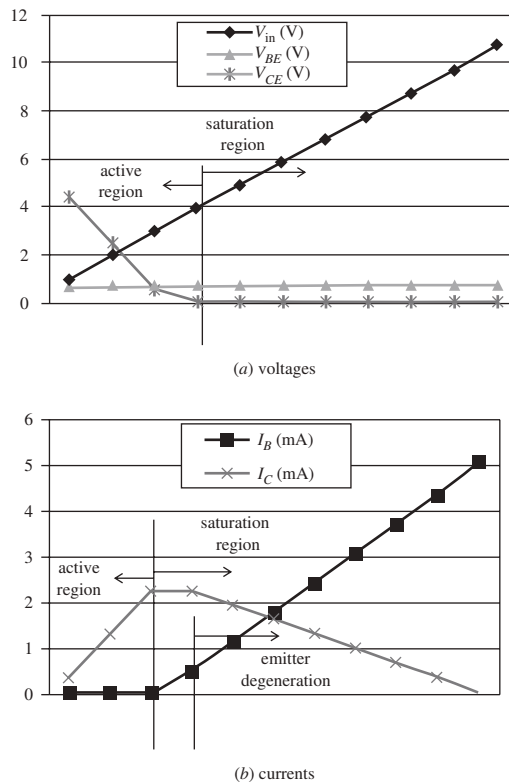


Figure 3.25 Emitter degeneration experimental results.

less collector current. The collector current actually decreases to zero as the voltage at the emitter ($V_E = I_E R_E$) approaches the collector supply voltage V_s . With no voltage difference across the collector resistor, no collector current will flow. For typical mechatronics switching applications, the common emitter configuration is more appropriate because it is easy to saturate the transistor and ensure maximum collector current over a wide range of circuit parameters.

3.4.3 Bipolar Transistor Switch

Figure 3.26 illustrates a simple transistor switch circuit. When V_{in} is less than 0.7 V, the BE junction of the transistor is not forward biased ($V_{BE} < 0.7$ V), and the transistor does not conduct ($I_C = I_E = 0$). You can therefore assume that the collector-to-emitter circuit can be replaced by a very high impedance or, for all practical purposes, an open circuit. This state, illustrated in Figure 3.27a, is referred to as the **cutoff** or OFF state of the transistor. In cutoff, the output voltage V_{out} is V_s because there is no current through or voltage drop across R_C .

When the BE junction is forward biased ($V_{BE} = 0.7$ V), the transistor conducts. Current passes through the CE circuit, and V_{out} is close to ground potential (0.2 V for a saturated BJT). This state, modeled by the forward biased diode illustrated in Figure 3.27b, is referred to as the **saturated** or ON state of the transistor. We assume that there is enough base current to saturate the transistor. The resistor R_B (see Figure 3.26)

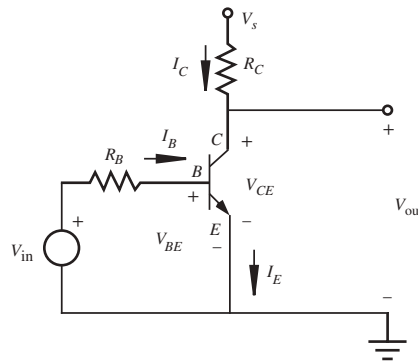


Figure 3.26 Transistor switch circuit.

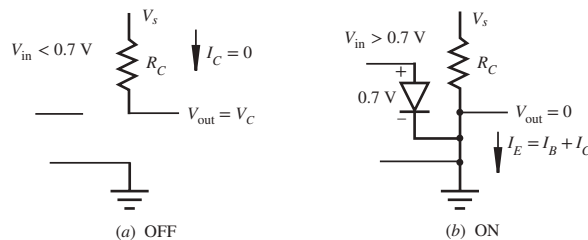


Figure 3.27 Models for transistor switch states.

is required in this circuit to limit the base current because the BE junction essentially behaves like a diode. The relationship between the base current and R_B is given by

$$I_B = (V_{in} - V_B)/R_B \quad (3.16)$$

where $V_B = V_{BE} = 0.7$ V. When $V_{in} < 0.7$, $I_B = 0$ and $V_{BE} = V_{in}$.

The circuit in Figure 3.26 can serve as a semiconductor switch to turn on or off an LED, electric motor, solenoid, electric light, or some other load (represented by R_C in the figure). These loads require large currents, ranging from milliamperes to many amperes, to function properly. When the input voltage and current are increased enough to saturate the transistor, a large collector current flows through the load R_C . The magnitude of the collector current is determined by the load resistance R_C and the collector voltage V_C , according to

$$I_C = (V_s - V_C)/R_C \quad (3.17)$$

where $V_C = V_{out} = 0.2$ V.

When the base-to-emitter voltage is below 0.7 V, the transistor is off, and no current flows through the load. Transistors used in power applications, called **power transistors**, are designed to conduct large currents and dissipate more heat. Power transistors are the basis for interfacing low-output current devices such as digital circuits and microcontroller outputs to devices requiring large currents (e.g., motors). Video Demo 3.4 does an excellent job explaining and showing how to use a BJT transistor as a switch in various applications.

Relays, which mechanically make and break connections, are an alternative to transistors. They cannot switch as fast as transistors and do not last as long, but they are very easy to use and can switch DC as well as AC power. For more information, see Section 10.3. AC current can also be switched with a **TRIAC** (triode for alternating current). A TRIAC is a semiconductor device based on **thyristors** or **silicon-controlled**



Video Demo

3.4 Transistor (BJT) as a Switch



Internet Link

3.1 TRIAC - triode for alternating current

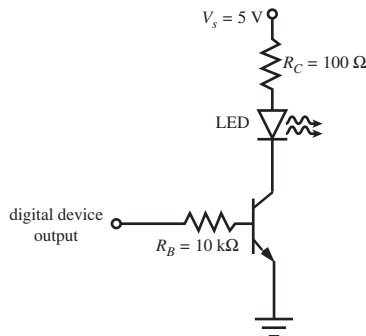
3.2 Thyristor

LED Switch

DESIGN EXAMPLE 3.2

Our objective is to turn a dashboard LED on or off with a digital device having an output voltage of either 0 V or 5 V and a maximum output current of 5 mA. The LED requires 20–40 mA to provide a bright display and has a 2 V voltage drop when forward biased.

We use a transistor switch circuit employing a small-signal transistor (e.g., 2N3904 npn) to provide sufficient current to the LED. The required circuit follows.



(continued)

(concluded)

When the digital output is 0 V, the transistor is in cutoff, and the LED is OFF. When the digital output (V_{in}) is 5 V, the transistor is in saturation so the voltage at the base of the transistor is 0.7 V more than the voltage at the emitter (0 V in this example). Therefore, the base current is

$$I_B = (V_{in} - V_B)/R_B = (5 \text{ V} - 0.7 \text{ V})/10 \text{ k}\Omega = 0.43 \text{ mA}$$

which is within the specifications. The 100Ω collector resistance is chosen to limit the LED current to the desired value. Since the collector voltage is 0.2 V higher than the emitter voltage (0 V in this example), and since the forward bias voltage of the LED is 2V, the collector current is:

$$I_C = [V_S - (V_C + V_{LED})]/R_C = (5 \text{ V} - 2 \text{ V} - 0.2 \text{ V})/100\Omega = 28 \text{ mA}$$

This current is within the desired range (20–40 mA) for the LED to be shine bright.



Lab Exercise

Lab 5 Transistors and photoelectric circuits



Video Demo

3.3 Turning a motor on and off with a transistor



Video Demo

3.6 Transistors

rectifiers (SCRs), which are diodes with a separate gate signal that controls conduction. For more information, see Internet Links 3.1 and 3.2.

Lab Exercise 5 demonstrates how to wire and use various types of diode and transistor circuits. Included are a basic transistor switch circuit, a motor driver circuit with flyback protection (see Video Demo 3.3), and a photo-interrupter.

Let us summarize the guidelines for designing a transistor switch. To be ON, the base-to-emitter voltage (V_{BE}) must be 0.7 V. The collector current I_C is independent of base current I_B when the transistor is saturated, as long as there is enough base current to ensure saturation. The minimum base current required can be estimated by first determining the collector current I_C and then applying $I_{B_{min}} \approx I_C/\beta$. For a given input voltage, the input resistance must be chosen so that the base current exceeds this value by a conservative margin (e.g., 2–5 times larger). The reasons for this are that β may vary among components, with temperature, and with voltage; and the load resistance may change as current flows through it. It is also important to calculate the maximum values of I_C and I_B to ensure that they fall within the manufacturer's specifications, and add or change series resistors if the currents are too large.

3.4.4 Bipolar Transistor Packages

Transistor manufacturers offer their devices in a number of packages as illustrated in Figure 3.28. The small-signal transistor packages are often the TO-92, and the power transistor packages are the TO-220. Surface mount technology is used on production printed circuit boards, but such devices are less useful for prototyping because of their small size and lack of pins for inserting them into breadboards or protoboards. Figure 3.29 and Video Demo 3.6 illustrate various common transistor packages. Included are BJTs, metal-oxide-semiconductor field-effect transistors (MOSFETs, which are covered in Section 3.5), and a photo-interrupter (covered in Section 3.4.6).



Figure 3.28 Bipolar transistor packages.

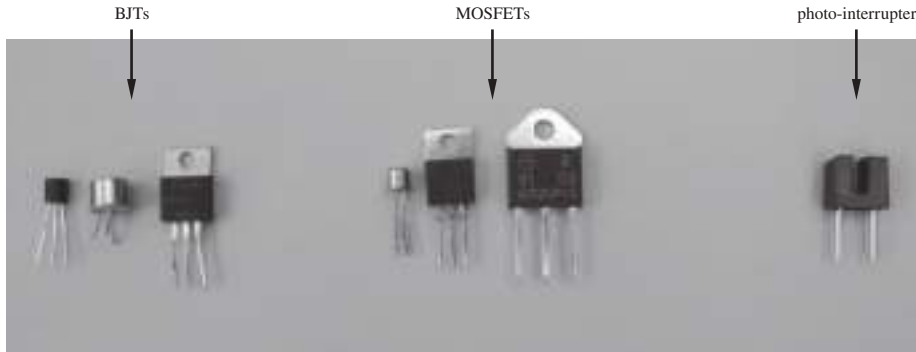


Figure 3.29 Various common transistor packages.

©David Alciatore

3.4.5 Darlington Transistor

The schematic in Figure 3.30 represents a transistor known as a **Darlington pair**, which usually comes in a single package (as indicated by the dashed box). The advantage of this combination is that the current gain is the product of the two individual transistor gains and can exceed 10,000. They may often be found in power circuits for mechatronic systems.

3.4.6 Phototransistor and Optoisolator

A special class of transistor is the **phototransistor**, whose junction between the base and emitter acts as a photodiode (see Section 3.3.2). LEDs and phototransistors are often found in pairs, where the LED is used to create the light, and this light in turn biases the phototransistor. The pair can be used to detect the presence of an object that may partially or completely interrupt the light beam between the LED and transistor (see Lab Exercise 5).

An **optoisolator** is composed of an LED and a phototransistor separated by a small gap as illustrated in Figure 3.31. The light emitted by the LED causes current

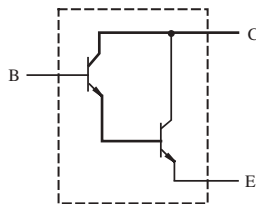


Figure 3.30 Darlington pair.



Lab Exercise

Lab 5 Transistors and photoelectric circuits

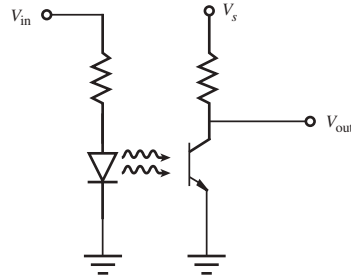


Figure 3.31 Optoisolator.

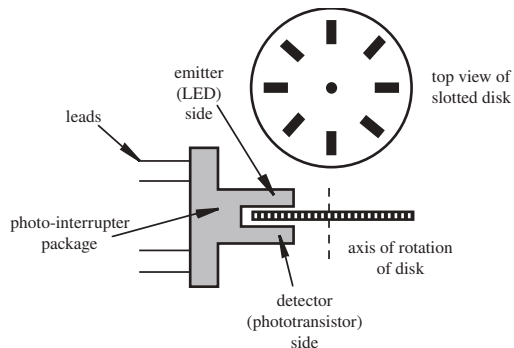
to flow in the phototransistor circuit. This output circuit can have a different ground reference, and the supply voltage V_s can be chosen to establish a desired output voltage range. With no common ground, the optoisolator creates a state of electrical isolation between the input and output circuits by transmitting the signal optically rather than through an electrical connection. A benefit of this isolation is that the

DESIGN EXAMPLE 3.3

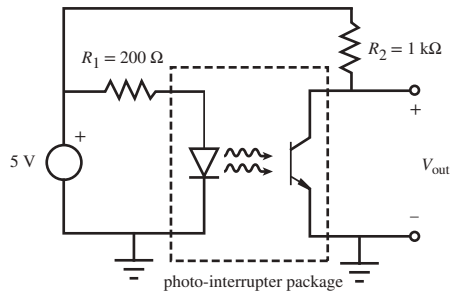
Angular Position of a Robotic Scanner

This design example illustrates an application of semiconductor optoelectronic components. Suppose, in the design of an autonomous robot, you wish to include a laser scanning device to sweep the environment to detect obstacles. The head of the scanner is rotated through 360° by a DC motor. Your problem here is to track the angular position of the scan head. How could you do this if you want an on-board computer to use the sensed values?

The solution requires a sensor that provides a digital output, that is, one that can be handled by a digital computer. We will learn more about digital interfacing in Chapter 6. To keep the solution simple at this point, we choose a device that produces a 5 V digital output. An LED-phototransistor pair, also known as a **photo-interrupter**, is at the heart of the design, which is illustrated in the following figure. The pair, which is readily available in a single package, produces a beam of light that can be broken or interrupted. A slotted disk must be designed to attach to the shaft of the motor driving the scan head and to pass through the gap in the photo-interrupter pair. Each slot in the disk provides a digital pulse as it interrupts the light beam during rotation.



For the sensor to function properly, we must add the external components shown in the following figure to provide a digital pulse each time a slot is encountered. The emitter LED and its current-limiting resistor R_1 are powered by a 5 V DC source. The phototransistor detector and external resistor R_2 provide output signal V_{out} . R_2 is called a **pull-up resistor** because it pulls the output voltage (V_{out}) up from ground (0 V) to 5 V when the transistor is in cutoff. When the transistor is saturated, the output voltage is near 0 V.



As the slotted disk rotates, light passes through each slot producing a 0 V output and then returns to 5 V when the segments between the slots interrupt the light. The result is a train of pulses. The number of pulses produced provides the measure of angular rotation as a digital approximation. For example, if the disk has 360 slots, each pulse would correspond to 1° of rotation.

output is protected from any excessive input voltages that could damage components in the output circuit. Also, because the supplies and grounds are separate, any fluctuations or disturbances that might occur in the output circuit have no effect on the control signals on the input side.

3.5 FIELD-EFFECT TRANSISTORS

Using what you have learned so far, you can design circuits for mechatronic systems using BJTs and other discrete components. We now examine the **field-effect transistor** (FET) that operates on a different principle than the BJT but serves a similar role in mechatronic system design. As we will see in Chapter 6, it is also an important component in the design of digital integrated circuits.

Both the BJT and FET are three-terminal devices allowing us to draw analogies between their function and how they are used in circuits. Before we look at the details of how FETs work, we describe their general characteristics. Both BJTs and FETs operate by controlling current between two terminals using a voltage applied to a third terminal. In Section 3.4, we saw that the forward bias of the base-to-emitter junction of the BJT allows charge carriers to enter a thin base region from the emitter, where they are attracted to the collector, resulting in a large collector current controlled by the much smaller base current. We concluded that the BJT is

a current amplifier. In contrast, with a FET, the electric field produced by a voltage on one electrode controls the availability of charge carriers in a narrow region, called a channel, through which a current can be made to flow. Therefore, a FET can be described as a transconductance amplifier, which means the output current is controlled by an input voltage.

The nomenclature describing the FET is as follows. The control electrode in the FET, called the **gate**, is analogous to the base of the BJT. In contrast to the BJT base, the FET gate draws no steady state current because it is insulated from the substrate to which it is attached. A conducting channel, whose conductivity is controlled by the gate, lies between the **drain**, which is analogous to the BJT collector, and the **source**, which is analogous to the BJT emitter. As we will see, current flows into or “down the *drain*” and is “sourced” or flows out of the *source*, and the current flow is “gated” or controlled by the *gate*. There are three families of FETs: enhancement-mode **metal-oxide-semiconductor FETs** (MOSFETs), depletion-mode MOSFETs, and **junction field-effect transistors** (JFETs). Each of these families is available in p-channel and n-channel varieties. Understanding the different families and varieties of FETs is somewhat complicated when encountering them for the first time, so we focus primarily on the widely used n-channel enhancement-mode MOSFET. We will see that it is a close analogy to the npn BJT.

The cross section and schematic symbol for an n-channel enhancement-mode MOSFET is illustrated in Figure 3.32. This MOSFET has a p-type substrate and an n-type source and drain that form pn junctions with the substrate. There is a thin silicon dioxide layer insulating the gate from the substrate. As illustrated in Figure 3.33, when a positive DC voltage is applied to the gate, an electric field formed in the substrate below the gate repels holes in the p-type substrate leaving a narrow layer or **channel** in the substrate in which electrons predominate. This is referred to as an **n-channel** in the p-type substrate. The substrate is usually connected to the source internally so that the substrate–source pn junction is not forward biased. In the schematic circuit symbol (see the right side of Figure 3.32), the arrowhead indicates the direction between the p-type substrate and the n-channel.

Before reading further, you might want to view Video Demo 3.1. It does an excellent job reviewing semiconductor physics and illustrating how a MOSFET transistor operates. This might help you better relate to the following explanations.



Video Demo

3.1 How does a transistor work?

3.5.1 Behavior of Field-Effect Transistors

Using an n-channel enhancement-mode MOSFET as our example, we explain the details of its operation and discuss the characteristic curves analogous to the BJT. If the gate is grounded ($V_g = 0$), no drain-to-source current I_d flows for a positive drain voltage V_{dd} because the drain pn junction is reverse biased and no conducting channel has formed. In this state, the MOSFET mimics a very large resistor ($\sim 10^8$ – $10^{12} \Omega$), and no current flows between the drain and source. The MOSFET is said to be in **cutoff**.

As V_{gs} ($V_g - V_{ss}$) is gradually increased beyond a gate-to-source **threshold voltage** V_p , the n-channel begins to form. V_t depends on the particular MOSFET considered but a typical value is about 2 V. Then as V_{ds} ($V_d - V_{ss}$) is increased from 0, conduction

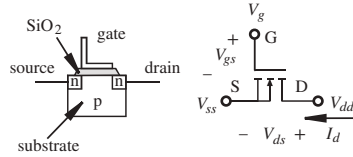


Figure 3.32 n-Channel enhancement-mode MOSFET.

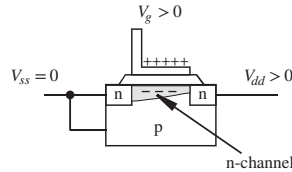


Figure 3.33 Enhancement-mode MOSFET n-channel formation.

occurs in the n-channel due to a flow of electrons from source to drain. The drain current I_d , by convention, is shown in the direction opposite to electron flow. As shown in Figure 3.33, a subtle feature of the n-channel is that it is wider near the source than at the drain because the electric field is larger due to the larger difference between V_g and ground at the source end and the smaller difference between V_g and V_{dd} at the drain end.

With a positive V_{gs} larger than V_t , as V_{ds} is increased from 0, we enter the **active region**, also called the **ohmic region**, of the MOSFET. In this region, as V_{gs} is further increased, the conduction channel grows correspondingly, and the MOSFET appears to function like a variable resistor whose resistance is controlled by V_{gs} . However, when $V_{gs} - V_t$ reaches V_{dd} , there is no longer an electric field at the drain end of the MOSFET. Therefore, the width of the n-channel shrinks to a minimum value close to the drain resulting in what is called **pinch-off**. This pinch-off limits a further increase in drain current, and the MOSFET is said to be in **saturation**. In saturation, the current is almost constant with further increases in V_{ds} . The drain-to-source resistance, called R_{on} , is minimal (usually less than $5\ \Omega$) as it enters the saturation region.

Figure 3.34 shows the characteristic family of curves for the n-channel enhancement-mode MOSFET, which graphically illustrates the features just described. The analogous npn BJT family of curves was shown in Figure 3.22. By comparing the characteristic curves, the saturation region of the MOSFET corresponds to the active region of the BJT, so one must be careful when using these terms.

As we did with the npn BJT transistor, let us look at some voltage and current measurements from an actual MOSFET circuit, using an IRF620 power MOSFET. The circuit is shown in Figure 3.35a. For the experiment, the voltage on the gate V_g (which is also the gate-to-source voltage V_{gs} , because the source is grounded) was gradually increased from 0 to 10 V, more gradually in the ranges of interest. Figure 3.35b shows the measurement results for the drain-to-source current I_{ds} and the drain-to-source voltage V_{ds} . Notice that for this MOSFET, the threshold voltage,

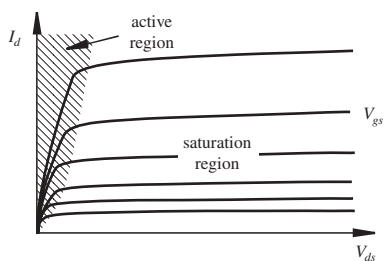
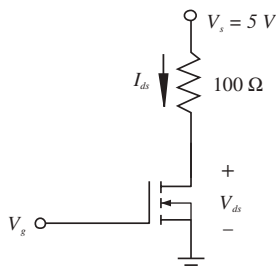
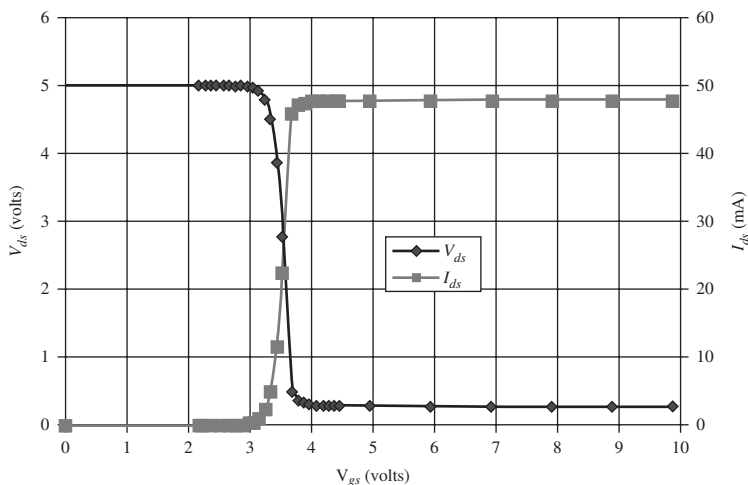


Figure 3.34 n-Channel enhancement-mode MOSFET characteristic curves.

where conduction begins ($I_{ds} > 0$), is about 3.5 V. Also note that the drain-to-source voltage V_{ds} does not drop to zero when the MOSFET is fully on. This is due to the drain-to-source resistance R_{on} of the device (see Question 3.24), which creates a small voltage drop ($V_{ds} = I_{ds}R_{on}$).



(a) test circuit



(b) results

Figure 3.35 MOSFET experiment.

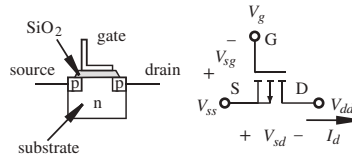


Figure 3.36 p-Channel enhancement-mode MOSFET.

The cross section and schematic symbol for a p-channel enhancement-mode MOSFET are illustrated in Figure 3.36. As with the n-channel MOSFET, the arrow-head indicates the direction of the substrate-channel pn junction. If the gate is negative with respect to the source ($V_{sg} > 0$), electrons in the n-type substrate are repelled, forming a p-channel conducting layer beneath the gate. This allows a current to flow from the source to the drain if V_{sd} is positive. The p-channel enhancement-mode MOSFET functions analogously to the pnp BJT.

MOSFETs are very useful in a variety of mechatronic applications. MOSFETs can be used to make excellent high-current voltage-controlled switches. Also, some MOSFETs are designed specifically as analog switches, where signals can be gated (blocked or passed) in circuits. These examples are presented in Section 3.5.3. MOSFETs are also used in special circuits for driving DC motors. Because of their characteristics, MOSFETs can be used as current sources as a result of the flat characteristics of the saturation region.

MOSFETs operate at much lower input current than BJTs. Because of this, they consume less power and generate less heat. This is particularly important in mobile electronic devices where heat can be a concern in small packages, and where low-power design is important to extend battery life as much as possible. MOSFETs also take less space and requires less fabrication steps when used in integrated circuits (ICs). Because of this, they are common in the internal design of ICs like microprocessors. The MOSFETs in ICs are often fabricated in complementary (n-channel and p-channel) pairs, and the resulting ICs are known as **complementary metal-oxide-semiconductor** (CMOS) devices. The symmetry of the n-channel and p-channel transistors allows for compact fabrication on a single IC and is useful in the internal design of logic devices (to be presented in Chapter 6).

MOSFETs have largely replaced BJTs in many applications, especially those at lower voltages. However, BJTs are still used in amplifiers, in high-voltage applications, and in high-frequency power switching applications. An improvement to the BJT is an **insulated-gate bipolar transistor (IGBT)**. It combines the best characteristics of both the MOSFET and BJT. Like a MOSFET, it is controlled by a voltage at the gate instead of a current into the base. The BJT has been largely replaced by the IGBT in high-voltage switching applications.

3.5.2 Symbols Representing Field-Effect Transistors

Because you will come across FETs in numerous circuit designs, it is important to recognize the subtleties of the schematic symbols for them. Because FETs (JFETs and MOSFETs) have two different kinds of channel doping, and because the substrate

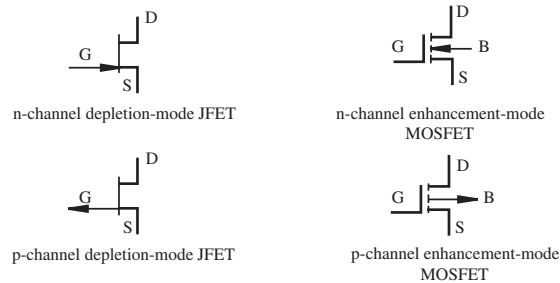


Figure 3.37 Field-effect transistor schematic symbols.

can be p-type or n-type, there are eight potential FET configurations. The symbols for the four most important classes of FETs are shown in Figure 3.37. The terminal designations are G for gate, S for source, D for drain, and B for substrate. Some of the principal characteristics of the schematic are

1. The direction of the gate or substrate arrow distinguishes between p-channel (arrow out) and n-channel (arrow in).
2. A separation is shown between the gate and the source in the MOSFET but not in the JFET. The separation represents the insulating layer of the metal oxide in the MOSFET.
3. A broken line between the source and drain indicates an enhancement-mode device in contrast to a solid line for a depletion-mode device. Enhancement-mode FETs require a gate voltage for conduction, and depletion-mode FETs require a gate voltage to reduce the conduction. JFETs are available only in the depletion mode, but MOSFETs are available in both varieties.
4. The gate line is offset toward the source, so the source side can be easily identified. Sometimes the gate line is shown centered; in this case there is no way to distinguish the drain from the source unless they are labeled.

The substrate of a MOSFET may be connected to a separate terminal or internally connected to the source. If there is a separate substrate lead, it must not be biased more positive than the source or drain for an n-channel device and must not be biased more negative than the source or drain for a p-channel device. It should always be connected to something (i.e., it should not be left “floating”).

3.5.3 Applications of MOSFETs

The first MOSFET application we consider is switching power to a load. This circuit is analogous to the BJT switch presented in Section 3.4.3. An n-channel enhancement-mode power MOSFET is used with the load on the drain side as shown in Figure 3.38. Note that this MOSFET switch is very easy to design because the gate draws practically no steady state current. We must ensure that

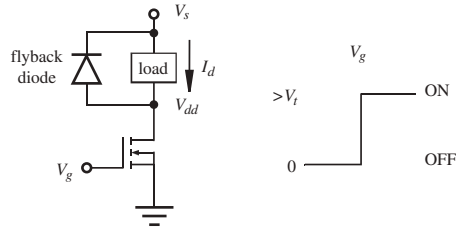


Figure 3.38 MOSFET power switch circuit.

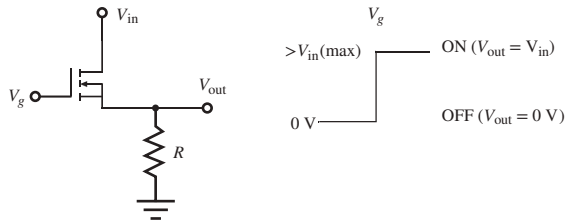


Figure 3.39 MOSFET analog switch circuit.

$V_g \leq 0$ for the MOSFET to be cutoff so that no current is delivered to the load. When $V_g - V_t \approx V_{dd}$, the MOSFET enters saturation resulting in nearly full voltage V_s across the load (because R_{on} is small). The controlling parameter for the MOSFET is gate voltage V_g . Recall that with the BJT, the controlling parameter is base current I_B . With the BJT, one must ensure adequate base current to saturate the BJT. Using the MOSFET, the current drawn by the gate is essentially 0, so current sourcing is not a concern. However, one needs to calculate the drain current I_d and power dissipation to select a MOSFET capable of switching the desired current for the load. Also, as with a BJT, if the load is inductive, a flyback diode (see Figure 3.38) is necessary to prevent damage to the MOSFET when it is switched off.

The second application we will consider is the use of a MOSFET as an analog switch. Suppose you have a positive analog signal V_{in} and you want to be able to couple it to another circuit or device, or block it altogether. This is an easy application for a MOSFET using the circuit shown in Figure 3.39. If the control signal V_g is 0 V, the MOSFET will be cutoff resulting in a huge drain to source impedance (in megaohms) essentially blocking the analog signal ($V_{out} = 0$ V). The **pull-down resistor** R is required to hold the V_{out} terminal at ground in the off state. When the control signal V_g is larger than the largest value of the analog input signal V_{in} plus threshold voltage V_t , the drain to source channel will conduct with a low resistance, and the output signal will track the input ($V_{out} = V_{in}$).

■ CLASS DISCUSSION ITEM 3.8

Analog Switch Limit

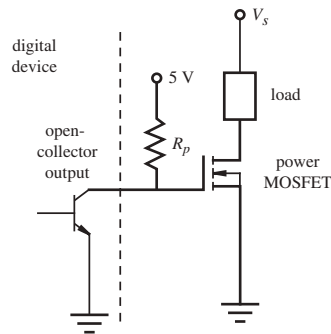
Considering the analog switch circuit shown in Figure 3.39, why does the gate control signal need to be larger than the largest value of the analog signal?

DESIGN EXAMPLE 3.4

Circuit to Switch Power

Among the general problems in a mechatronic system design is delivering electrical power to different portions of the system. MOSFETs are useful devices for this task.

Suppose you have a digital device that produces a binary output, which means its output can be one of two states. For the moment, assume that the output circuit consists of an npn transistor that can be in cutoff or saturation, but with the collector as of yet not connected to anything. As we will see later, this is called an **open-collector-output** device. All you need to know for now is that the output transistor can be turned on and off. Also, it can sink only a very small current, in the milliampere range. How then can we interface the binary output to control the current to a load that may require a current of many amperes? A solution to this problem employing an n-channel enhancement-mode MOSFET power transistor is shown in the following figure. The output circuit from the digital device is drawn to the left of the dashed line, and the portion we are designing is to the right of the dashed line.



Resistor R_p , connected to the collector lead to complete the digital output circuit, is called a **pull-up resistor** because it “pulls up” the collector voltage to a DC power source (in this case +5 V). It results in 0 V at the MOSFET gate when the output transistor is on, and 5 V at the gate when it is off. To drive a load requiring a current larger than what the digital output can provide, we use a power MOSFET to switch a different power supply V_s .

Now if you are given the specific current and voltage requirements for a load (e.g., a motor), you can refer to manufacturer or supplier data to select the appropriate MOSFET to do the job.

■ CLASS DISCUSSION ITEM 3.9

Common Usage of Semiconductor Components

Cite specific examples in your experience where and how each of the following electrical components is used:

- Signal and power diodes
- Light-emitting diodes
- Signal and power transistors



Internet Link

2.5 Electronic component online resources and vendors

3.3 Semiconductor (IC) manufacturers and online resources

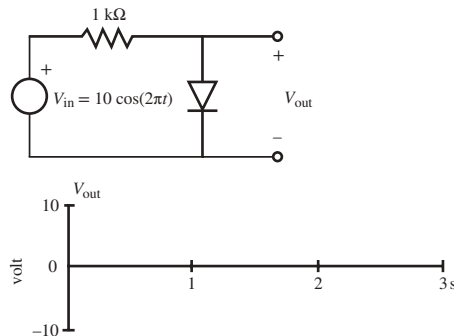
3.4 All about circuits – Vol. III – semiconductors

Internet Link 2.5 provides links to various resources and vendors for all types of electronic components, including all of the devices presented in this book. Electronics vendors provide a wealth of online information to make it easy to find data and place orders for their products. Internet Link 3.3 provides links to the largest manufacturers of semiconductor components. The semiconductor manufacturers provide volumes of information for all sorts of integrated circuits. Internet Link 3.4 is an excellent resource providing a thorough review of semiconductor physics, devices, application circuits, and circuit analysis.

QUESTIONS AND EXERCISES

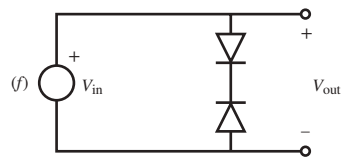
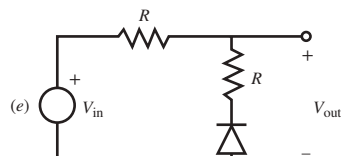
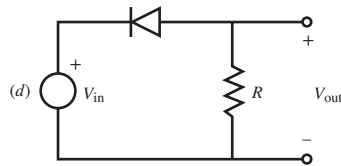
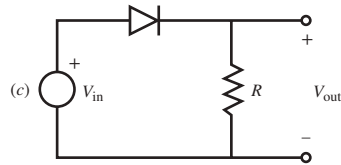
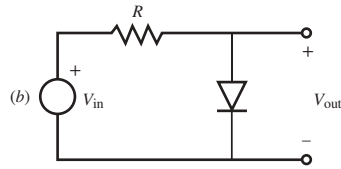
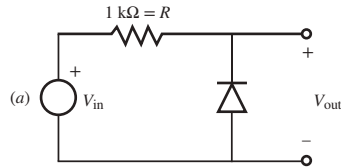
Section 3.3 Junction Diode

- 3.1.** Sketch the output waveform for V_{out} in the following circuit on axes as shown. Assume the diode is ideal.



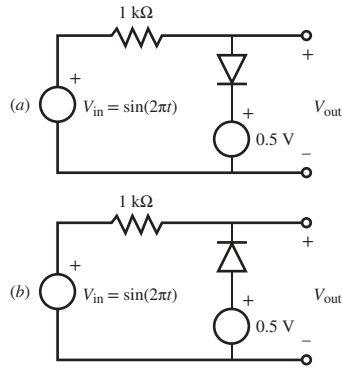
- 3.2.** Solve Question 3.1, assuming a “real” approximation of the diode.

- 3.3.** Sketch the output V_{out} on a set of axes for circuits “a” through “f” with $V_{\text{in}} = 1.0 \sin(2\pi t)$ V. Assume the diodes are ideal. Plot the output for one complete cycle of the input ($0 \leq t \leq 1$ s).

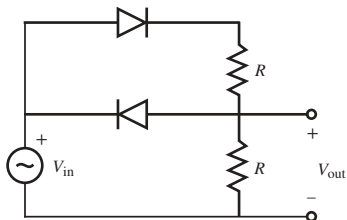


- 3.4.** Solve Question 3.3, assuming the “real” diode approximation.
3.5. Document a complete and thorough answer to Class Discussion Item 3.1.
3.6. Document a complete and thorough answer to Class Discussion Item 3.2.
3.7. Document a complete and thorough answer to Class Discussion Item 3.3.
3.8. Document a complete and thorough answer to Class Discussion Item 3.6.

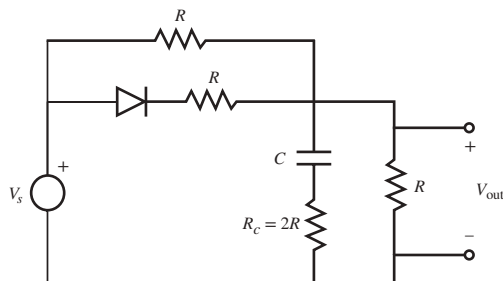
- 3.9.** The following circuits are called **clipping circuits**. Assume ideal diodes and sketch the output voltage V_{out} for two cycles of the input V_{in} .



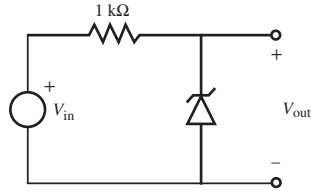
- 3.10.** Compute the currents (I_1 , I_2 , I_3 , I_4) and the diode voltage (V_{diode}) in the final circuit shown in Example 3.3.
- 3.11.** In Example 3.3, for the case where both diodes are assumed to be reverse biased, find I_1 , I_4 , and V_{AB} (the voltage of node A relative to node B) in the assumed-polarity circuit. Based on voltage V_{AB} , for which diode was the polarity assumption correct?
- 3.12.** Document a complete and thorough answer to Class Discussion Item 3.4.
- 3.13.** For the following circuit, assuming ideal diodes and given $R = 1\text{ k}\Omega$ and $V_{\text{in}} = 10 \sin(\pi t)\text{ V}$, plot the output voltage V_{out} on axes with labeled scales for two periods of the input.



- 3.14.** For the following circuit, assuming the diode is ideal, find the steady state values for V_{out} , the voltage across and current into the capacitor, and the current through the output resistor for
- $V_s = 10\text{ V DC}$
 - $V_s = -10\text{ V DC}$



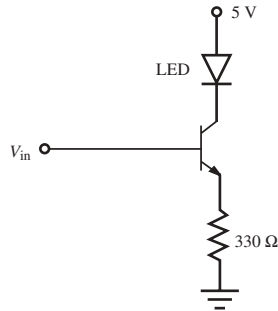
- 3.15.** For Class Discussion Item 3.4 with $V_{in} = 15 \sin(2\pi t)$ V and $R_i = R_L = 1 \text{ k}\Omega$, draw and label one cycle of V_{in} and V_{out} . Assume ideal diodes.
- 3.16.** Given the following ideal zener diode circuit with breakdown voltage 5.1 V, sketch the output voltage on a set of axes if
- $V_{in} = 1.0 \sin(2\pi t)$
 - $V_{in} = 10.0 + \sin(2\pi t)$



- 3.17.** A digital circuit can output a voltage of either 0 V or 5 V relative to ground. Design a circuit that uses this output to turn an LED on or off assuming the LED
- has no forward voltage drop and can carry a maximum of 50 mA
 - has a forward voltage drop of 2 V and can carry a maximum of 50 mA

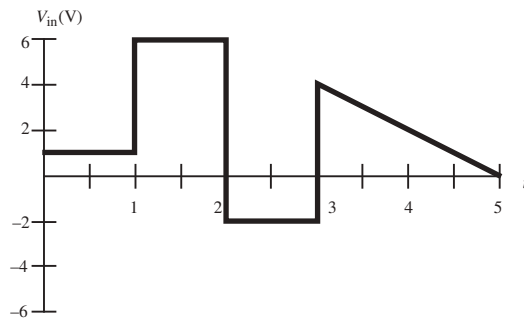
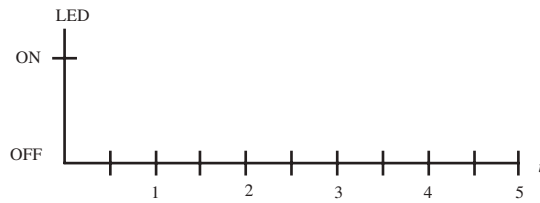
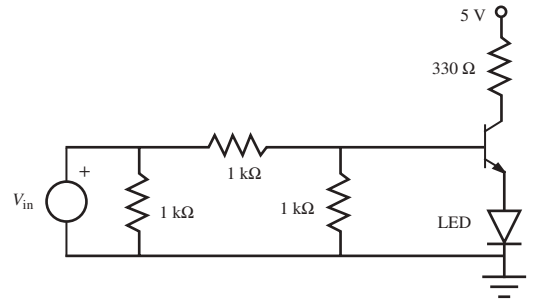
Section 3.4 Bipolar Junction Transistor

- 3.18.** In the following circuit, what minimum steady state voltage V_{in} is required to turn the LED on and keep the transistor fully saturated? Assume that the forward bias voltage for the LED is 2 V and there is a 0.2 V collector-to-emitter voltage drop when the transistor is saturated.

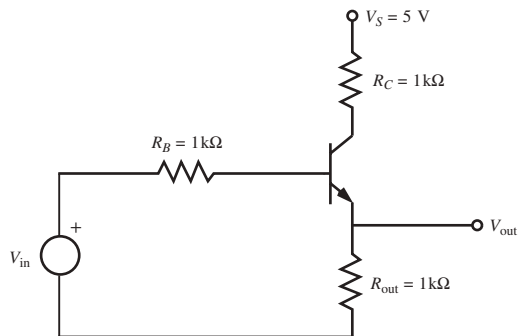


- 3.19.**
- Given V_{in} (see the graph that follows) for the following circuit, and assuming the current into the base of the transistor is very small (i.e., assume $I_B = 0$), sketch the LED on–off curve on a graph similar to that shown below the circuit. Assume that the LED has a forward bias voltage of 1 V. Also assume the transistor is in saturation when the LED is on.
 - Calculate the minimum value of V_{in} required to saturate the transistor assuming a β of 100. Do not assume $I_B = 0$ in this part.

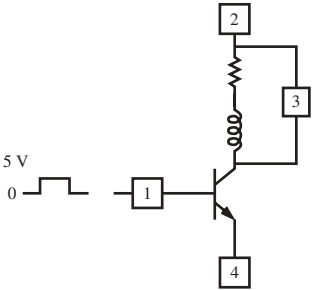
(continued)



- 3.20.** In the following circuit, find the minimum V_{in} required and the resulting voltage V_{out} to put the transistor in full saturation. Assume that the β for the transistor is 100 in full saturation.



3.21. Consider the design of a solid state switch using an npn power transistor that you plan to control with a digital signal (0 V = off, 5 V = on). Start with the following schematic where components that you must select are labeled with numbers. The series resistor and inductor represents a DC motor that requires 1 A of current at 24 V_{DC}. Replace each of the labeled boxes shown in the figure with the appropriate schematic symbol and then specify the component as completely as you can.

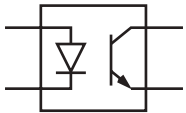


3.22. Here is the data for the plots shown in Figure 3.20:

V_{in} (V)	I_B (mA)	V_{BE} (V)	I_C (mA)	V_{CE} (V)
0.69	0.007	0.68	0.927	4.1
0.78	0.054	0.73	4.869	0.16
0.88	0.146	0.73	4.915	0.11
0.97	0.238	0.74	4.932	0.099
1.07	0.333	0.74	4.942	0.089
1.16	0.426	0.74	4.948	0.083
1.44	0.71	0.74	4.961	0.07
2.01	1.316	0.74	5.029	0.008
5.02	4.341	0.75	5.033	0.006
10.72	10.114	0.78	5.032	0.007

What is the approximate (β), base-to-emitter voltage, and collector-to-emitter voltage drop of the transistor on the verge of saturation? What do we usually assume these values are when we analyze BJT circuits?

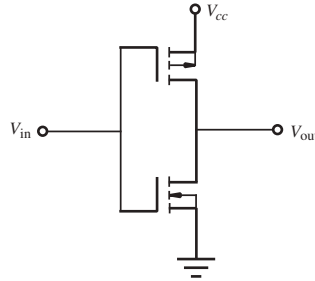
3.23. A photo-interrupter comes in a manufactured package that includes the phototransistor and corresponding LED as shown in the following schematic. What external circuitry must be added to obtain a functioning photo-interrupter? Sketch the resulting schematic.



Section 3.5 Field-Effect Transistors

3.24. For the MOSFET used in the experiment of Figure 3.35, estimate the fully on drain-to-source resistance R_{on} from the values in the plot.

- 3.25.** Answer Question 3.22 using an n-channel enhancement-mode power MOSFET instead of the npn BJT.
- 3.26.** In Design Example 3.4, suppose $V_s = 15$ V. Replace the MOSFET with a BJT power transistor and specify the type (nnp or pnp) and any additional components required. Draw the circuit schematic and describe its characteristics.
- 3.27.** The output of most digital CMOS devices looks like this:



Identify the types of MOSFETs used. What is the value of V_{out} for $V_{in} = 5$ V and for $V_{in} = 0$ V?

- 3.28.** The following table lists various MOSFETs available for a design project. You have a requirement to switch 10 A at 10 V. Select the MOSFET adequate for the requirements and justify your choice.

MOSFET	V_{ds} (V)	R_{ds} (on) (Ω)	I_d cont (A) @ 25°C	P_d (max) (W)
IRF510	100	0.6	16	20
IRF530N	100	0.11	60	63
IRF540	100	0.077	110	150
IRF540N	100	0.052	110	94
IRF610	200	1.5	10	20

- 3.29.** For each state of an n-channel enhancement-mode MOSFET that follows, determine what operating region the MOSFET is in if the threshold voltage V_t is 3 V.
- $V_{gs} = 2$ V, $V_{ds} = 5$ V
 - $V_{gs} = 4$ V, $V_{ds} = 5$ V
 - $V_{gs} = 6$ V, $V_{ds} = 5$ V
 - $V_{gs} = -2.5$ V

BIBLIOGRAPHY

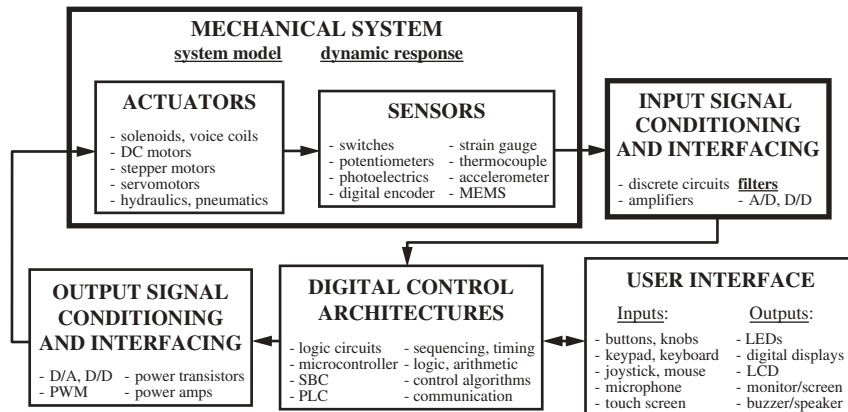
- Bailar, J. et al., *Chemistry*, Academic Press, New York, 1978.
- Gibson, G. and Liu, Y., *Microcomputers for Engineers and Scientists*, Prentice-Hall, Englewood Cliffs, NJ, 1980.
- Horowitz, P. and Hill, W., *The Art of Electronics*, 3rd Edition, Cambridge University Press, New York, 2015.

- Johnson, D., Hilburn, J., and Johnson, J., *Basic Electric Circuit Analysis*, 5th Edition, Prentice-Hall, Englewood Cliffs, NJ, 1995.
- Lerner, R. and Trigg, G., *Encyclopedia of Physics*, VCH Publishers, New York, 1991.
- Malvino, A. and Bates, D., *Electronic Principles*, 7th Edition, McGraw-Hill, New York, 2007.
- McWhorter, G. and Evans, A., *Basic Electronics*, Master Publishing, Richardson, TX, 2004.
- Millman, J. and Grabel, A., *Microelectronics*, 2nd Edition, McGraw-Hill, New York, 1987.
- Mims, F., *Engineer's Mini-Notebook: Basic Semiconductor Circuits*, Radio Shack Archer Catalog No. 276-5013, 1986.
- Mims, F., *Engineer's Mini-Notebook: Optoelectronics Circuits*, Radio Shack Archer Catalog No. 276-5012A, 1986.
- Mims, F., *Getting Started in Electronics*, 3rd Edition, Master Publishing, Richardson, TX, 2003.
- Rizzoni, G., *Principles and Applications of Electrical Engineering*, 5th Edition, McGraw-Hill, New York, 2005.

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System Response

This chapter describes how to mathematically model a physical system and characterize its response to dynamic inputs. These topics are important in understanding how actuators, sensors, amplifiers, filters, and other mechatronic system components function. ■



CHAPTER OBJECTIVES

After you read, discuss, study, and apply ideas in this chapter, you will:

1. Understand the three characteristics of a good measurement system: amplitude linearity, phase linearity, and adequate bandwidth
2. Be able to define the Fourier series representation of a signal and use it to show the components of the spectrum of the signal
3. Understand the relationship between an instrument's bandwidth and the spectra of its input and output signals

4. Understand the dynamic response of zero-, first-, and second-order measurement and mechatronic systems
5. Be able to use step and sinusoidal inputs to analyze and characterize the response of measurement and mechatronic systems
6. Understand the analogies among mechanical, electrical, and hydraulic systems.

4.1 SYSTEM RESPONSE

The relationship between the desired output of a mechatronic or measurement system and its actual output is the basis of system response analysis. This chapter deals with analysis techniques that characterize and predict how linear systems respond to specific inputs. We concentrate on measurement systems, which are often integral parts of mechatronic systems.

As we saw in Chapter 1, a measurement system consists of three parts: a transducer, a signal processor, and a recorder. A transducer is a device that usually converts a physical quantity into a time-varying voltage, called an **analog signal**. A signal processor can modify the analog signal, and a recorder provides either a transitory display or storage of the signal. The physical variable we wish to measure is called the input to the measurement system. The transducer transforms the input into a form compatible with the signal processor, which in turn modifies the signal, which then becomes the output of the measurement system. Usually, the recorded output is different from the actual input, as illustrated in Figure 4.1. Generally, we want to have the reproduced output signal match the input as closely as possible unless there is information in the input that we want to eliminate (e.g., electrical noise).

Certain conditions must be satisfied to accomplish adequate reproduction of the input. For a measurement system with time-varying inputs, three criteria must be satisfied to ensure that we obtain a quality measurement:

1. Amplitude linearity
2. Adequate bandwidth
3. Phase linearity

We examine each of these criteria in detail in the following sections.

4.2 AMPLITUDE LINEARITY

A good measurement system satisfies the criterion of amplitude linearity. Mathematically, this is expressed as

$$V_{\text{out}}(t) - V_{\text{out}}(0) = \alpha [V_{\text{in}}(t) - V_{\text{in}}(0)] \quad (4.1)$$

where α is a constant of proportionality. This means that the output always changes by the same factor times the change in the input. If this does not occur, then the system is not linear with respect to amplitude, and it becomes more difficult to interpret the

output. Figure 4.2 displays examples of amplitude linearity and nonlinearity. The first example is linear and $\alpha = 20$. The second two examples are nonlinear because α is not constant. In the third example, the output changes by a factor of 20 on the first pulse and by a factor of 15 on the second pulse.

Normally, a measurement system will satisfy amplitude linearity over only a limited range of input amplitudes. Also, the system usually responds linearly only when the rate of change of the input is within certain limits. This second issue is related to the bandwidth of the system, addressed in Section 4.4. An ideal measurement system will exhibit amplitude linearity for any amplitude or frequency of the input.

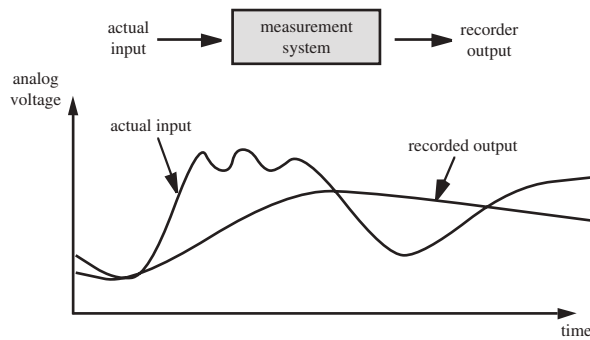


Figure 4.1 Measurement system input-output.

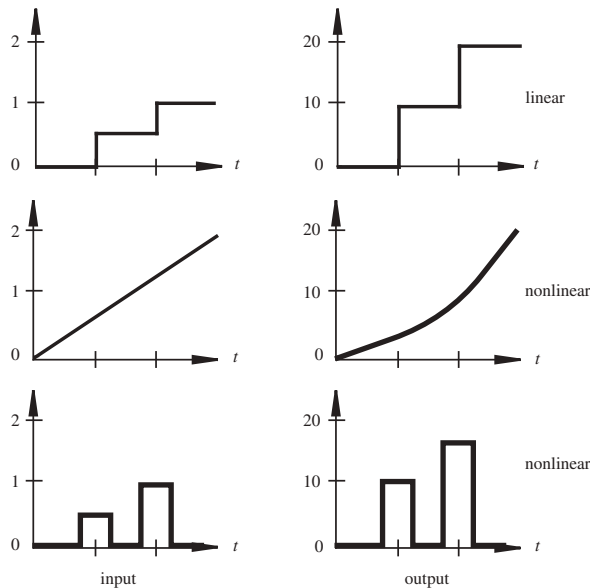


Figure 4.2 Amplitude linearity and nonlinearity.

4.3 FOURIER SERIES REPRESENTATION OF SIGNALS

Before we look at the concepts of bandwidth and phase linearity, which apply to frequency components of an input signal, we first need to review the concept of **Fourier series** representation of a signal. The fundamental premise of the Fourier series representation of a signal is that any periodic waveform can be represented as an infinite series of sine and cosine waveforms of different amplitudes and frequencies. When this infinite series is summed up, it will reproduce the original periodic waveform exactly. What this means is that we can take any complicated but periodic waveform and decompose it into a series of sine and cosine waveforms. In practice, we do not need the entire infinite series because a finite number of the sine and cosine waveforms can adequately represent the original signal.

We define the **fundamental** or first **harmonic** ω_0 as the lowest frequency component of a periodic waveform. It is inversely proportional to the period T :

$$\omega_0 = \frac{2\pi}{T} = 2\pi f_0 \quad (4.2)$$

where f_0 is the fundamental frequency expressed in hertz (Hz). The other sine and cosine waveforms have frequencies that are integer multiples of the fundamental frequency. The second harmonic would be $2\omega_0$, the third harmonic would be $3\omega_0$, and so on. The Fourier series representation of an arbitrary periodic waveform $f(t)$ can be expressed mathematically as

$$F(t) = C_0 + \sum_{n=1}^{\infty} A_n \cos(n\omega_0 t) + \sum_{n=1}^{\infty} B_n \sin(n\omega_0 t) \quad (4.3)$$

where the constant C_0 is the DC component of the signal, and the two summations are infinite series of sine and cosine waveforms. The coefficients of the sine and cosine terms are defined by

$$A_n = \frac{2}{T} \int_0^T f(t) \cos(n\omega_0 t) dt \quad (4.4)$$

$$B_n = \frac{2}{T} \int_0^T f(t) \sin(n\omega_0 t) dt \quad (4.5)$$

where $f(t)$ is the waveform being represented and T is the period of the waveform. The DC term C_0 represents the average value of the waveform over its period; therefore, it can be expressed as

$$C_0 = \frac{1}{T} \int_0^T f(t) dt = \frac{A_0}{2} \quad (4.6)$$

where A_0 is given by substituting $n = 0$ into Equation 4.4.

In the Fourier series representation given by Equation 4.3, there are two different amplitudes (A_n and B_n). However, the cosine and sine terms can be combined with a trigonometric identity (Question 4.4) to create an alternative representation described by a single amplitude and phase. This alternative representation is

$$F(t) = C_0 + \sum_{n=1}^{\infty} C_n \cos(n\omega_0 t + \phi_n) \quad (4.7)$$

where the total amplitude for each harmonic is given by

$$C_n = \sqrt{A_n^2 + B_n^2} \quad (4.8)$$

and the phase for each harmonic is given by

$$\phi_n = -\tan^{-1}\left(\frac{B_n}{A_n}\right) \quad (4.9)$$

To illustrate the application and meaning of a Fourier series, consider an ideal square wave as an example of a periodic waveform. The square wave illustrated in Figure 4.3 is defined mathematically as

$$f(t) = \begin{cases} 1 & 0 \leq t < T/2 \\ -1 & T/2 \leq t < T \end{cases} \quad (4.10)$$

where T is the period. There are discontinuities at $t = 0$ and $T/2$.

For the square wave defined by Equation 4.10, the coefficients A_n , including A_0 , are 0 (see Question 4.5). The coefficients B_n can be found from Equation 4.5:

$$B_n = \frac{2}{T} \left(\int_0^{T/2} \sin(n\omega_0 t) dt - \int_{T/2}^T \sin(n\omega_0 t) dt \right) \quad (4.11)$$

Integration results in

$$B_n = \frac{2}{T} \left(-\frac{1}{n\omega_0} [\cos(n\omega_0 t)]_0^{T/2} + \frac{1}{n\omega_0} [\cos(n\omega_0 t)]_{T/2}^T \right) \quad (4.12)$$

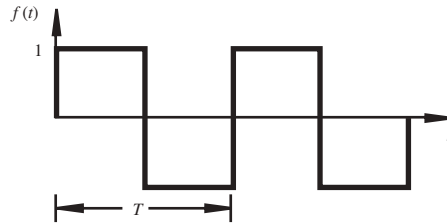


Figure 4.3 Square wave.

Using Equation 4.2 in evaluating the bracketed terms at each of the limits in Equation 4.12 gives

$$B_n = \frac{1}{n\pi} [-\cos(n\pi) + 1 + 1 - \cos(n\pi)] \quad (4.13)$$

This can be written as

$$B_n = \frac{2}{n\pi} [1 - \cos(n\pi)] = \begin{cases} \frac{4}{n\pi} & n: \text{odd} \\ 0 & n: \text{even} \end{cases} \quad (4.14)$$

Therefore, from Equation 4.3, the Fourier series representation of a square wave of amplitude 1 is

$$F(t) = \frac{4}{\pi} \sin(\omega_0 t) + \frac{4}{3\pi} \sin(3\omega_0 t) + \frac{4}{5\pi} \sin(5\omega_0 t) + \cdots \quad (4.15)$$

or, using an infinite sum representation,

$$F(t) = \sum_{n=1}^{\infty} \frac{4}{(2n-1)\pi} \sin[(2n-1)\omega_0 t] \quad (4.16)$$

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4.1 Fourier series representation of a square wave

Figure 4.4 shows the effects of combining the individual harmonics of the signal incrementally. Mathcad/Matlab Example 4.1 includes the analysis used to create the figure. Shown on the left side of the figure are the individual harmonics along with their respective frequencies and amplitudes. Note that, as the harmonic frequency increases, the amplitude decrease. Illustrated on the right are the superpositions of the successive harmonics, illustrating how the addition of higher harmonics improves the representation of the square wave. If we take the first, third, and fifth harmonics and add them together, we obtain a waveform that begins to look similar to a square wave. As we add additional harmonics to this signal, the quality of the reproduction of the waveform improves and sharp changes are better approximated. If an infinite number of harmonics were used, the result would be a square wave.

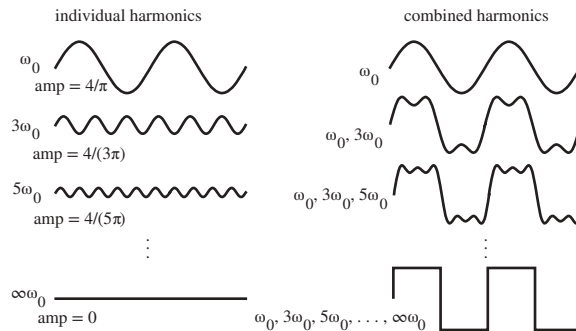


Figure 4.4 Harmonic decomposition of a square wave.

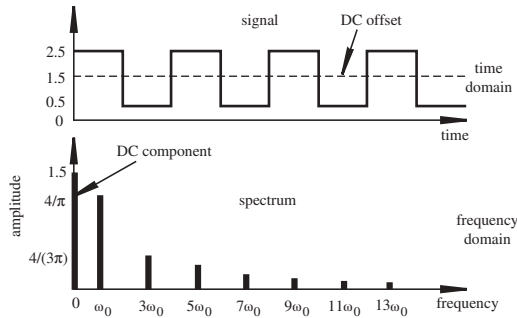


Figure 4.5 Spectrum of a square wave.

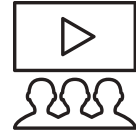
Waveforms such as a square wave, which have very sharp or rapid changes associated with them (e.g., at discontinuities), require a large number of higher harmonics for good reproduction.

The top half of Figure 4.5 illustrates a plot of a unity amplitude square wave with a DC offset of 1.5. This plot is known as the **time-domain** representation of the signal. The bottom half of the figure is a plot of the Fourier series amplitudes vs. frequency, which is called the signal's **spectrum**. Since the harmonics are represented as bars or lines on the graph, it is also called a **line spectrum**. Note that the DC offset is the zero-frequency component. The spectrum is the signal's **frequency-domain** representation.

When plotting the spectrum for a signal represented by a Fourier series, one should use the single-amplitude version given by Equation 4.7. For the square wave Fourier series given in Equation 4.15, the A_n coefficients are 0, and the C_n coefficients are the same as the B_n coefficients (see Equation 4.8). Each bar in Figure 4.5 represents a different amplitude value. The first bar represents a DC offset of $C_0 = B_0 = 1.5$. The second bar represents the first term in Equation 4.15: $C_1 = B_1 = 4/\pi$. The remaining bars represent the higher nonzero harmonics ($B_3, B_5, \dots$).

Video Demo 4.1 shows spectra for various output signals from a function generator. A digital oscilloscope makes it very easy to display the spectrum of any electrical signal. Observe how signals with fast transitions (e.g., sharp corners) contain larger amplitude harmonics at higher frequencies.

Internet Link 4.1 provides various resources and demonstrations relating to how signal spectrum concepts can be applied to sound and music theory. Sound consists of pressure waves. A microphone can acquire a pressure signal and convert it into a voltage signal that can be processed and displayed (e.g., on an oscilloscope). The spectral content of a sound is what differentiates its character (timbre) from other sounds (see Class Discussion Item 4.1). Furthermore, a musical note (i.e., its pitch) is defined by its fundamental frequency, and its signal amplitude determines its volume (i.e., loudness). Video Demos 4.2 through 4.7 show different examples of these concepts. Internet Link 4.2 describes, illustrates, and demonstrates why a clarinet has a spectrum (and timbre) much like a square wave, where even harmonics are missing due to the open end of the instrument. Video Demo 4.8 demonstrates an interesting mechanical computer that uses gears, springs, and levers to compute or synthesize a Fourier series.



Video Demo

4.1 Sine-wave, saw-tooth-wave, and square-wave signal spectra

4.2 Spectra of whistling and humming, and amplifier saturation

4.3 Bugle tone amplitude, frequency, and spectra

4.4 Guitar harmonics and chords

4.5 Piano harmonics and tone spectra

4.6 Piano keyboard harmonics and chords

4.7 Tuning fork waveform analysis

4.8 Mechanical computer harmonic analyzer



Internet Link

4.1 Video demonstrations and online resources for sound and vibration principles

4.2 Clarinet physics

■ CLASS DISCUSSION ITEM 4.1

Musical Harmonics

Using your knowledge of harmonics, explain each of the following musical phenomena:

- Why does a C on a flute sound different from the same C on a violin?
- Guitar players achieve an effect called *harmonics* by lightly placing a finger on the midpoint of a string before picking. Explain why this changes the quality of the sound produced.
- When striking middle C on a piano while holding the damper pedal down (allowing all strings to ring freely), why do strings other than middle C begin to vibrate? Which strings vibrate with the largest amplitude?

4.4 BANDWIDTH AND FREQUENCY RESPONSE

It is important to estimate the spectrum of a signal when choosing a system to measure the signal. Ideally, a measurement system should replicate all frequency components of a signal. Real systems, however, have limitations in their ability to reproduce all frequencies. A scale commonly used to measure the degree of fidelity of a measurement system's reproduction at different frequencies is the **decibel** scale. It is a logarithmic scale that allows comparison of the change in amplitude of a component of a signal when it passes through a measurement system. The decibel (dB) is defined as

$$\text{dB} = 20 \log_{10} \left(\frac{A_{\text{out}}}{A_{\text{in}}} \right) \quad (4.17)$$

where A_{in} is the input amplitude and A_{out} is the output amplitude of a particular harmonic.

The graph shown in Figure 4.6 is an example of a **frequency response curve** for a system. This graph is also called a **Bode plot** (when plotted with log-log scales). It is a plot of the **amplitude ratio**, $A_{\text{out}}/A_{\text{in}}$, vs. the input frequency. It characterizes how components of an input signal are amplified or attenuated by the system. The term **bandwidth** is used to quantify the range of frequencies a system can adequately reproduce. The bandwidth of a system is defined as the range of frequencies where the input of the system is not **attenuated** by more than -3 dB. As illustrated in the figure, a system usually has two frequencies at which the attenuation of the system

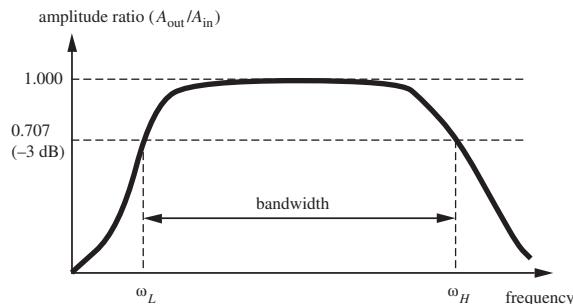


Figure 4.6 Frequency response and bandwidth.

is -3 dB. They are defined as the low and high **corner** or **cutoff frequencies** ω_L and ω_H . These two frequencies define the bandwidth of the system:

$$\text{bandwidth} = \omega_L \text{ to } \omega_H \quad (4.18)$$

Measurement systems often exhibit no attenuation at low frequencies (i.e., $\omega_L \approx 0$), and the amplitude ratio degrades only at high frequencies. For these systems, the bandwidth extends from 0 (DC) to ω_H .

The -3 dB cutoff is the decibel value at which the power of the output signal (P_{out}) is attenuated to half of its input value (P_{in}):

$$\frac{P_{\text{out}}}{P_{\text{in}}} = \frac{1}{2} \quad (4.19)$$

For this reason, the cutoff frequencies are referred to as the half-power points. The power of a sinusoidal signal is proportional to the square of the signal's amplitude, thus at the cutoff value,

$$\frac{A_{\text{out}}}{A_{\text{in}}} = \sqrt{\frac{P_{\text{out}}}{P_{\text{in}}}} = \sqrt{\frac{1}{2}} \approx 0.707 \quad (4.20)$$

Therefore, at the cutoff frequencies, the amplitude of the signal is attenuated by 29.3% (to 70.7% of its original value), which is approximately -3 dB:

$$\text{dB} = 20 \log_{10} \sqrt{\frac{1}{2}} \approx -3 \text{ dB} \quad (4.21)$$

At first it may seem illogical to define the bandwidth to exclude signal components that exist outside the range of the bandwidth. The half-power points are admittedly somewhat arbitrary, but if applied consistently, they allow us to compare a variety of instruments and system responses. All signal amplitudes of components outside the bandwidth are attenuated by more than 3 dB. Components that lie within the bandwidth, especially those close to the cutoff frequencies, may also be attenuated but by less than 3 dB.

The frequency response of an ideal measurement system has an amplitude ratio of 1, extending from 0 to infinite frequency (i.e., over an infinite bandwidth). An ideal system reproduces all harmonics in a signal without amplification or attenuation. A real measurement system, however, has a limited bandwidth. The bandwidth of a system is influenced by such factors as capacitance, inductance, and resistance in electrical systems and mass, stiffness, and damping in mechanical systems. Through careful design, these parameters can be selected to achieve a desired bandwidth. A properly designed measurement system reproduces all frequency components in a typical input signal. When it does, the system is said to exhibit high **fidelity**.

The proper design or selection of a measurement system requires an understanding of measurement system bandwidth and signal spectrum. Figure 4.7 illustrates an input signal spectrum, a measurement system's frequency response, and the resulting spectrum of the output signal, all using the same frequency scale. The measurement system has a limited bandwidth, so not all input signal frequency components are reproduced satisfactorily. Therefore, the output signal differs from the input signal. Given the input signal spectrum in the figure, the signal can be written as

$$V_{\text{in}}(t) = A_1 \sin(\omega_0 t) + A_2 \sin(2\omega_0 t) + A_3 \sin(3\omega_0 t) + \cdots \quad (4.22)$$

■ CLASS DISCUSSION ITEM 4.2

Measuring a Square Wave with a Limited Bandwidth System

Assume you have a measurement system whose bandwidth is 0 to $5.1 \omega_0$, with no attenuation below the cutoff frequency and complete attenuation above. If the input to the system is a square wave with a fundamental frequency of ω_0 , describe the difference between the input and the output.

Given the measurement system frequency response curve, the output amplitude A'_i can be determined for each input frequency amplitude A_i using the following equation:

$$A'_i = (A_{\text{out}}/A_{\text{in}})_i \times A_i \quad (4.23)$$

where i is the frequency component number. For example, for $i = 2$ corresponding to frequency $2\omega_0$,

$$A'_2 = (A_{\text{out}}/A_{\text{in}})_2 \times A_2 = 0.25 A_2 \quad (4.24)$$

Applying Equation 4.23 to each frequency component results in the spectrum shown at the bottom of the figure, and the output signal can be written as

$$V_{\text{out}}(t) = A'_2 \sin(2\omega_0 t) + A'_3 \sin(3\omega_0 t) + \cdots + A'_9 \sin(9\omega_0 t) + A'_{10} \sin(10\omega_0 t) \quad (4.25)$$

or

$$V_{\text{out}}(t) = 0.25 A_2 \sin(2\omega_0 t) + A_3 \sin(3\omega_0 t) + \cdots + A_9 \sin(9\omega_0 t) + 0.5 A_{10} \sin(10\omega_0 t) \quad (4.26)$$

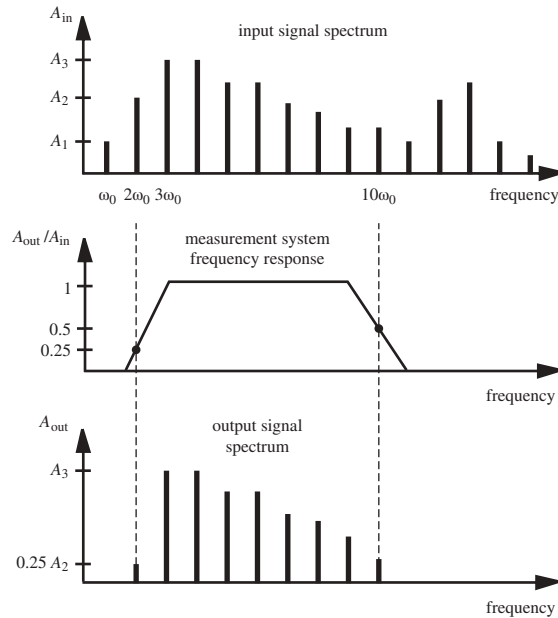


Figure 4.7 Effect of measurement system bandwidth on signal spectrum.

Because $A_{\text{out}}/A_{\text{in}} = 1$ for all frequencies between and including $3\omega_0$ and $9\omega_0$, $A'_i = A_i$ for $i = 3$ through 9. Because $A_{\text{out}}/A_{\text{in}} = 0$ for the frequency component ω_0 and for all components above $10\omega_0$, these components are completely attenuated and no longer exist in the output signal (i.e., $A'_1 = A'_{11} = A'_{12} = \dots = 0$). The frequency components at $2\omega_0$ and $10\omega_0$ still exist in the output signal, but their amplitudes are partially attenuated ($0 < A_{\text{out}}/A_{\text{in}} < 1$).

When designing or choosing a measurement system for an application, it is important that the bandwidth of the system be large enough to adequately reproduce the important frequency components present in the input signal. A measurement system that does not reproduce high frequencies cannot accurately reproduce signals that have rapid changes associated with them.

To experimentally determine the bandwidth of a system, it is necessary to systematically apply pure sinusoidal inputs and to determine the output-to-input amplitude ratio for the desired range of frequencies. The sweep feature on a function generator, which generates a linearly increasing frequency over a selected time, provides a convenient method to perform this for systems with electrical inputs. Lab Exercise 4 applies this technique to filter circuits (see the demonstration in Video Demo 4.9). A method for theoretically determining the frequency response of a system model is presented in Section 4.10.2. Example 4.1 illustrates the basics of the method, applied to a simple RC filter.



Lab Exercise

Lab 4 Band-width, filters, and diodes



Video Demo

4.9 Filter (RC circuit) frequency response

■ CLASS DISCUSSION ITEM 4.3

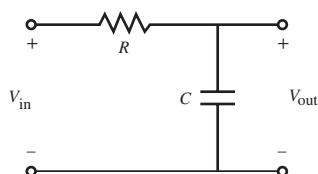
Audio Speaker Frequency Response

Audio speakers must replicate music with high fidelity. Given that humans are capable of hearing sounds over a range of frequencies from 20 Hz to 20 kHz, what would you expect the overlapping frequency response curves to look like for a speaker unit containing bass, midrange, and tweeter components?

Bandwidth of an Electrical Network

EXAMPLE 4.1

The bandwidth of an electrical system can be readily determined analytically with the help of the steady state AC circuit analysis technique presented in Section 2.6. Consider the following RC circuit as an example.



(continued)

(continued)

Using the voltage divider rule for the complex impedances of the resistor ($Z_R = R$) and capacitor ($Z_C = 1/j\omega C$), the output voltage for the network can be written as

$$V_{\text{out}} = \frac{\frac{1}{j\omega C}}{\frac{1}{j\omega C} + R} V_{\text{in}}$$

Therefore, the output-to-input ratio as a function of frequency is

$$\frac{V_{\text{out}}}{V_{\text{in}}} = \frac{1}{j\omega RC + 1}$$

The magnitude of this complex number gives us the amplitude ratio as a function of frequency:

$$\left| \frac{V_{\text{out}}}{V_{\text{in}}} \right| = \frac{1}{\sqrt{1 + (\omega RC)^2}}$$

The cutoff frequency ω_c for the circuit is

$$\omega_c = \frac{1}{RC}$$

because when $\omega = \omega_c$,

$$\left| \frac{V_{\text{out}}}{V_{\text{in}}} \right| = \frac{1}{\sqrt{2}} = 0.707$$

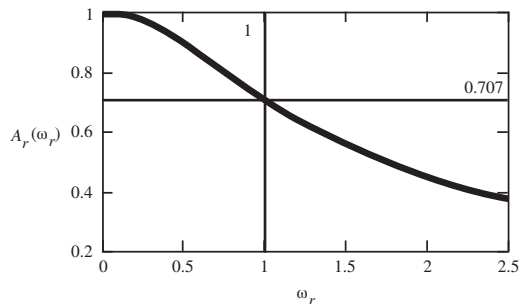
Using ω_c , the amplitude ratio can also be expressed as

$$\left| \frac{V_{\text{out}}}{V_{\text{in}}} \right| = \frac{1}{\sqrt{1 + (\omega/\omega_c)^2}}$$

The frequency response curve representing this relationship follows, where ω_r is the frequency ratio ω/ω_c and A_r is the amplitude ratio $|V_{\text{out}}/V_{\text{in}}|$. Note that, as ω_r approaches 0, A_r approaches 1 and as ω_r approaches ∞ , A_r approaches 0. Mathcad/Matlab Example 4.2 includes the analysis used to generate the frequency response plot.

This circuit is called a **low-pass filter** because lower frequencies are “passed” to the output with little attenuation and higher frequencies are significantly attenuated (i.e., not “passed”).

$$\omega_r = 0, 0.01 \dots 2.5 \qquad A_r(\omega_r) = \frac{1}{\sqrt{1 + \omega_r^2}}$$



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examples

4.2 Low-pass filter

If the resistor and capacitor were reversed, the resulting circuit would be called a **high-pass filter** because it would attenuate low frequencies. Two other useful filters are the notch filter and band-pass filter. The **notch filter**, sometimes called the band-reject filter, passes all frequencies except for a narrow band of frequencies that are highly attenuated. A common use for this filter is to eliminate 60 Hz interference often found on signal lines. The **band-pass filter**, on the other hand, passes a narrow band of frequencies and significantly attenuates all others. Much more information about filters, including active filters using op amps (the topic of Chapter 5) and digital filters using microcontroller software (the topic of Chapter 7), can be found at Internet Link 4.3.



Internet Link

4.3 Filters and signal processing

4.5 PHASE LINEARITY

The third criterion for a good measurement system is phase linearity, which expresses how well a system preserves the phase relationship between frequency components of the input.

Consider the relationship between phase angle and time displacement between two signals as illustrated in Figure 4.8. Signal 2 lags signal 1 because it occurs later (to the right) on the time axis. The time displacement between the signals t_d is $T/4$, where T is the period of the signals. Since a cycle of a signal corresponds to 2π radians or 360° , the phase angle between signal 1 and signal 2 is

$$\phi = 360 t_d / T \text{ degrees} = 2\pi t_d / T \text{ radians} \quad (4.27)$$

So for $t_d = T/4$, the phase angle is 90° or $\pi/2$ radians.

Measurement systems can cause a delay or time displacement between the input and output signals. For a given frequency f , where $f = 1/T$, Equation 4.27 can be expressed as

$$\phi = 360f \cdot t_d \text{ degrees} = 2\pi f \cdot t_d \text{ radians} \quad (4.28)$$

Therefore, for a given time displacement, the phase shift for a signal depends on its frequency. Since an input signal may be composed of many frequency components, it is important that all the individual components are displaced by the same amount of time; otherwise, the output of the measurement system would be distorted. For equal time displacement t_d for all frequency components, the following must hold:

$$\phi = k \cdot f \quad (4.29)$$

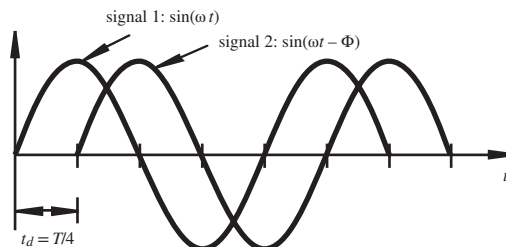


Figure 4.8 Relationship between phase and time displacement.

where k is a constant equal to $360t_d$ degrees or $2\pi t_d$ radians. Therefore, the phase angle must be linear with frequency for equal time displacement of frequency components. When a system functions in this way, it is said to exhibit **phase linearity**. k is usually negative for a measurement system, implying that the recorded output lags behind the actual input signal.

4.6 DISTORTION OF SIGNALS

When a system does not exhibit amplitude linearity, the amplitudes of the output frequency components are attenuated. As a result, the output suffers from **amplitude distortion** as illustrated in Figure 4.9 for a square wave. In the figure, the coefficients of the harmonics contain exponential functions whose magnitudes decrease (a) or increase (b) with frequency. Note the change (distortion) in the resulting outputs. Mathcad/Matlab Example 4.3 includes the analysis used to create the plots in Figure 4.9.

When a system does not exhibit phase linearity, the output frequency components may be of the proper amplitude but are displaced in time with respect to one another. As a result, the output exhibits **phase distortion** as illustrated in Figure 4.10 for a square wave. Mathcad/Matlab Example 4.4 includes the analysis used to create the plots in Figure 4.10.

A high-fidelity measurement system must exhibit amplitude linearity to prevent amplitude distortion, have adequate bandwidth to pass all frequency components contained in an input signal, and exhibit phase linearity to prevent phase distortion.

When designing or analyzing a measurement system, we want to predict the system's performance. Therefore, we need to be able to model the system and express its behavior in mathematical terms. The remainder of the chapter presents systems analysis tools that let us do this.

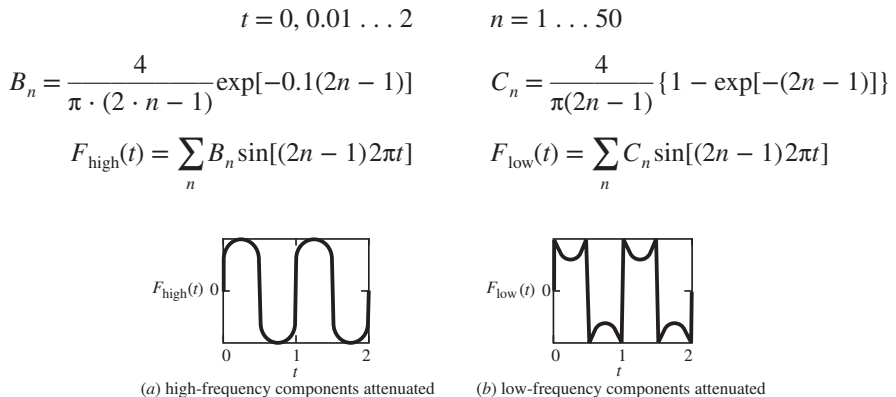
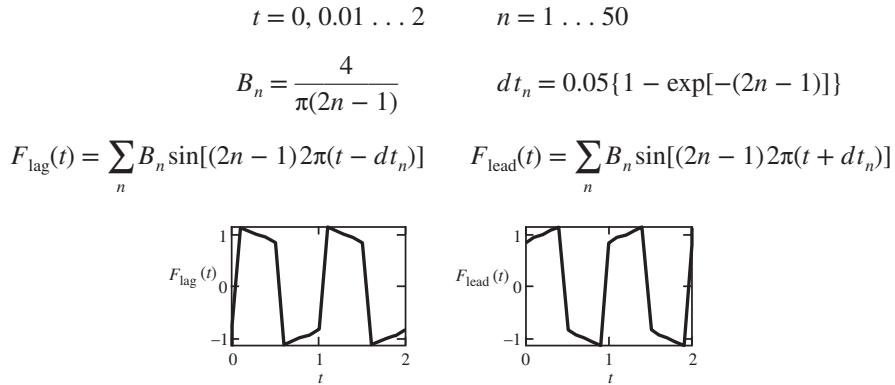


Figure 4.9 Amplitude distortion of a square wave (generated with Mathcad).

MATLAB®
examples

4.3 Amplitude distortion

4.4 Phase distortion



(a) high-frequency components lagging (b) high-frequency components leading

Figure 4.10 Phase distortion of a square wave (generated with Mathcad).

■ CLASS DISCUSSION ITEM 4.4

Analytical Attenuation

In Figure 4.9, the following exponential terms were used to attenuate amplitude components at low and high frequencies:

$$e^{-0.1(2n-1)} \quad \text{and} \quad 1 - e^{-(2n-1)}$$

Explain how these exponential terms cause the resulting distortion of the square wave. (Hint: Plot the exponential functions and describe how they change the amplitudes of the components of the square wave spectrum.)

4.7 DYNAMIC CHARACTERISTICS OF SYSTEMS

As we will see, many measurement systems can be modeled as linear ordinary differential equations with constant coefficients. This is also true of many mechatronic systems or their component subsystems. These linear models have the following general form:

$$\sum_{n=0}^N A_n \frac{d^n X_{\text{out}}}{dt^n} = \sum_{m=0}^M B_m \frac{d^m X_{\text{in}}}{dt^m} \quad (4.30)$$

where X_{out} is the output variable, X_{in} is the input variable, and A_n and B_n are constant coefficients. N defines the **order** of the system, independent of M . The approach used to determine the differential equation model depends on the type of system being analyzed. For example, Newton's laws and free-body diagrams can be applied to mechanical systems, and KVL and KCL equations can be applied to electric circuits.

As we will see, the constant coefficients A_n represent physical properties of the system of interest.

Many electromechanical systems exhibit nonlinear behavior and cannot be accurately modeled as linear systems. However, a nonlinear system may often exhibit linear behavior over a limited range of inputs and a linear model can be derived that provides an adequate approximation over this range. This process of modeling a nonlinear system with a linear model is called **linearization**.

The next three sections present methods to characterize the simplest and most common forms of Equation 4.30, where $M = 0$ and $N = 0, 1$, or 2 . These cases are referred to as zero-order, first-order, and second-order systems, respectively.

4.8 ZERO-ORDER SYSTEM

When $N = M = 0$ in Equation 4.30, the model represents a **zero-order** system whose behavior is described by

$$A_0 X_{\text{out}} = B_0 X_{\text{in}} \quad (4.31)$$

or

$$X_{\text{out}} = \frac{B_0}{A_0} X_{\text{in}} = K X_{\text{in}} \quad (4.32)$$

where $K = B_0/A_0$ is a constant referred to as the **gain** or **sensitivity** of the system, because it represents a scaling between the input and the output. When the sensitivity is high, a small change in the input can result in a significant change in the output. Note that the output of a zero-order system follows the input exactly with no time delay or distortion.

An example of a zero-order measurement system is a potentiometer used to measure displacement. A potentiometer is a variable resistance device whose output resistance changes as an internal wiper moves across a resistive surface. As illustrated in Figure 4.11, it produces an output voltage V_{out} that is directly proportional to the wiper displacement X_{in} . This is a result of the voltage division rule, which gives

$$V_{\text{out}} = \frac{R_x}{R_p} V_s = \left(\frac{V_s}{L} \right) X_{\text{in}} \quad (4.33)$$

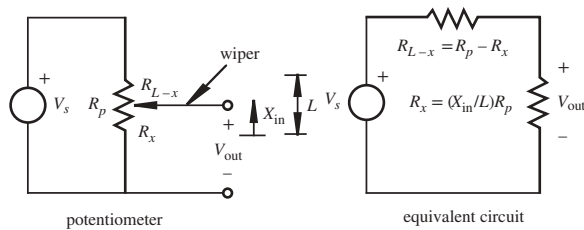


Figure 4.11 Displacement potentiometer.

where R_x is the resistance between the potentiometer leads, R_p is the maximum resistance of the potentiometer, X_{in} is the displacement of the potentiometer wiper, and L is the maximum amount of wiper travel.

■ CLASS DISCUSSION ITEM 4.5

Assumptions for a Zero-Order Potentiometer

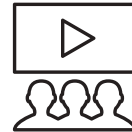
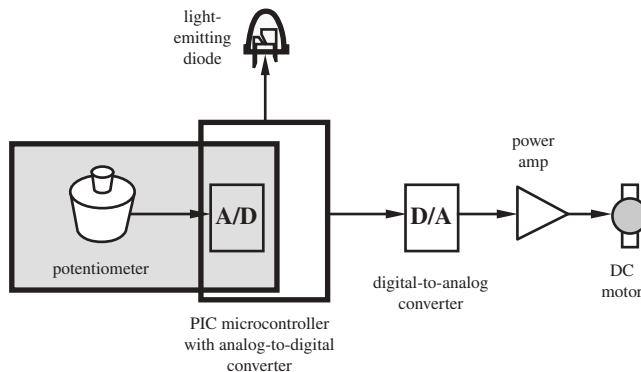
What approximating assumptions must be made regarding the potentiometer to ensure that it is a zero-order measurement system?

THREADED DESIGN EXAMPLE

DC motor power-op-amp speed controller—potentiometer interface

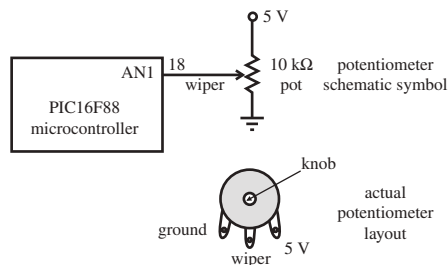
A.2

The figure below shows the functional diagram for Threaded Design Example A (see Section 1.3 and Video Demo 1.6). The portion described here is highlighted.


Video Demo

1.6 DC motor power-op-amp speed controller

To interface a potentiometer to a microcontroller, the analog voltage output (see Equation 4.30) must be converted to digital form. Fortunately, a PIC microcontroller can be selected that has a built-in analog-to-digital (A/D) converter. This allows the PIC to sense the potentiometer position, as a voltage, using the simple circuit shown below. The potentiometer has three leads, wired as shown, with the center “wiper” lead connected to the PIC analog input (pin 18, designated as AN1). The voltage on the wiper line varies from 0 V (ground) to 5 V as the knob is turned.



4.9 FIRST-ORDER SYSTEM

When $N = 1$ and $M = 0$ in Equation 4.30, the equation models a **first-order** system whose behavior is described by

$$A_1 \frac{dX_{\text{out}}}{dt} + A_0 X_{\text{out}} = B_0 X_{\text{in}} \quad (4.34)$$

or

$$\frac{A_1}{A_0} \frac{dX_{\text{out}}}{dt} + X_{\text{out}} = \frac{B_0}{A_0} X_{\text{in}} \quad (4.35)$$

As with the zero-order system, the coefficient ratio on the right-hand side is called the sensitivity or **static sensitivity**, defined as

$$K = \frac{B_0}{A_0} \quad (4.36)$$

The coefficient ratio on the left side of Equation 4.35 has a special name and meaning. It is called the **time constant** and is defined as

$$\tau = \frac{A_1}{A_0} \quad (4.37)$$

The choice of this name will become clear in the subsequent analysis. With these definitions, the first-order system equation can be written as

$$\tau \frac{dX_{\text{out}}}{dt} + X_{\text{out}} = K X_{\text{in}} \quad (4.38)$$

Note that in this standard form, the coefficient of the X_{out} term must be 1.

To characterize how a system responds to various types of inputs, we apply standard inputs to the model, including step, impulse, and sinusoidal functions. A **step input** changes instantaneously from 0 to a constant value A_{in} and is stated mathematically as

$$X_{\text{in}} = \begin{cases} 0 & t < 0 \\ A_{\text{in}} & t \geq 0 \end{cases} \quad (4.39)$$

The output of the system in response to this input is called the **step response** of the system. For a first-order system, we can find the step response by solving Equation 4.38 with the initial condition

$$X_{\text{out}}(0) = 0 \quad (4.40)$$

Assuming a solution of the form Ce^{st} for the homogeneous form of differential Equation 4.38, the **characteristic equation** is

$$\tau s + 1 = 0 \quad (4.41)$$

Since the root of this equation is $s = -1/\tau$, the **homogeneous** or **transient solution** is

$$X_{\text{out}_h} = C e^{-t/\tau} \quad (4.42)$$

where C is a constant determined later by applying initial conditions. A **particular** or **steady state solution** resulting from the step input is

$$X_{\text{out}_p} = KA_{\text{in}} \quad (4.43)$$

The **general solution** is the sum of the homogeneous and particular solutions:

$$X_{\text{out}}(t) = X_{\text{out}_h} + X_{\text{out}_p} = Ce^{-t/\tau} + KA_{\text{in}} \quad (4.44)$$

Applying the initial condition (Equation 4.40) to this equation gives

$$0 = C + KA_{\text{in}} \quad (4.45)$$

thus,

$$C = -KA_{\text{in}} \quad (4.46)$$

and the resulting step response is

$$X_{\text{out}}(t) = KA_{\text{in}}(1 - e^{-t/\tau}) \quad (4.47)$$

As illustrated in Figure 4.12, this represents an exponential rise in the output asymptotically toward a final value of KA_{in} . The rate of the rise depends only on the time constant τ . The response is faster for a smaller time constant.

After a period of time of one time constant, the step response reaches 63.2% of its final value:

$$X_{\text{out}}(\tau) = KA_{\text{in}}(1 - e^{-1}) = 0.632KA_{\text{in}} \quad (4.48)$$

After four time constants, the step response is

$$X_{\text{out}}(4\tau) = KA_{\text{in}}(1 - e^{-4}) = 0.982KA_{\text{in}} \quad (4.49)$$

Since this value is more than 98% of the steady state value KA_{in} , we usually assume that a first-order system has reached its steady state value within four time constants.

When designing a first-order measurement system, look at quantities that affect τ and try to reduce them if possible. The larger τ is, the longer the measurement system takes to respond to an input.

An important example of a first-order system is an RC circuit (see Example 4.1), which has a time constant of $\tau = RC$ (see Question 4.19). RC circuits are very common in timing, filtering, and other applications (e.g., see Example 4.1, Section 6.12.3, and

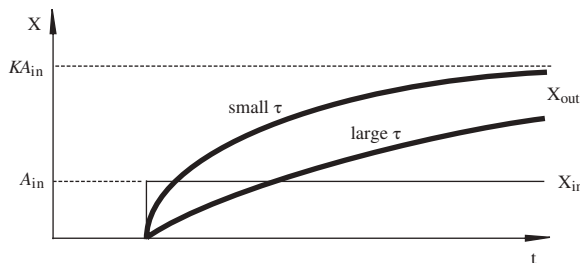


Figure 4.12 First-order response.



Video Demo

4.10 RC circuit charging and discharging

Example 7.6). Video Demo 4.10 illustrates the step response of an RC circuit, showing how the voltage across the capacitor builds over time. The speed of charging and discharging the capacitor is directly related to the time constant of the circuit.

■ CLASS DISCUSSION ITEM 4.6

Thermal Analogy of an Electrical RC Circuit

A first-order-system electrical RC circuit is analogous to any first-order thermal system experiencing heat exchange (e.g., from a heat source and from convection or conduction) and a change in temperature due to internal energy. Explain these analogies in detail by comparing variables of interest in both. (Hint: See Section 4.11 and Question 4.21.)

4.9.1 Experimental Testing of a First-Order System

To characterize and evaluate an existing first-order system, we need methods to experimentally determine the time constant τ and the static sensitivity K . K may be obtained by static calibration, where a known static input is applied, and the output is observed. A common method to determine the time constant τ is to apply a step input to the system and determine the time for the output to reach 63.2% of its final value (see Equation 4.48). An alternative method to determine a value for τ follows.

We can rearrange Equation 4.47, expressing it as

$$\frac{X_{\text{out}} - KA_{\text{in}}}{KA_{\text{in}}} = -e^{-t/\tau} \quad (4.50)$$

Simplifying, we get

$$1 - \frac{X_{\text{out}}}{KA_{\text{in}}} = e^{-t/\tau} \quad (4.51)$$

If we take the natural logarithm of both sides, we get

$$\ln\left(1 - \frac{X_{\text{out}}}{KA_{\text{in}}}\right) = -\frac{t}{\tau} \quad (4.52)$$

If we define the left-hand side as Z , then

$$Z = -t/\tau \quad (4.53)$$

and a plot of Z vs. t is a straight line with the slope

$$\frac{dZ}{dt} = -\frac{1}{\tau} \quad (4.54)$$

Therefore, if we collect experimental data from a step response and plot Z vs. t as illustrated in Figure 4.13, we can determine τ from the slope of the line:

$$\tau = -\frac{\Delta t}{\Delta Z} \quad (4.55)$$

Note that if experimental data for Z vs. t deviates from a straight line, then the system is not first order. If this is the case, then the system is either of higher order or nonlinear.

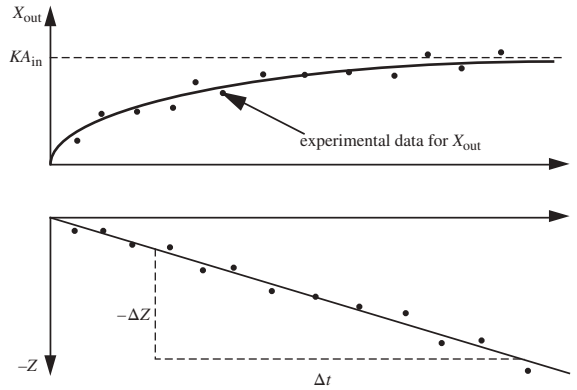


Figure 4.13 Experimental determination of τ .

4.10 SECOND-ORDER SYSTEM

An example of a **second-order** system, where $N = 2$ in Equation 4.30, is the mechanical spring-mass-damper system illustrated in Figure 4.14. Applying Newton's law of motion (in this case, $\Sigma F_x = ma_x$) to the free-body diagram gives the second-order differential equation, which is the mathematical model for the system:

$$m \frac{d^2 x}{dt^2} + b \frac{dx}{dt} + kx = F_{\text{ext}}(t) \quad (4.56)$$

where m is the mass, b is the damping coefficient, k is the spring constant, and x is the displacement of the mass from the equilibrium (rest) position of the mass measured positively in the downward direction as shown. $F_{\text{ext}}(t)$ represents the resultant of all applied external forces (inputs) in the direction of x . The weight of the mass is not included as a force in the free-body diagram because the displacement x is measured from the equilibrium position. In the equilibrium position, the spring is stretched an amount δ from its unstretched length so that the effect of gravity is

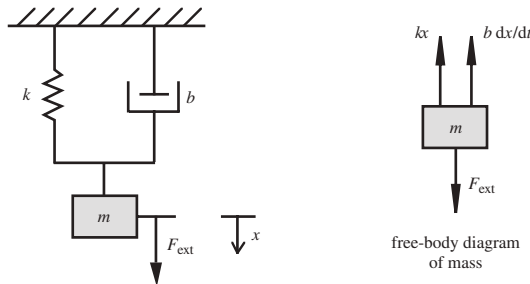


Figure 4.14 Second-order mechanical system and free-body diagram.

is balanced: $k\delta = mg$. Note that the spring force (kx) is in the opposite direction from the mass displacement, and the damper force ($b \, dx/dt$) is in the opposite direction from the velocity of the mass.

As we will see in Section 4.11, the governing equations for many second-order systems other than mechanical spring-mass-damper systems (e.g., mechanical rotational systems and hydraulic systems) have the same form as Equation 4.56.

A good example of a second-order measurement system is the strip chart recorder illustrated in Figure 4.15. It consists of a continuously moving roll of paper on which a pen is moved back and forth. A spring is attached to the pen carriage to keep it centered in a neutral position when an applied force is removed. The strip chart recorder can be thought of as a mechanical oscilloscope. It was used much more before the digital age whenever a large amount of time-varying data needed to be stored (e.g., for later analysis). They are still used in some applications (e.g., in older remote seismograph stations and polygraph machines). The applied force F_{ext} is provided by an electromagnetic coil whose core is attached to the pen carriage. The spring keeps the pen carriage centered in the zero position when the input is 0. The pen carriage bearings and the pen-paper interface result in the damping force. The carriage and the pen constitute the mass to which the forces in the system are applied.

To characterize the unforced response of a second-order system, we need to solve the differential Equation 4.56 with $F_{\text{ext}} = 0$. The characteristic equation is

$$ms^2 + bs + k = 0 \quad (4.57)$$

This quadratic equation has two roots for s :

$$s_1 = -\frac{b}{2m} + \sqrt{\left(\frac{b}{2m}\right)^2 - \frac{k}{m}} \quad (4.58)$$

$$s_2 = -\frac{b}{2m} - \sqrt{\left(\frac{b}{2m}\right)^2 - \frac{k}{m}} \quad (4.59)$$

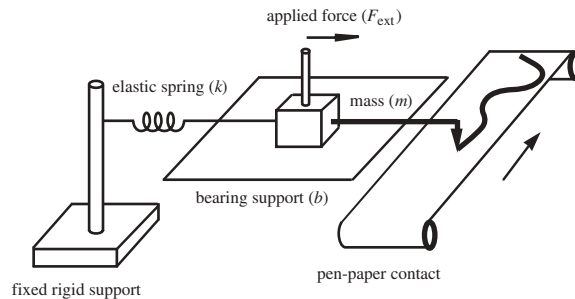


Figure 4.15 Strip chart recorder as an example of a second-order system.

If there were no damping in the system (i.e., $b = 0$), the roots would be

$$s_1 = j\sqrt{\frac{k}{m}} \quad (4.60)$$

$$s_2 = -j\sqrt{\frac{k}{m}} \quad (4.61)$$

and the corresponding homogeneous solution would be

$$x_h(t) = A \cos\left(\sqrt{\frac{k}{m}} t\right) + B \sin\left(\sqrt{\frac{k}{m}} t\right) \quad (4.62)$$

where A and B are constants determined from the initial conditions $x(0)$ and $dx/dt(0)$. This motion represents pure **undamped** oscillatory motion with angular frequency:

$$\omega_n = \sqrt{\frac{k}{m}} \quad (4.63)$$

This is called the **natural frequency** of the system, because it is the frequency at which the undamped system would naturally oscillate if the spring were stretched and the mass released and allowed to move without any external force ($F_{\text{ext}} = 0$).

If there is damping in the system (i.e., $b \neq 0$) and the radicand in Equations 4.58 and 4.59 is zero, then the roots are double real roots, and the resulting transient homogeneous solution is

$$x_h(t) = (A + Bt)e^{-\omega_n t} \quad (4.64)$$

This represents an exponentially decaying motion. A system with this behavior is said to be **critically damped**, because it is just on the verge of damped oscillatory motion. The damping constant that results in critical damping is called the **critical damping constant** b_c . It is the value of b that makes the radicand 0, so

$$b_c = 2\sqrt{km} = 2m\omega_n \quad (4.65)$$

The **damping ratio** ζ (zeta) for a damped system is defined as

$$\zeta = \frac{b}{b_c} = \frac{b}{2\sqrt{km}} \quad (4.66)$$

It is a measure of the proximity to critical damping. A critically damped system has a damping ratio of 1.

With the definitions of natural frequency and damping ratio, the roots of the characteristic equations (Equations 4.58 and 4.59) can be written as

$$s_1 = -\zeta\omega_n + \omega_n\sqrt{\zeta^2 - 1} \quad (4.67)$$

$$s_2 = -\zeta\omega_n - \omega_n\sqrt{\zeta^2 - 1} \quad (4.68)$$

If there is damping in the system (i.e., $b \neq 0$) and the radicand in Equations 4.67 and 4.68 is negative (i.e., $\zeta < 1$), then the roots are complex conjugates, and the resulting transient homogeneous solution is

$$x_h(t) = e^{-\zeta\omega_n t} [A \cos(\omega_n \sqrt{1 - \zeta^2} t) + B \sin(\omega_n \sqrt{1 - \zeta^2} t)] \quad (4.69)$$

This motion represents damped oscillation consisting of sinusoidal motion with exponentially decaying amplitude. A system with these characteristics is said to be **underdamped**, because it has less than critical damping ($\zeta < 1$). The frequency of oscillation is

$$\omega_d = \omega_n \sqrt{1 - \zeta^2} \quad (4.70)$$

which is called the **damped natural frequency** of the system.

If there is damping in the system (i.e., $b \neq 0$) and the radicand in Equations 4.67 and 4.68 is positive (i.e., $\zeta > 1$), then the roots are distinct real roots, and the resulting transient homogeneous solution is

$$x_h(t) = A e^{(-\zeta + \sqrt{\zeta^2 - 1})\omega_n t} + B e^{(-\zeta - \sqrt{\zeta^2 - 1})\omega_n t} \quad (4.71)$$

This represents an exponentially decaying output. A system with these characteristics is said to be **overdamped**, because its damping exceeds critical damping ($\zeta > 1$).

Examples of transient responses for all three cases of damping (underdamped, critically damped, and overdamped) are illustrated in Figure 4.16. The curves represent unforced motion of a second-order system with different amounts of damping, when the system is released from rest ($dx/dt(0) = 0$) at $x(0) = 1$.

Based on the definitions above, a more standard form for the differential equation representing a second-order system can be written as

$$\ddot{x} + 2\zeta\omega_n \dot{x} + \omega_n^2 x = \frac{\omega_n^2}{k} F_{\text{ext}} \quad (4.72)$$

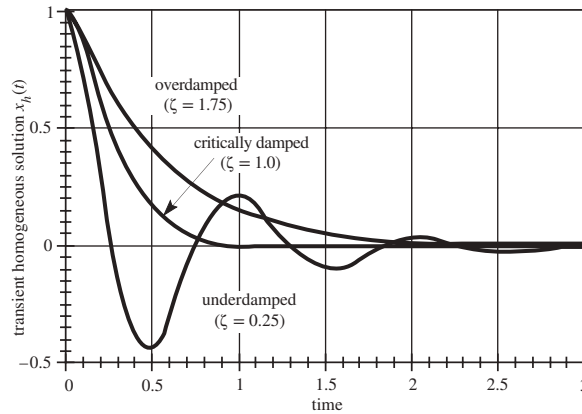


Figure 4.16 Transient response of second-order systems.

Equations 4.63 and 4.66 define how the terms in this equation relate to the coefficient parameters in Equation 4.56.

■ CLASS DISCUSSION ITEM 4.7

Spring-Mass-Damper System in Space

Would a spring-mass-damper system behave any differently inside a space station orbiting the earth than it does on the surface of the earth? Why or why not? How could you use a spring to measure the mass of an astronaut in the orbiting space station?

4.10.1 Step Response of a Second-Order System

As we found when analyzing a first-order system, an important input used to study the dynamic characteristics of a system is a step function. The step response is a good measure of how fast and smoothly a system responds to abrupt changes in input. The step response consists of two parts: a transient homogeneous solution $x_h(t)$, which is of the form presented in Section 4.10 for the unforced response, plus a steady state particular solution $x_p(t)$, which is a result of the forcing function. For a step input given by

$$F_{\text{ext}}(t) = \begin{cases} 0 & t < 0 \\ F_i & t \geq 0 \end{cases} \quad (4.73)$$

it is clear from Equation 4.56 that a particular solution is

$$x_p(t) = \frac{F_i}{k} \quad (4.74)$$

The general solution for the step response is then

$$x(t) = x_h(t) + x_p(t) \quad (4.75)$$

where the constants in $x_h(t)$ are determined by applying the initial conditions $x(0)$ and $dx/dt(0)$ to the general solution $x(t)$. As with the unforced case, there are three distinctly different types of response based on the amount of damping in the system, as illustrated in Figure 4.17.

Figure 4.18 illustrates the step response of an underdamped system and defines several terms used when describing the step response. The **steady state value** is the value the system reaches after all transients dissipate. The **rise time** is the time required for the system to go from 10% to 90% of the steady state value. The **overshoot** is a measure of the maximum amount the output exceeds the steady state value before settling, usually specified as a percentage of the steady state value. The **settling time** is the time required for the system to settle to within an amplitude band whose height is a specified $\pm$ percentage of the steady state value. A settling time tolerance band of $\pm 10\%$ is shown in Figure 4.18, although, $\pm 2\%$ is more commonly used when calculating and reporting values. These terms can be used to characterize the step

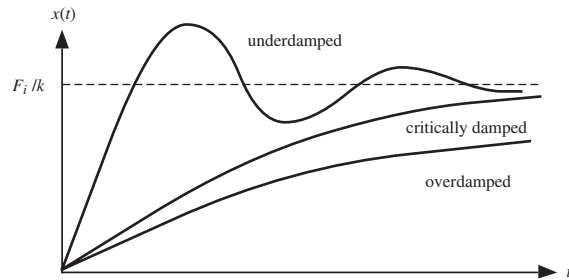


Figure 4.17 Second-order step responses.

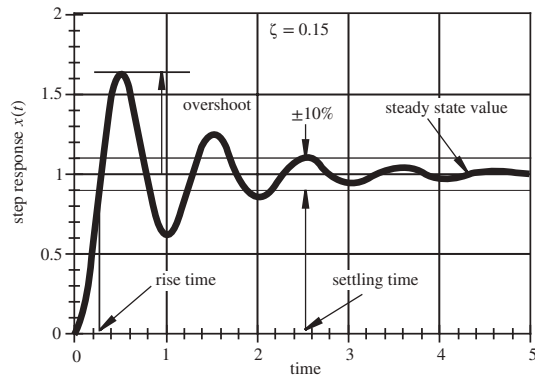


Figure 4.18 Features of an underdamped step response.

response of a second-order system with different amounts of damping: An underdamped system exhibits a fast rise time, but it overshoots and may take a while to settle; although, with the right amount of damping, it can settle faster than critically damped or overdamped systems. For cases where no overshoot is allowed or desired, a critically damped system has the fastest rise and settle times. An overdamped system also has no overshoot, but has slower rise and settle times.

The step response may be useful in identifying the order of a system, because the shape of the response curve can help indicate the order (along with the frequency response amplitude and phase plots presented in the next section). Also, if the system is second order, we can learn from the step response whether the system is underdamped, overdamped, or critically damped.

■ CLASS DISCUSSION ITEM 4.8

Good Measurement System Response

Describe and sketch what you think is a “good” step response of a measurement system. Is overshoot bad? What advantage does it provide? Does critical damping provide optimal response?

4.10.2 Frequency Response of a System

To determine the frequency response of a linear system, we apply a sinusoidal input and determine the output response for different input frequencies. For the second-order system described in Section 4.10, the sinusoidal forcing function input can be represented as

$$F_{\text{ext}}(t) = F_i \sin(\omega t) \quad (4.76)$$

where F_i is the amplitude of the external force and ω is the input frequency.

When the sinusoidal input is first applied, the system exhibits a combined transient and steady state response. Once the transients dissipate, the steady state output of the system is sinusoidal with the same frequency as the input but possibly out of phase with the input. We can represent this steady state output in the following general form:

$$x(t) = X_o \sin(\omega t + \phi) \quad (4.77)$$

where X_o is the output magnitude and ϕ is the phase difference between the input and the output.

The procedure to determine analytically the frequency response of a linear system follows. The linear system could model a measurement system or a more general linear mechatronic system of any order. Each step in the procedure is shown in its generic form and then applied to a second-order system, as an example.

Analytical Procedure to Determine the Frequency Response of a System

1. Find the Laplace transform of the system differential equation assuming initial conditions are zero: $x(0) = \dot{x}(0) = 0$. The Laplace transform converts the differential equation into an algebraic equation that is related to the frequency response of the system.

The governing equation for a second-order system (from Equation 4.72) can be expressed as

$$\frac{d^2x(t)}{dt^2} + 2\zeta\omega_n \frac{dx(t)}{dt} + \omega_n^2 x(t) = \frac{\omega_n^2}{k} F_{\text{ext}}(t) \quad (4.78)$$

Applying the Laplace transform to both sides of the equation, assuming zero initial conditions, gives

$$(s^2 + 2\zeta\omega_n s + \omega_n^2)X(s) = \frac{\omega_n^2}{k} F_{\text{ext}}(s) \quad (4.79)$$

where $F_{\text{ext}}(s)$ and $X(s)$ are the Laplace transforms of the input forcing function and the output displacement, respectively.

2. Find the **transfer function** of the system, which is the ratio of the output and input Laplace transforms.

For this system, the transfer function is

$$G(s) = \frac{X(s)}{F_{\text{ext}}(s)} = \frac{\frac{\omega_n^2}{k}}{(s^2 + 2\zeta\omega_n s + \omega_n^2)} \quad (4.80)$$

3. To simulate a harmonic input, replace s with $j\omega$ in the transfer function. This yields the frequency response behavior of the system.

For this system, replacing s with $j\omega$ in Equation 4.80 and dividing the numerator and denominator by ω_n^2 gives

$$G(j\omega) = \frac{1/k}{\left[1 - \left(\frac{\omega}{\omega_n}\right)^2\right] + j\left(2\zeta\frac{\omega}{\omega_n}\right)} \quad (4.81)$$

4. Find the desired **amplitude ratio** between the output and input by determining the magnitude of the complex transfer function:

$$\text{mag}[G(j\omega)] = |G(j\omega)| \quad (4.82)$$

For this system, taking the magnitude of the denominator, which is the square root of the sum of the squares of the real and imaginary components, and moving the k term to the left-hand side of the equation, results in the following dimensionless ratio:

$$\frac{X_o}{F_i/k} = \frac{1}{\left\{\left[1 - \left(\frac{\omega}{\omega_n}\right)^2\right]^2 + 4\zeta^2\left(\frac{\omega}{\omega_n}\right)^2\right\}^{1/2}} \quad (4.83)$$

5. Find the **phase angle** ϕ between the output and input by determining the argument of the complex transfer function:

$$\phi = \arg[G(j\omega)] = \angle G(j\omega) \quad (4.84)$$

From Equation 4.81, recalling that the argument of a complex number is the arctangent of the ratio of its imaginary and real parts and that the argument of a ratio is the difference of the numerator and denominator arguments, the phase angle for this system is found as

$$\phi = 0 - \tan^{-1} \left\{ \frac{2\zeta\frac{\omega}{\omega_n}}{\left[1 - \left(\frac{\omega}{\omega_n}\right)^2\right]} \right\} = -\tan^{-1} \left\{ \frac{2\zeta}{\frac{\omega_n}{\omega} - \frac{\omega}{\omega_n}} \right\} \quad (4.85)$$

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4.5 Second-order system frequency response

A plot of the frequency response of the second-order system as a function of the damping ratio ζ is shown in Figure 4.19. Mathcad/Matlab Example 4.5 includes the analysis used to create the plot. When the input frequency ω equals the natural frequency ω_n (i.e., $\omega/\omega_n = 1$), **resonance** occurs. Often ω_n is called the resonant frequency. For small damping ratios, the output amplitude becomes quite large at the resonant frequency. For input frequencies less than the natural frequency (i.e., $\omega/\omega_n < 1$), the amplitude ratio is close to 1. The damping ratio ζ affects the range of frequencies

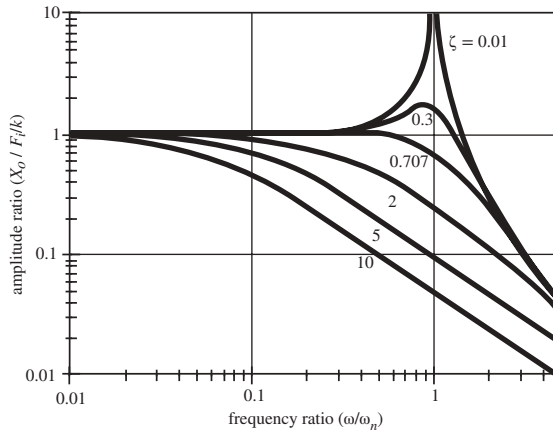


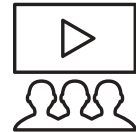
Figure 4.19 Second-order system amplitude response.

for which this is true. Recall that, for a good measurement system, we require the amplitude ratio to be nearly constant (within ± 3 dB) over the range of frequencies we wish to measure. As shown by the dashed line in Figure 4.20, a damping ratio of 0.707 provides the best amplitude linearity over the largest range of input frequencies, especially at lower frequencies.

A plot of the phase angle as a function of frequency ratio and damping ratio is shown in Figure 4.20. The phase angle is negative, implying that the output lags behind the input, and the magnitude ranges from 0° , which represents no phase difference, to 180° , which represents a half-cycle phase difference. As ω approaches the natural frequency ω_n (i.e., $\omega/\omega_n = 1$), the output lags the input by 90° (a quarter of a cycle). When the damping in a system is very small (e.g., $\zeta = 0.01$) and the value of the excitation frequency passes through the natural frequency (ω_n), the phase shift changes abruptly by 180° . A damping ratio of 0.707 provides the best approximation of phase linearity for a second-order system.

A very large number of mechanical systems can be approximated by second-order linear ordinary differential equations. Also, complex systems or their component subsystems can often be reduced to second-order systems for a first-approximation analysis. Therefore, all engineers should completely understand all implications of Figures 4.19 and 4.20. Video Demos 4.11 through 4.13 show examples of how the second-order system response concepts apply to some basic systems. Video Demo 4.14 shows a classic failure that resulted from engineers not having a firm understanding of some of these concepts. In this case, there were poorly understood wind-induced oscillating loads and inadequate damping, leading to catastrophic failure of this famous suspension bridge.

The output of second-order measurement systems always differs from the input in both amplitude and phase. In designing a measurement system, the goal is to minimize these effects when possible, so the choice of 0.707 for the damping ratio is optimal because it results in the best combination of amplitude linearity



Video Demo

4.11 Spring-mass second-order system frequency response

4.12 Pendulum second-order system frequency response

4.13 Torsional system frequency response and control

4.14 Tacoma Narrows bridge failure

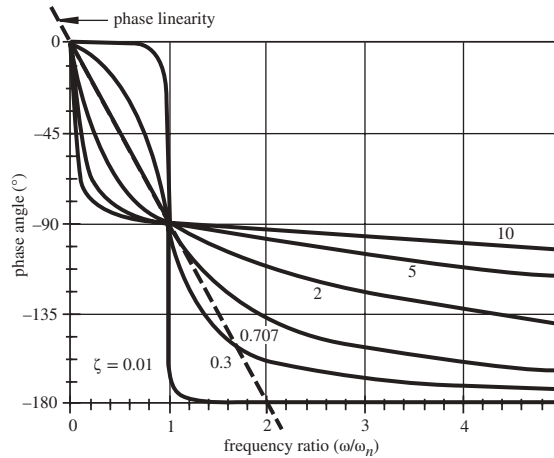


Figure 4.20 Second-order system phase response.

and phase linearity over the widest range of frequencies. When designing other types of systems (e.g., see Design Example 4.1, which addresses the design of a car suspension), damping ratios other than 0.707 might be more appropriate for the application.

In general, whenever a periodic input is applied to a second-order system, resonance, attenuation, and phase shift may occur. In order to predict how a system will respond, it is important to be able to determine the system's frequency response characteristics.

■ CLASS DISCUSSION ITEM 4.9

Slinky Frequency Response

Using a Slinky with a mass suspended from one end, demonstrate the frequency response characteristics illustrated in Figures 4.19 and 4.20.

DESIGN EXAMPLE 4.1

Automobile Suspension Selection

A design team has been asked to select a spring and shock absorber for the front suspension of a new automobile. The team's task is to choose a suspension that will provide the best response to varying road conditions. Since many U.S. manufacturers still specify their products in English units, the design team has reluctantly agreed to perform all analyses using the English system.

After preliminary analyses and meetings with other design teams, the suspension team has narrowed its choices down to three alternative suspension designs. The three

alternatives are characterized by the following spring constants k and damping constants b :

Alternative	k (lbf/in)	b (lbf sec/in)
1	500	10
2	200	20
3	120	10

To evaluate the alternatives under different road conditions, the design team decides to simulate bumps or pot holes as a ground force step input of magnitude F_0 and regular bumps or waviness in the road as a sinusoidal ground force input of magnitude B_0 and frequency ω . To subject each alternative to similar input displacement levels, the following fixed ratios are used in the comparison:

$$F_0/k = 6 \text{ in} \quad B_0/k = 3 \text{ in}$$

Each alternative is subjected to the following three frequencies to simulate different speeds or bump spacing:

$$\omega_1 = 10 \text{ rad/sec} \quad \omega_2 = 20 \text{ rad/sec} \quad \omega_3 = 30 \text{ rad/sec}$$

The team decides on a single degree of freedom system that models only a single wheel and neglects the response of the other wheels. The resulting model is a second-order system described by Equation 4.56, where m is the mass supported (“sprung”) by the suspension and F_{ext} is the ground force. The weight of the entire vehicle is 2000 lbf; therefore, the sprung mass supported by a single wheel is assumed to be 1/4 of the total mass:

$$m = 500 \text{ lbm} = 15.53 \text{ slugs}$$

Note that the wheel mass and tire dynamics are not included in this simplified model (see Class Discussion Item 4.10).

Using Equations 4.63 and 4.66, the natural frequency ω_n and the damping constant ζ are calculated for each alternative:

Alternative	ω_n	ζ
1	19.6	0.20
2	12.4	0.62
3	9.6	0.40

Since $\zeta < 1.0$ for each alternative, the suspensions will exhibit an underdamped step response described by Equation 4.69.

The step response and sinusoidal response analyses are performed in Mathcad (see Mathcad/Matlab Example 4.6). The input variables (for Alternative 1) are defined as

$$\begin{aligned} k &= 500 \frac{\text{lbf}}{\text{in}} & b &= 10 \text{ lbf} \frac{\text{sec}}{\text{in}} & m &= 500 \text{ lbm} \\ F_0 &= (6 \text{ in})k & B_0 &= (3 \text{ in})k \\ \omega_1 &= 10 \frac{\text{rad}}{\text{sec}} & \omega_2 &= 20 \frac{\text{rad}}{\text{sec}} & \omega_3 &= 30 \frac{\text{rad}}{\text{sec}} \end{aligned}$$

$$t = 0 \text{ sec}, 0.01 \text{ sec} \dots 2 \text{ sec}$$

(continued)

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4.6 Suspension design

(continued)

The step response is defined by (see Question 4.29)

$$\omega_n = \sqrt{\frac{k}{m}} \quad \zeta = \frac{b}{2\sqrt{km}} \quad \omega_d = \omega_n \sqrt{1 - \zeta^2}$$

$$x(t) = \frac{F_0}{k} \left[1 - e^{-\zeta \omega_n t} \cos(\omega_d t) \right]$$

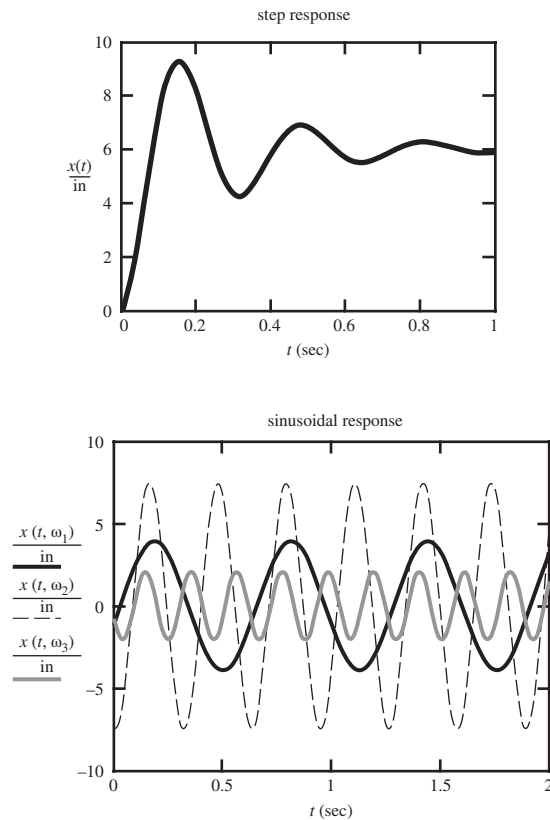
and the sinusoidal response is defined by

$$X_0(\omega) = \frac{\frac{B_0}{k}}{\sqrt{\left[1 - \left(\frac{\omega}{\omega_n}\right)^2\right]^2 + 4\zeta^2\left(\frac{\omega}{\omega_n}\right)^2}} \quad \phi(\omega) = -\text{angle}\left[\left(\frac{\omega_n - \omega}{\omega_n}\right), 2\zeta\right]$$

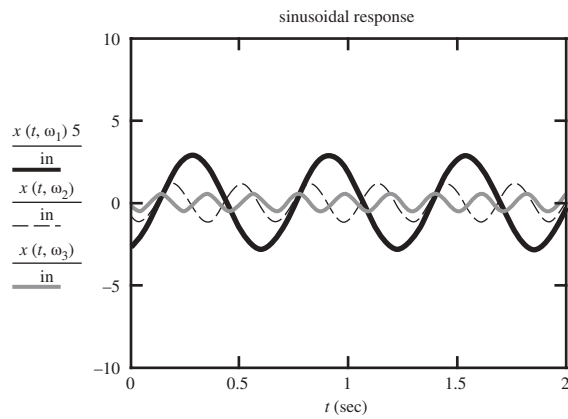
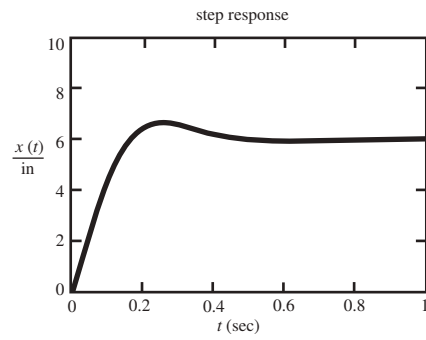
$$x(t, \omega) = X_0(\omega)[\sin(\omega t + \phi(\omega))]$$

The results for the three alternatives follow.

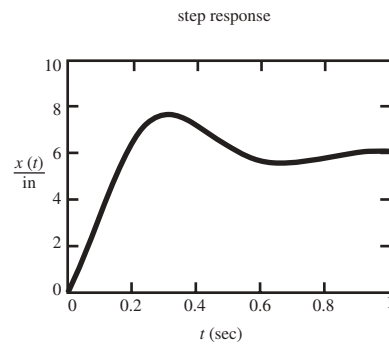
■ Alternative 1



Alternative 2

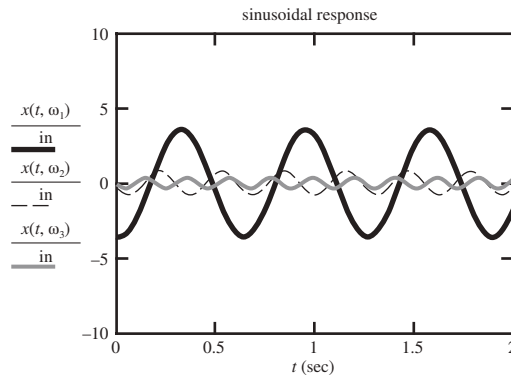


Alternative 3



(continued)

(concluded)



A good suspension has a fast response (short settling time), resulting in good handling, and prevents excessive bounce (oscillation) or large displacement, which improves rider comfort. From the preceding results, it appears that Alternative 2 is the best of the three designs. The step response settles fast with little bounce and the sinusoidal responses have low amplitude.

■ CLASS DISCUSSION ITEM 4.10

Suspension Design Results

Were the step response and sinusoidal response graphs required to draw conclusions about the three alternatives? Also, why was the amplitude of the sinusoidal response excessive for Alternative 1 and least for Alternative 2? What would it take to include the wheel mass and tire dynamics in the system model?

4.11 SYSTEM MODELING AND ANALOGIES

Any system—whether it be mechanical, electrical, hydraulic, thermal, or some combination—can be modeled by ordinary linear differential equations that relate how the outputs change in response to the system inputs. These differential equations are all very similar mathematically and differ only in the constants that appear in front of the derivative terms. These constants represent the physical parameters of the system, and there are analogies for these parameters among the different system genres. For instance, a resistor in an electrical system is analogous to a dashpot or damper in a mechanical system or to a valve or flow restriction in a hydraulic system. Similarly, mass or inertia in a mechanical system is analogous to inductance in an electrical system and fluid inertance in a hydraulic system. The generic terms used to describe the analogous system parameters and variables are **effort**, **flow**, **displacement**, **momentum**, **resistance**, **capacitance**, and **inertia**. Table 4.1 summarizes the generic quantities along with specific analogies for mechanical, electrical, and hydraulic systems. Also included are equations relating variables for energy storage and energy dissipation elements in each system.

Table 4.1 Second-order system modeling analogies

Generic quantity	Mechanical translation	Mechanical rotation	Electrical	Hydraulic
Effort (E)	Force (F)	Torque (T)	Voltage (V)	Pressure (P)
Flow (F)	Speed (v)	Angular speed (ω)	Current (i)	Volumetric flow rate (Q)
Displacement (q)	Displacement (x)	Angular displacement (θ)	Charge (q)	Volume ($\forall$)
Momentum (p)	Linear momentum ($p = mv$)	Angular momentum ($h = J\omega$)	Flux linkage ($I = N\Phi = Li$)	Momentum/area ($\Gamma = IQ$)
Resistor (R)	Damper (b)	Rotary damper (B)	Resistor (R)	Resistor (R)
Capacitor (C)	Spring ($1/k$)	Torsion spring ($1/k$)	Capacitor (C)	Tank (C)
Inertia (I)	Mass (m)	Moment of inertia (J)	Inductor (L)	Inertance (I)
Inertia energy storage (special case)	$F = \dot{p}$ ($F = ma$)	$T = \dot{h}$ ($T = J\alpha$)	$V = \dot{\lambda}$ ($V = L di/dt$)	$P = \dot{\Gamma}$ ($P = I dQ/dt$)
Capacitor energy storage	$F = kx$	($T = k\theta$)	$V = (1/C)q$	$P = (1/C)\forall$
Dissipative	$F = bv$	$T = B\omega$	$V = Ri$	$P = RQ$

The only problematic analogy in the table is hydraulic resistance, because this quantity is usually not constant. It is typically a nonlinear function of flow rate and geometry. Analogies can also be extended to other phenomena such as heat transfer, where temperature difference is the “effort,” heat flow is the “flow,” the amount of heat transferred is the “displacement,” heat capacity due to mass and specific heat is “capacitance,” and thermal resistance due to convection and conduction is “resistance.” However, heat transfer and many other phenomena cannot be adequately modeled by second-order linear differential equations, so there are no direct analogies for the relations given in the table.

Figure 4.21 illustrates an example of electrical, mechanical, and hydraulic system analogies along with their governing equations. Each of these systems is described by differential equations of exactly the same form. The only differences are the constant parameters that describe the analogous elements. Any quantity in one system is directly analogous to a quantity in each of the other two systems. For example, the capacitor in the electrical system is analogous to the spring in the mechanical system and to the tank in the hydraulic system, and the current through the capacitor ($I_2 = I_1 - I_3$) is analogous to the rate of compression of the spring ($v_2 = v_1 - v_3$) in the mechanical system and to the flow rate into the tank ($Q_2 = Q_1 - Q_3$) in the hydraulic system.

Knowledge of these analogies helps one gain a deeper understanding and intuitive feel for how different systems respond. For example, if one has difficulty relating to how an electrical circuit functions, one can visualize the mechanical equivalent instead. This can be helpful, especially to mechanical engineers who sometimes find electrical circuits elusive. The analogies also provide a framework to model and analyze a great variety of systems in a generic form. An understanding of the characteristics and analysis of one type of system can directly apply to any other system.

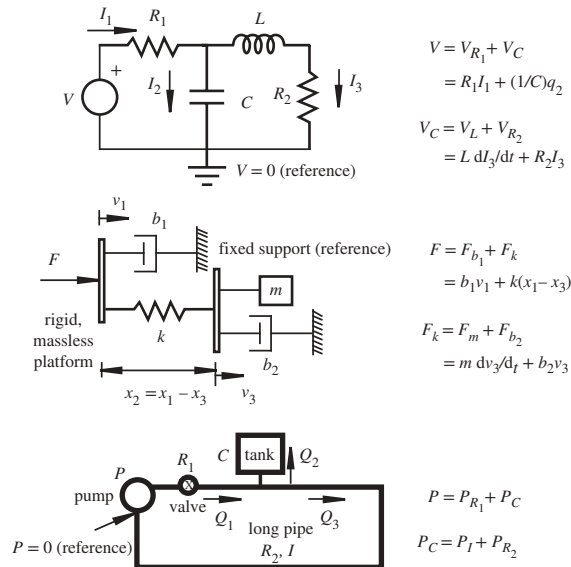


Figure 4.21 Example of system analogies.

In the past, before the advent of digital computers, modeling analogies were essential in the application of analog computers to simulating and analyzing the behavior of various types of systems. The procedure was to develop an electrical system analogous to the physical system of interest; build the analogous electrical system with the aid of an analog computer, which provided scaling, integration, differentiation, mixing, and other functions; and perform simulations by providing inputs in the form of voltage signals resulting in voltage or current outputs analogous to quantities of interest in the physical system being simulated. As an example, the behavior of the mechanical system shown in Figure 4.21 could be studied by building the electrical circuit in the figure with $C = c/k$, $R_1 = c \cdot b_1$, $R_2 = c \cdot b_2$, and $L = c \cdot m$, where c is some constant scaling factor. Predicting the force on and speed of the mass m given some applied force $F(t)$ would be a simple matter of applying $V(t) = c \cdot F(t)$ volts to the circuit and monitoring the voltage across and the current through the inductor. The force and speed that would be experienced by the mass in the actual mechanical system would be $F_m = (V_L/c)$ and $v_m = (I_L/c)$. Before the availability of numerical integration simulation software on digital computers, this was the only method for simulating the behavior of complex physical systems.

■ CLASS DISCUSSION ITEM 4.11

Initial Condition Analogy

What is the electrical analogy for an initial displacement of a spring in a mechanical system? In other words, what is the corresponding initial condition in the electrical system?

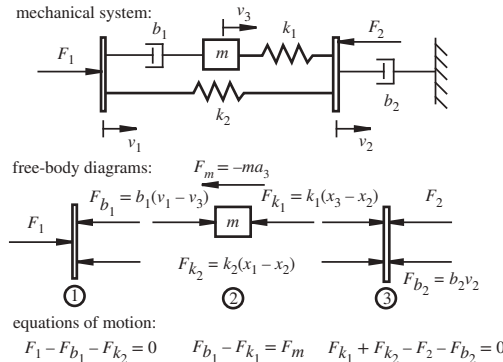


Figure 4.22 Mechanical system analogy example.

The following procedure facilitates converting from a system in one form to an analogous system in some other form. As an illustrative example, the mechanical system shown in Figure 4.22 is converted to its analogous electrical system.

Steps in Converting from One System to an Analogous System

1. Label the flows with the appropriate sign for each element in the system and its analogy.

The algebraic sign given to a flow depends on the direction of the effort on the element. For the example in Figure 4.22, the applied load F_1 is in the direction of speed v_1 , so its flow is v_1 , but applied load F_2 is in the opposite direction to v_2 , so its flow is $-v_2$. For the spring and damper flows, because the forces are drawn assuming compression, the flow for b_1 is $(v_1 - v_3)$ and the flow for k_1 is $(v_3 - v_2)$, both of which are rates of compression. The quantities for the analogous system are obtained by direct substitution with quantities based on Table 4.1. The flows and analogies for the entire example are shown in the following table.

Mechanical element	Mechanical flow	Electrical flow	Electrical element
F_1	v_1	I_1	V_1
b_1	$v_1 - v_3$	$I_1 - I_3$	R_1
m	v_3	I_3	L
k_1	$v_3 - v_2$	$I_3 - I_2$	C_1
k_2	$v_1 - v_2$	$I_1 - I_2$	C_2
b_2	v_2	I_2	R_2
F_2	$-v_2$	$-I_2$	V_2

2. Formulate the system equations at each node using the equations of motion ($\Sigma F = ma$) for mechanical systems or KVL loop equations for electrical systems.

For example, see the free-body diagrams and system equations in Figure 4.22. Note that for the massless, rigid platforms, the equation is of the form $\Sigma F = 0$, because they are assumed to have negligible mass. For the mass m , the form

is $\Sigma F = ma$. Or, alternatively, the inertial term (ma) can be considered as an inertial force ($F_m = -ma$) as shown in Figure 4.22. In this case, the system equation is again of the form $\Sigma F = 0$.

3. *Pick an element to start with and begin constructing the schematic for the analogy using the flows for guidance. It is best to start with an element that is embedded in the system (i.e., its flow affects many other elements), although any element would suffice.*

Figure 4.23 shows how the schematic is started, beginning with inductor L (mass m) and recursively branching to other elements that involve its flow (I_3). Note that the free-body diagram (FBD) or KVL equations and the element flow relationships need to be enforced as the schematic is constructed. The completed circuit is shown in Figure 4.24.

4. *Verify the graph with the analogous system equations.*

For example, the KVL loop equations indeed are the same form as the free-body diagram equations of motion (see Figures 4.22 and 4.24).

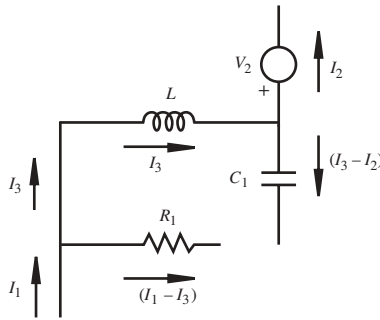


Figure 4.23 Beginning the analog schematic.

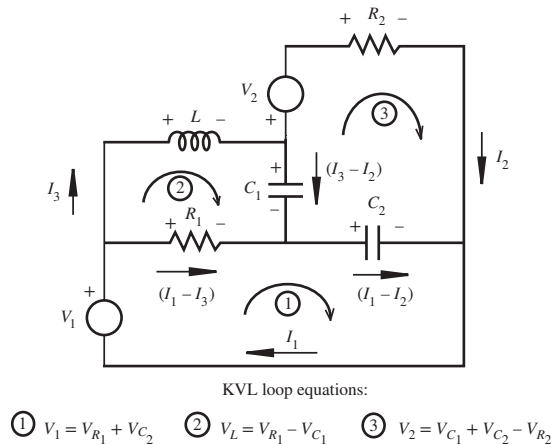


Figure 4.24 Electrical system analogy example.

■ CLASS DISCUSSION ITEM 4.12

Measurement System Physical Characteristics

Inertia, capacitance, and damping are almost always present in a measurement system. Sometimes these characteristics are desirable; other times they are undesirable. Think of examples of measurement systems containing mechanical, electrical, or hydraulic components and discuss the advantages and disadvantages of changing the physical characteristics of the system. Also describe how these changes might be made.

QUESTIONS AND EXERCISES

Section 4.2 Amplitude Linearity

- 4.1. If the following input (V_{in}) and output (V_{out}) relationships exist for different measurement systems, indicate whether each is linear or nonlinear?
- $V_{out}(t) = 5 V_{in}(t)$
 - $V_{out}(t)/V_{in}(t) = 5t$
 - $V_{out}(t) = V_{in}(t) + 5$
 - $V_{out}(t) = V_{in}(t) + V_{in}(t)$
 - $V_{out}(t) = V_{in}(t) \times V_{in}(t)$
 - $V_{out}(t) = V_{in}(t) + 10t$
 - $V_{out}(t) = V_{in}(t) + \sin(5)$

Section 4.3 Fourier Series Representation of Signals

- 4.2. What is the Fourier series and fundamental frequency (in hertz) of the waveform $f(t) = 5 \sin(2\pi t)$?
- 4.3. What is the Fourier series and fundamental frequency (in rad/sec) of a standard U.S. household AC voltage?
- 4.4. Verify that Equations 4.7 through 4.9 are equivalent to Equation 4.3.
- 4.5. Show that the Fourier series coefficients A_n for the square wave defined by Equation 4.10 are 0.
- 4.6. The discrete Fourier series representation of a half-sine-wave pulse train waveform is mathematically represented as

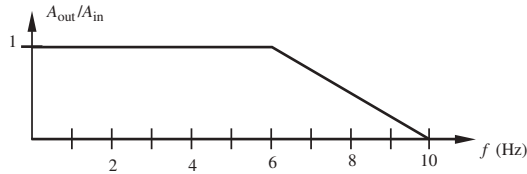
$$V(t) = \frac{1}{\pi} + \frac{\sin(2\pi t)}{2} - \frac{2}{\pi} \left[\frac{\cos(4\pi t)}{1 \cdot 3} + \frac{\cos(8\pi t)}{3 \cdot 5} + \frac{\cos(12\pi t)}{5 \cdot 7} + \dots \right]$$

Using a computer plotting application, plot three cycles of $V(t)$ displaying

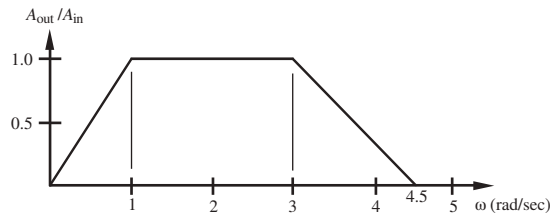
- DC component + fundamental (first harmonic)
- DC component + first 10 harmonics (Note that some harmonics have zero amplitude.)
- DC component + as many harmonics as you think are necessary to provide a good reproduction of the waveform

Section 4.4 Bandwidth and Frequency Response

- 4.7.** Given the following measurement system frequency response curve with a linear scale on the vertical axis,
- What is the bandwidth of the measurement system?
 - If the input signal (V_{in}) is a 2 V, peak-to-peak, square wave of period 1 sec, what will the steady state output signal ($V_{out}(t)$) from the measurement system be? Use the square-wave Fourier series representation given in Equation 4.15 or 4.16 for $V_{in}(t)$.
 - Plot the resulting output on a computer for $t = 0$ to 2 sec.



- 4.8.** For an RC low-pass filter with $R = 1 \text{ k}\Omega$ and $C = 1 \text{ }\mu\text{F}$,
- What is the bandwidth of the filter?
 - If the input is a 2 V, peak-to-peak, square wave of period 1 sec, what will the filter output be? Use the square wave Fourier series representation given in Equation 4.15 or 4.16 for $V_{in}(t)$.
 - Plot the resulting output on a computer for $t = 0$ to 2 sec.
- 4.9.** Solve Question 4.8 with $R = 100 \text{ k}\Omega$ instead.
- 4.10.** What is the bandwidth (in Hz) of a system with the frequency response that follows?



- 4.11.** If a signal is given by

$$F(t) = \sum_{n=1}^5 n \sin(n\omega t)$$

where $\omega = 1 \text{ rad/sec}$,

- What is the range of frequencies of the signal?
- Plot the spectrum of $F(t)$.
- Assuming the signal is being measured by a measurement system with the frequency response curve shown in Question 4.10, plot the spectrum of the resulting output of the system.

- 4.12. Determine and plot the frequency response curve for a high-pass filter (see Example 4.1). Also derive an expression for the cutoff frequency.
- 4.13. Derive an expression for the phase angle between the output and input voltages of the low-pass filter in Example 4.1. Plot the result for frequencies between 0 and 2.5 times the cutoff frequency.
- 4.14. Document a complete and thorough answer to Class Discussion Item 4.2.

Section 4.6 Distortion of Signals

- 4.15. Using the Fourier series representation of a square wave in Equation 4.15 or 4.16, plot a square wave using 20 harmonics. Then plot it with the first three harmonics attenuated by 1/4. Finally, plot it with the first three harmonics unattenuated and the next 17 attenuated by 1/4. What do you conclude about the influence of the amplitudes of low and high harmonics?
- 4.16. Plot the frequency response curves for the exponential attenuation terms in Class Discussion Item 4.4.

Section 4.8 Zero-Order System

- 4.17. A simple static spring scale is an example of a zero-order system where the input is the mass to be measured and the output is the calibrated deflection of the spring. Given this, what is the gain or sensitivity of the scale?
- 4.18. We generally assume that an oscilloscope is a zero-order measurement system. Why is this so? When will this assumption be in error?

Section 4.9 First-Order System

- 4.19. Relate the time constant, cutoff frequency, and bandwidth for the low-pass filter circuit shown in Example 4.1 by writing a general first-order differential equation for the circuit. What is the dependent variable in the differential equation? Write an expression for the output voltage as a function of time $V_{\text{out}}(t)$ for a step input voltage of amplitude A_i . Assume the capacitor is discharged to begin with.
- 4.20. In Section 3.3.1, analyze the LR circuit in Figure 3.10b and derive an equation for how the current changes over time. Also determine the time constant for the rate of current dissipation.
- 4.21. A simple glass bulb thermometer is an example of a first-order system where the input is the surrounding temperature (T_{in}) and the output is the temperature of the liquid inside the bulb (T_{out}), which expands to provide a reading on a scale. Using basic heat transfer principles, where the rate of convective heat transfer to the liquid equals the rate of change of internal energy of the fluid, derive the system equation and put it in standard form. Identify the time constant and relate the heat transfer parameters and fluid properties to the electrical parameters in an RC circuit (see Question 4.19). The parameters in your equation should include the fluid mass (m) and specific heat (c), and the bulb external area (A) and heat transfer coefficient (h).
- 4.22. The following set of data were collected from a system. Would it be appropriate to assume that this system is first order? If so, find the time constant of the system. Also, what is an approximate value for the static sensitivity?

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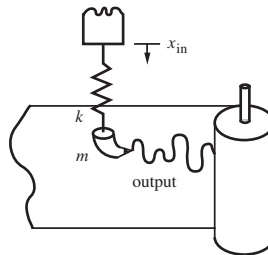
t	$X_{\text{out}}(t)$
0.0	0.0
0.1	1.4
0.2	2.3
0.3	3.0
0.4	3.6
0.5	4.1
0.6	4.2
0.7	4.6
0.8	4.7
0.9	4.8
1.0	4.9

Section 4.10 Second-Order System

- 4.23. Is the damped natural frequency greater or smaller than the natural frequency of a second-order system? Explain why.
- 4.24. Draw a schematic and write the system equation for an example second-order system for each of the following categories:
- mechanical rotary
 - electrical
 - hydraulic
- 4.25. Use the procedure presented in Section 4.10.2 to derive the amplitude ratio and phase relationship for a first-order system expressed in standard form. Mathcad/Matlab Example 4.7 shows plots of the results.
- 4.26. For a spring-mass-damper system with $F_{\text{ext}}(t) = 20 \sin(0.75t)$ N, $m = 10$ kg, $k = 12$ N/m, and $b = 10$ Ns/m, what is the equation for the steady state sinusoidal response of $x(t)$?
- 4.27. A cheap, mechanically actuated, strip chart recording system consisting of a plotter head of mass m driven by an elastic belt of stiffness k is illustrated in the following figure.

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4.7 First-order
system frequency
response



The input displacement x_{in} is coupled mechanically to the pen head through the spring. The spring constant k is 32.4 N/m and the mass of the pen head is 0.10 kg. Derive the differential equation of motion for the pen head, given the displacement input. Assume that the damping constant between the pen and paper is 10 Ns/m. Using the procedure in Section 4.10.2, determine the steady state output displacement magnitude and phase angle for each steady state input that follows. Explain the differences between the output and input displacements and phase angles.

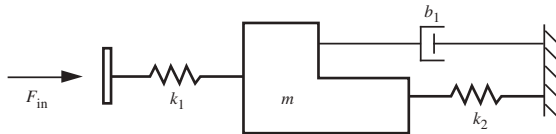
(continued)

- a. $x_{\text{in}} = 0.05 \sin(10t)$
- b. $x_{\text{in}} = 0.05 \sin(1000t)$
- c. $x_{\text{in}} = 0.05 \sin(10,000t)$

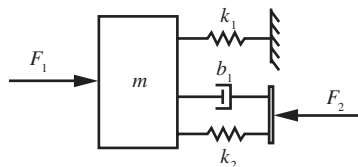
- 4.28. Document a complete and thorough answer to Class Discussion Item 4.7.
- 4.29. Derive the expression for the step response $x(t)$ in Design Example 4.1.
- 4.30. Document a complete and thorough answer to Class Discussion Item 4.10.

Section 4.11 System Modeling and Analogies

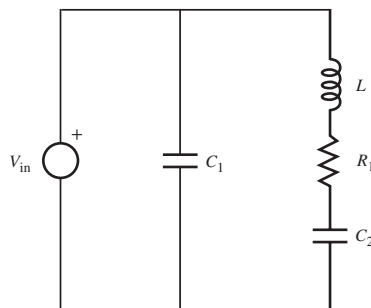
- 4.31. Using the capacitor energy storage equation, derive the expression for the capacitance of a cylindrical tank of diameter D and fluid height h holding bottom-fed fluid of specific weight γ .
- 4.32. Using the inertia energy storage equation, derive the expression for the inertance of the fluid (of density ρ) in a straight pipe of length L and cross-sectional area A . Start by applying $F = ma$ to a control volume surrounding the fluid.
- 4.33. Convert the translational mechanical system shown to an analogous electrical system.



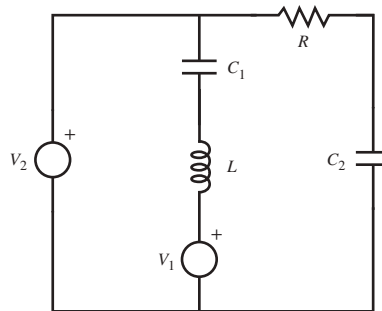
- 4.34. Convert the following translational mechanical system to an analogous electrical system.



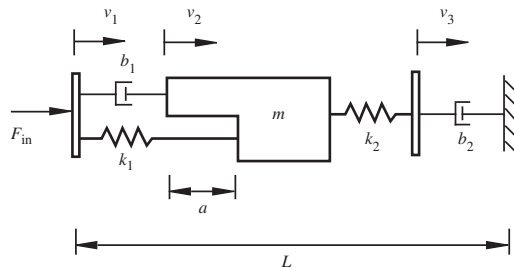
- 4.35. Convert the following electrical system to an analogous hydraulic system.



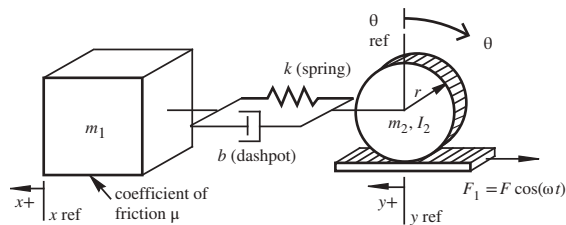
4.36. Convert the following electrical circuit to an analogous mechanical system:



4.37. For the translational mechanical system that follows, draw free-body diagrams for each node, list the flow for each element, and construct (draw) an analogous electrical system with all elements and flows labeled.



4.38. For the three-degree-of-freedom mechanical system that follows, draw free-body diagrams for each of the components, carefully showing all external forces and moments. Be sure to show the reference positions for the position variables on the free-body diagrams. Directly from the component free-body diagrams, write down the equations of motion.



BIBLIOGRAPHY

Beckwith, T., Marangoni, R., and Lienhard, J., *Mechanical Measurement*, 6th Edition, Pearson, New York, 2006.

Doebelin, E., *Measurement Systems Application and Design*, McGraw-Hill, New York, 1990.

- Figliola, R. and Beasley, D., *Theory and Design for Mechanical Measurements*, 5th Edition, John Wiley, New York, 2010.
- Holman, J. P., *Experimental Methods for Engineers*, 8th Edition, McGraw-Hill, New York, 2011.
- Ross, S., *Introduction to Ordinary Differential Equations*, 3rd Edition, John Wiley, New York, 1980.
- Shearer, J., Murphy, A., and Richardson, H., *Introduction to System Dynamics*, Addison-Wesley, Reading, MA, 1971.
- Thomson, W., *Theory of Vibration with Applications*, 5th Edition, Pearson, New York, 1997.

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4. Be able to design an inverting amplifier, noninverting amplifier, summer, difference amplifier, instrumentation amplifier, integrator, differentiator, and sample and hold amplifier
5. Understand the characteristics and limitations of a “real” operational amplifier

5.1 INTRODUCTION

Since electrical circuits occur in virtually all mechatronic and measurement systems, it is essential that engineers develop a basic understanding of the acquisition and processing of electrical signals. Often these signals come from transducers, which convert physical quantities (e.g., temperature, strain, displacement, flow rate) into currents or voltages, usually the latter. The transducer output is usually described as an **analog signal**, which is continuous and time varying.

Often the signals from transducers are not in the form we would like them to be. They may

- Be too small, usually in the millivolt range
- Be too “noisy,” usually due to electromagnetic interference
- Contain the wrong information, sometimes due to poor transducer design or installation
- Have a DC offset, usually due to the transducer and instrumentation design

Many of these problems can be remedied, and the desired signal information extracted through appropriate analog signal processing. The simplest and most common form of signal processing is amplification, where the magnitude of the voltage signal is increased. Other forms include signal inversion, differentiation, integration, addition, subtraction, and comparison.

Analog signals are very different from digital signals, which are discrete, using only a finite number of states or values. Since digital devices like microcontrollers require digital signals, any application involving digital measurement or control requires analog-to-digital conversion. This chapter covers the basic elements of analog signal processing including the design and analysis of signal processing circuits. The operational amplifier is an integrated circuit used as a building block in many of these circuits. Chapter 6 focuses on digital circuits, and Chapter 8 deals with converting analog signals into a format that can be processed by digital devices such as microcontrollers.

5.2 AMPLIFIERS

People have spent their lives studying and writing about amplifiers, so we cannot expect to do justice to the subject in a few pages. However, we will look at the salient features of amplifiers and determine how we may design one using integrated circuits.

Ideally, an **amplifier** increases the amplitude of a signal without affecting the phase relationships of different components of the signal. When choosing or designing

an amplifier, we must consider size, cost, power consumption, input impedance, output impedance, gain, and bandwidth. Physical size depends on the components used to construct the amplifier. Prior to the 1960s, vacuum tube amplifiers were common, but they were heavy power consumers with significant heat dissipation. Portable units were large and heavy and required frequent battery replacement. Vacuum tube technology has been replaced by **solid state** technology, where charge carriers move through a solid semiconductor material instead of moving through a low-pressure gas contained in bulky tubes. Today, solid state transistors and integrated circuits have dramatically changed amplifier design, resulting in small, cool-running amplifiers. They consume little power and are easily made portable using rechargeable batteries.

Generally, we model an amplifier as a two-port device, with an input and output voltage referenced to ground, as illustrated in Figure 5.1. The voltage **gain** A_v of an amplifier defines the factor by which the voltage is changed:

$$V_{\text{out}} = A_v V_{\text{in}} \quad (5.1)$$

Normally we want an amplifier to exhibit amplitude linearity, where the gain is constant for all frequencies. However, amplifiers may be designed to intentionally amplify only certain frequencies, resulting in a filtering effect. In such cases, the output characteristics are governed by the amplifier's bandwidth and associated cutoff frequencies.

The input impedance of an amplifier, Z_{in} , is defined as the ratio of the input voltage and current:

$$Z_{\text{in}} = V_{\text{in}}/I_{\text{in}} \quad (5.2)$$

Most amplifiers are designed to have a large input impedance so very little current is drawn from the input.

The output impedance is a measure of how much the output voltage changes with a change in output current:

$$Z_{\text{out}} = \Delta V_{\text{out}}/\Delta I_{\text{out}} \quad (5.3)$$

Most amplifiers are designed to have a very small output impedance so the output voltage will not change much as the output current changes.

See Section 2.4 for more information related to input and output impedance. The input impedance of an amplifier is analogous to that of a voltmeter, and the output impedance is analogous to that of a voltage source.

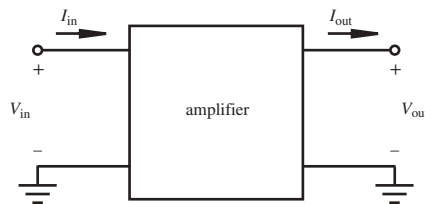


Figure 5.1 Amplifier model.

5.3 OPERATIONAL AMPLIFIERS

The operational amplifier, or **op amp**, is a low-cost and versatile integrated circuit consisting of many internal transistors, resistors, and capacitors manufactured into a single chip of silicon. It can be combined with external discrete components to create a wide variety of signal processing circuits. The op amp is the basic building block for

- Amplifiers
- Integrators
- Summers
- Differentiators
- Comparators
- A/D and D/A converters
- Active filters
- Sample and hold amplifiers

We present most of these applications in subsequent sections. The op amp derives its name from its ability to perform so many different operations.

5.4 IDEAL MODEL FOR THE OPERATIONAL AMPLIFIER

Figure 5.2 shows the schematic symbol and terminal nomenclature for an ideal op amp. It is a differential input, single output amplifier that is assumed to have infinite gain. The two inputs are called the **inverting input**, labeled with a minus sign, and the **noninverting input**, labeled with a plus sign. The ∞ symbol is sometimes used in the schematic to denote infinite gain and the assumption that it is an ideal op amp. The voltages are all referenced to a common ground. The op amp is an **active device** requiring connection to an external power supply, often plus and minus 15 V. The external supply is not normally shown on circuit schematics. Since the op amp is an active device, output voltages and currents can be larger than the signals applied to the inverting and noninverting terminals.

As illustrated in Figure 5.3, an op amp circuit usually includes **feedback** from the output to the negative (inverting) input. This so-called **closed loop** configuration results in stabilization of the amplifier and control of the gain. When feedback is

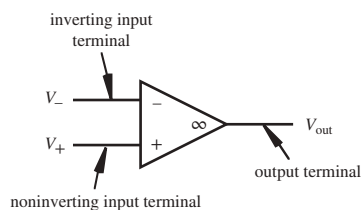


Figure 5.2 Op amp terminology and schematic representation.

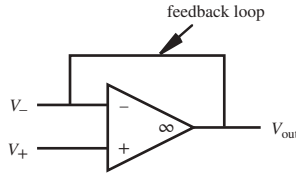


Figure 5.3 Op amp feedback.

absent in an op amp circuit, the op amp is said to have an **open loop** configuration. This configuration results in considerable instability due to the very high gain, and it is seldom used. The utility of feedback will become evident in the examples presented in the following sections.

Figure 5.4 illustrates an ideal model that can aid in analyzing circuits containing op amps. This model is based on the following assumptions that describe an ideal op amp:

1. *It has infinite impedance at both inputs;* hence, no current is drawn from the input circuits. Therefore,

$$I_+ = I_- = 0 \quad (5.4)$$

2. *It has infinite gain.* As a consequence, the difference between the input voltages must be 0; otherwise, the output would be infinite. This is denoted in Figure 5.4 by the shorting of the two inputs. Therefore,

$$V_+ = V_- \quad (5.5)$$

Even though we indicate a short between the two inputs, we assume no current may flow through this short.

3. *It has zero output impedance.* Therefore, the output voltage does not vary with output current.

Note that V_{out} , V_+ , and V_- are all referenced to a common ground. Also, for stable linear behavior, there must be feedback between the output and the inverting input.

These assumptions and the model may appear illogical and confusing, but they provide a close approximation to the behavior of a real op amp when used in a circuit

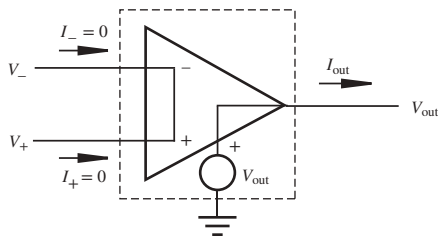


Figure 5.4 Op amp equivalent circuit.

that includes negative feedback. With the aid of this ideal model, we need only Kirchhoff's laws and Ohm's law to completely analyze op amp circuits.

Actual op amps are usually packaged in an eight-pin dual in-line package (DIP) integrated circuit (IC), sometimes called a chip. The designation for a general purpose op amp produced by many IC manufacturers is 741. It is illustrated in Figure 5.5 with its pin configuration (pin-out). As with all ICs, one end of the chip is marked with an indentation or spot, and the pins are numbered counterclockwise (looking at the top of the IC) and consecutively starting with 1 at the left side of the marked end. For a 741 series op amp, pin 2 is the inverting input, pin 3 is the noninverting input, pins 4 and 7 are for the external power supply, and pin 6 is the op amp output. Pins 1, 5, and 8 are not normally used, and no connections are required. Figure 5.6 illustrates the internal design of a 741 IC available from National Semiconductor. Note that the circuits are composed of transistors, resistors, and capacitors that are easily manufactured on a single silicon chip. The most valuable details for the user are the input and output parts of the circuit having characteristics that affect externally connected components.

The manufacture of integrated circuits is very involved, requiring extremely expensive equipment. Video Demo 5.1 shows various common packages in which ICs are made available, and Video Demos 5.2 through 5.4 describe and illustrate all of the steps of the manufacturing process. Fortunately, due to high production volume of components used in consumer and industrial applications, the economy of scale prevails, and ICs can be sold at very affordable prices.

Many different op amp designs are available from IC manufacturers. The input impedances, bandwidth, and power ratings can vary significantly. Also, some require only a single-output (unipolar) power supply. Although the 741 is widely used, another common op amp is the TL071 manufactured by Texas Instruments. Its pin configuration is identical to the 741, but because it has FET inputs, it has a larger input impedance and a wider bandwidth.

IC manufacturers provide complete information on their devices in documents called **data sheets**. Internet Links 5.1 and 5.2 point to the complete data sheets for both the 741 and TL071. If you don't have much experience looking at these data sheets, they can be very overwhelming. However, they contain all the information you would ever need to use the devices. Useful information includes the device pin-out (e.g., Figure 5.5), input and output current and voltage specifications, voltage source requirements, and impedances. Section 5.14 at the end of this chapter provides some guidance on specific things to look for in an op data sheet.

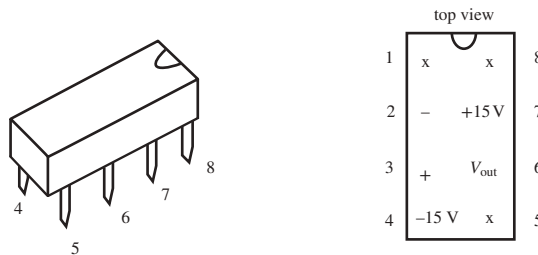
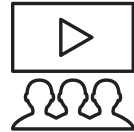


Figure 5.5 741 op amp pin-out.



Video Demo

5.1 Integrated circuits

5.2 Integrated circuit manufacturing process stages

5.3 Chip manufacturing process

5.4 How a CPU is made



Internet Link

5.1 μ A741 op amp data sheet

5.2 TL071 FET input op amp data sheet

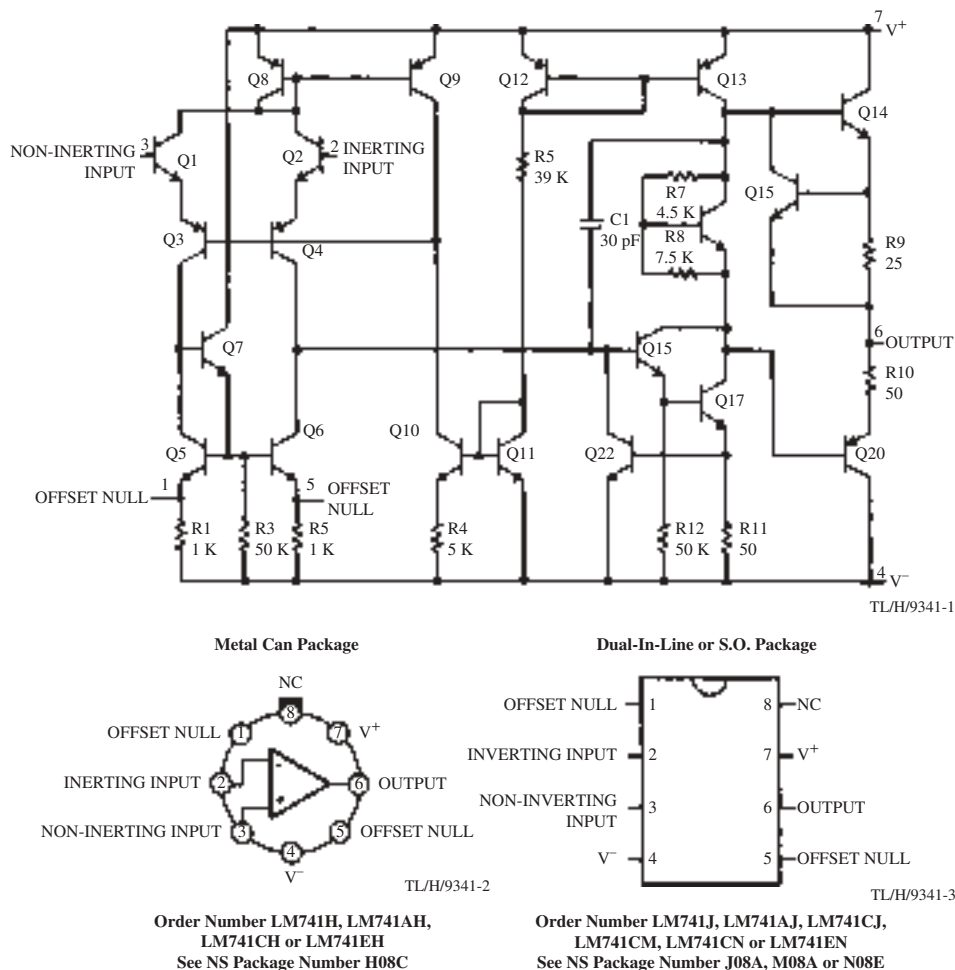


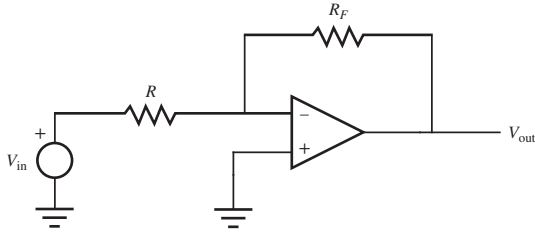
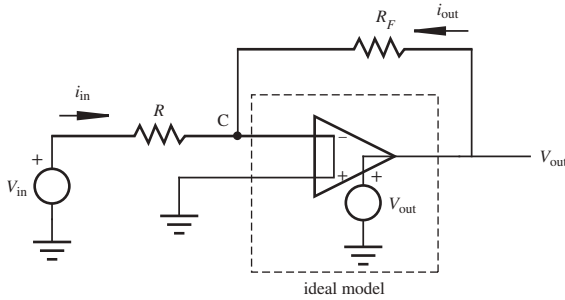
Figure 5.6 741 internal design.

Source: National Semiconductor, Santa Clara, CA.

5.5 INVERTING AMPLIFIER

An **inverting amplifier** is constructed by connecting two external resistors to an op amp as shown in Figure 5.7. As the name implies, this circuit inverts and amplifies the input voltage. Note that the resistor R_f forms the feedback loop. This feedback loop always goes from the output to the inverting input of the op amp, implying negative feedback.

We now use Kirchhoff's laws and Ohm's law to analyze this circuit. First, we replace the op amp with its ideal model shown within the dashed box in Figure 5.8.

**Figure 5.7** Inverting amplifier.**Figure 5.8** Equivalent circuit for an inverting amplifier.

Applying Kirchhoff's current law at node C and utilizing assumption 1, that no current can flow into the inputs of the op amp,

$$i_{\text{in}} = -i_{\text{out}} \quad (5.6)$$

Also, because the two inputs are assumed to be shorted in the ideal model, C is effectively at ground potential:

$$V_C = 0 \quad (5.7)$$

Because the voltage across resistor R is $V_{\text{in}} - V_C = V_{\text{in}}$, from Ohm's law,

$$V_{\text{in}} = i_{\text{in}} R \quad (5.8)$$

and because the voltage across resistor R_F is $V_{\text{out}} - V_C = V_{\text{out}}$,

$$V_{\text{out}} = i_{\text{out}} R_F \quad (5.9)$$

Substituting Equation 5.6 into Equation 5.9 gives

$$V_{\text{out}} = -i_{\text{in}} R_F \quad (5.10)$$

Dividing Equation 5.10 by Equation 5.8 yields the input/output relationship:

$$\frac{V_{\text{out}}}{V_{\text{in}}} = -\frac{R_F}{R} \quad (5.11)$$

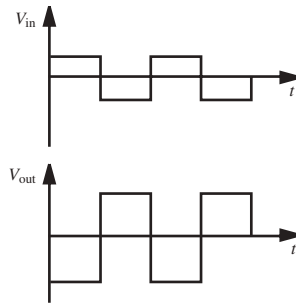


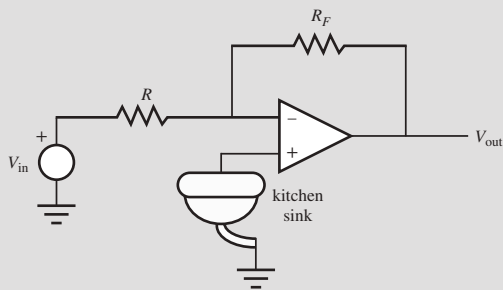
Figure 5.9 Illustration of inversion.

Therefore, the voltage gain of the amplifier is determined simply by the external resistors R_F and R , and it is always negative. The reason this circuit is called an inverting amplifier is that it reverses the polarity of the input signal. This results in a phase shift of 180° for periodic signals. For example, if the square wave V_{in} shown in Figure 5.9 is connected to an inverting amplifier with a gain of -2 , the output V_{out} is inverted and amplified, resulting in a larger amplitude signal 180° out of phase with the input.

■ CLASS DISCUSSION ITEM 5.1

Kitchen Sink in an Op Amp Circuit

Consider the following op amp circuit:



What is the effect of the kitchen sink at the noninverting input of the op amp?

5.6 NONINVERTING AMPLIFIER

The schematic of a **noninverting amplifier** is shown in Figure 5.10. As the name implies, this circuit amplifies the input voltage without inverting the signal. Again, we can apply Kirchhoff's laws and Ohm's law to determine the voltage gain of this amplifier. As before, we replace the op amp with the ideal model shown in the dashed box in Figure 5.11.

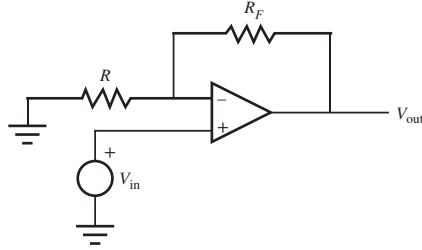


Figure 5.10 Noninverting amplifier.

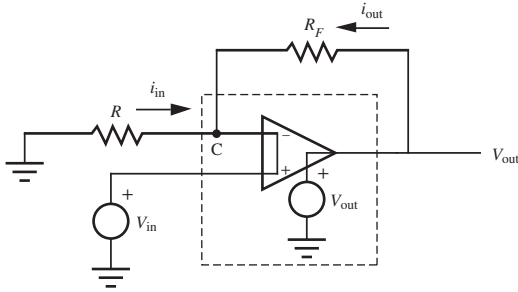


Figure 5.11 Equivalent circuit for a noninverting amplifier.

The voltage at node C is V_{in} because the inverting and noninverting inputs are at the same voltage. Therefore, applying Ohm's law to resistor R ,

$$i_{in} = \frac{-V_{in}}{R} \quad (5.12)$$

and applying it to resistor R_F ,

$$i_{out} = \frac{V_{out} - V_{in}}{R_F} \quad (5.13)$$

Solving Equation 5.13 for V_{out} gives

$$V_{out} = i_{out} R_F + V_{in} \quad (5.14)$$

Applying KCL at node C gives

$$i_{in} = -i_{out} \quad (5.15)$$

so Equation 5.12 can be written as

$$V_{in} = i_{out} R \quad (5.16)$$

Using Equations 5.14 and 5.16, the voltage gain can be written as

$$\frac{V_{out}}{V_{in}} = \frac{i_{out} R_F + V_{in}}{V_{in}} = \frac{i_{out} R_F + i_{out} R}{i_{out} R} = 1 + \frac{R_F}{R} \quad (5.17)$$

Therefore, the noninverting amplifier has a positive gain greater than or equal to 1. This is useful in isolating one portion of a circuit from another by transmitting a scaled voltage without drawing appreciable current.

If we let $R_F = 0$ and $R = \infty$ in the noninverting op amp circuit in Figure 5.10, the resulting circuit can be represented as shown in Figure 5.12. This circuit is known as a **buffer** or **follower** because $V_{\text{out}} = V_{\text{in}}$. It has a high input impedance and low output impedance. This circuit is useful in applications where you need to couple to a voltage signal without loading the source of the voltage. The high input impedance of the op amp effectively **isolates** the source from the rest of the circuit. Figure 5.13 shows a very useful follower circuit that creates a stable voltage reference (V_{ref}) from a larger supply voltage (V_s) using a voltage divider, where the potentiometer (R_p) resistance can be varied to create a wide voltage range. If the follower were not there, and the output of the voltage divider were attached directly to a circuit or device instead, the resulting voltage would vary with the amount of current flowing into the circuit or device. Since the input impedance of the follower is large, this effect is not an issue with the full circuit, even when it is attached to a load and current flows (and changes). Lab Exercise 6 explores this characteristic by showing how to tap a voltage in a resistor circuit without affecting the currents in the circuit.



Lab Exercise

Lab 6

Operational
amplifier circuits

■ CLASS DISCUSSION ITEM 5.2

Positive Feedback

Ideally, what would happen to the output of the buffer amplifier shown in Figure 5.12 if V_{in} was applied to the inverting input and feedback was from the output to the noninverting input instead?

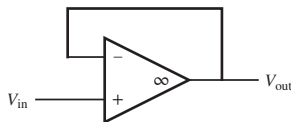


Figure 5.12 Buffer or follower.

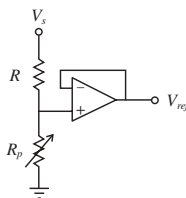


Figure 5.13 Follower voltage reference.

■ CLASS DISCUSSION ITEM 5.3

Example of Positive Feedback

A good example of positive feedback is the effect Jimi Hendrix used to achieve when he would move his guitar close to the front of his amplifier speaker. Describe the effect of this technique and describe what is going on physically. Video Demo 5.5 demonstrates how positive feedback can be used to accentuate string harmonics (modes of vibration), and Video Demo 5.6 shows an example of Jimi's performance style, which was quite unique and impressive.



Video Demo

5.5 Guitar harmonic feedback demonstration

5.6 Jimi Hendrix ... the master of feedback

■ CLASS DISCUSSION ITEM 5.4

Voltage Divider with No Follower

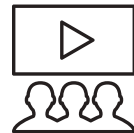
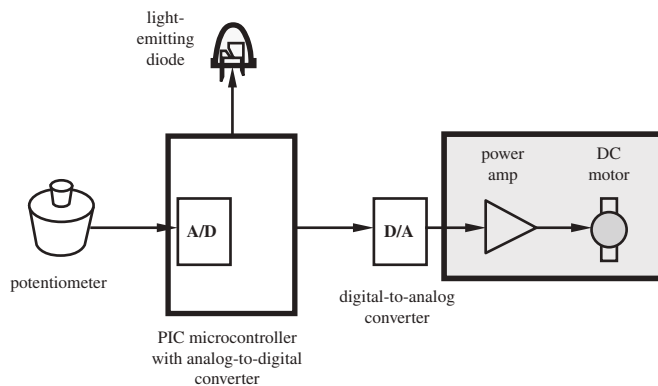
With the voltage-divider follower circuit in Figure 5.13, what effect does the choice of resistance values have? Also, explain in detail what would happen if the follower circuit were not included and the reference voltage were used to source current to another circuit or device.

THREADED DESIGN EXAMPLE

DC motor power-op-amp speed controller—Power amp motor driver

A.3

The figure below shows the functional diagram for Threaded Design Example A (see Section 1.3 and Video Demo 1.6), with the portion described here highlighted.



Video Demo

1.6 DC motor power-op-amp speed controller

The D/A converter outputs a voltage directly related to the potentiometer position. However, the D/A converter's output current is limited and not enough to drive a motor. A power op amp circuit, configured as a noninverting amplifier, can drive the motor at the higher currents needed. In effect, the power amp will serve as a buffer between the D/A converter and the motor. The circuit below shows the components used along with their interconnections.

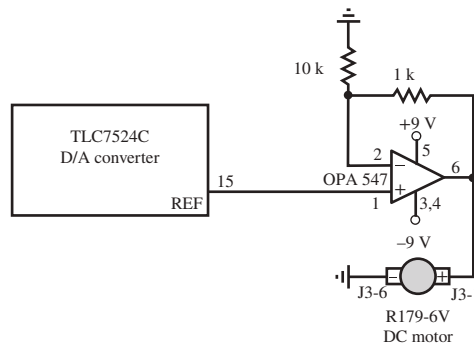
**Internet Link**

1.4 Threaded design example components

1.5 Digikey electronics supplier

1.6 Jameco electronics supplier

As shown, the OPA547 can be powered by a bipolar ($\pm$) 9 V supply (instead of a common bipolar 15 V supply). In Video Demo 1.6, we show how these voltages can be created with either a standard laboratory power supply or with two 9 V batteries wired in series. With an input resistor of 10 k Ω and a feedback resistor of 1 k Ω , from Equation 5.17, the power amp circuit has a gain of 1.1. Therefore, the voltage from the D/A converter is not amplified very much, but the circuit is able to source ample current to the motor. Op amp components that are designed to output significant current are called power op amps. The OPA547 is one such op amp. As with all of the design examples, if you want more information about any of the components used, see Internet Links 1.4 through 1.6.



5.7 SUMMER

The **summer** op amp circuit shown in Figure 5.14 is used to add analog signals. By analyzing the circuit with

$$R_1 = R_2 = R_F \quad (5.18)$$

we can show (Question 5.8) that

$$V_{\text{out}} = -(V_1 + V_2) \quad (5.19)$$

Therefore, the circuit output is the negative sum of the inputs.

5.8 DIFFERENCE AMPLIFIER

The **difference amplifier** circuit shown in Figure 5.15 is used to subtract analog signals (see Lab Exercise 6). In analyzing this circuit, we can use the principle of **superposition**, which states that, whenever multiple inputs are applied to a linear system (e.g., an op amp circuit), we can analyze the circuit and determine the response for each of the individual inputs independently. The sum of the individual responses is the overall response to the multiple inputs. Specifically, when the inputs are ideal voltage sources, to analyze the response due to one source, the other sources are shorted. If some inputs are current sources, they are replaced with open circuits.

**Lab Exercise****Lab 6**

Operational amplifier circuits

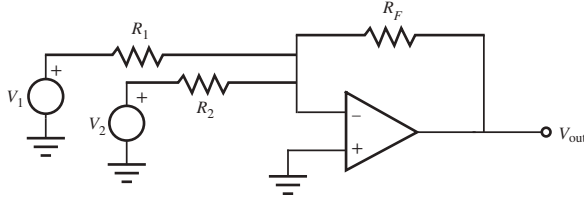


Figure 5.14 Summer circuit.

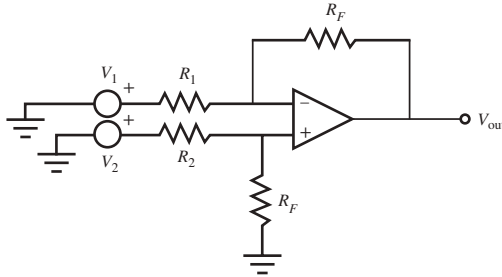


Figure 5.15 Difference amplifier circuit.

The first step in analyzing the circuit in Figure 5.15 is to replace V_2 with a short circuit, effectively grounding R_2 . As shown in Figure 5.16, the result is an inverting amplifier (see Figure 5.7 and Class Discussion Item 5.1). Therefore, from Equation 5.11, the output due to input V_1 is

$$V_{\text{out}_1} = -\frac{R_F}{R_1} V_1 \quad (5.20)$$

The second step in analyzing the circuit in Figure 5.15 is to replace V_1 with a short circuit, effectively grounding R_1 , as shown in Figure 5.17a. This circuit is equivalent to the circuit shown in Figure 5.17b where the input voltage is

$$V_3 = \frac{R_F}{R_2 + R_F} V_2 \quad (5.21)$$

because V_2 is divided between resistors R_2 and R_F .

The circuit in Figure 5.17b is a noninverting amplifier (see Figure 5.10). Therefore, the output due to input V_2 is given by Equation 5.17:

$$V_{\text{out}_2} = \left(1 + \frac{R_F}{R_1}\right) V_3 \quad (5.22)$$

By substituting Equation 5.21, this equation can be written as

$$V_{\text{out}_2} = \left(1 + \frac{R_F}{R_1}\right) \left(\frac{R_F}{R_2 + R_F}\right) V_2 \quad (5.23)$$

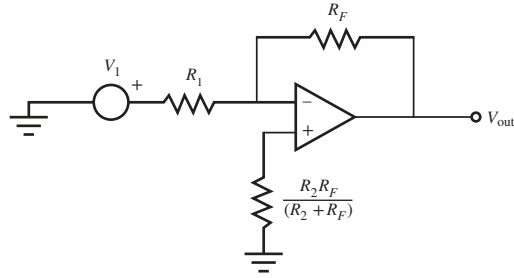


Figure 5.16 Difference amplifier with V_2 shorted.

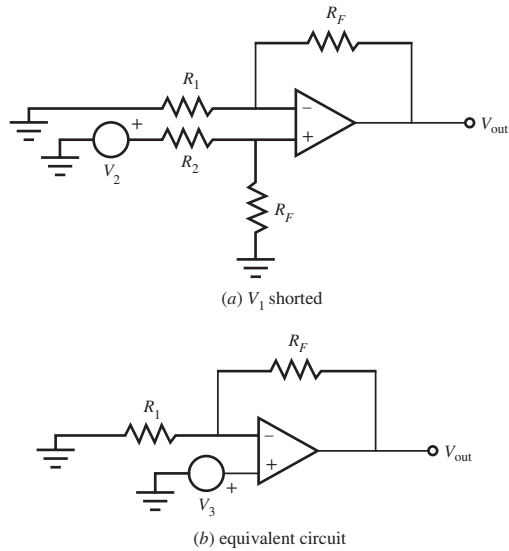


Figure 5.17 Difference amplifier with V_1 shorted.

The principle of superposition states that the total output V_{out} is the sum of the outputs due to the individual inputs:

$$V_{\text{out}} = V_{\text{out}_1} + V_{\text{out}_2} = -\left(\frac{R_F}{R_1}\right) V_1 + \left(1 + \frac{R_F}{R_1}\right) \left(\frac{R_F}{R_2 + R_F}\right) V_2 \quad (5.24)$$

When $R_1 = R_2 = R$, the output voltage is an amplified difference of the input voltages:

$$V_{\text{out}} = \frac{R_F}{R} (V_2 - V_1) \quad (5.25)$$

This result can also be obtained, without using superposition, using the op amp rules, KCL, and Ohm's law (Question 5.10).

5.9 INSTRUMENTATION AMPLIFIER

The difference amplifier presented in Section 5.8 may be satisfactory for low-impedance sources, but its input impedance is too low for high-output impedance sources. Furthermore, if the input signals are very low level and include noise, the difference amplifier is unable to extract a satisfactory difference signal. The solution to this problem is the **instrumentation amplifier**. It has the following characteristics:

- Very high input impedance.
- Large **common mode rejection ratio** (CMRR). The CMRR is the ratio of the difference mode gain to the common mode gain. The **difference mode gain** is the amplification factor for the difference between the input signals, and the **common mode gain** is the amplification factor for the average of the input signals. For an ideal difference amplifier, the common mode gain is 0, implying an infinite CMRR. When the common mode gain is nonzero, the output is nonzero when the inputs are equal and nonzero. It is desirable to minimize the common mode gain to suppress signals such as noise that are common to both inputs.
- Capability to amplify low-level signals in a noisy environment, often a requirement in differential-output sensor signal-conditioning applications.
- Consistent bandwidth over a large range of gains.

Instrumentation amplifiers are commercially available as monolithic ICs (e.g., Analog Devices 524 and 624 and National Semiconductor LM 623). A single external resistor is used to set the gain. This gain can be higher, and is more stable, than gains achievable with a simple difference amplifier.

An instrumentation amplifier can also be constructed with inexpensive discrete op amps and precision resistors as illustrated in Figure 5.18. We analyze this circuit in two parts. The two op amps on the left provide a high-impedance amplifier stage where each input is amplified separately. This stage involves a moderate CMRR. The outputs V_3 and V_4 are supplied to the op amp circuit on the right, which is a difference amplifier with a potentiometer R_5 used to maximize the overall CMRR.

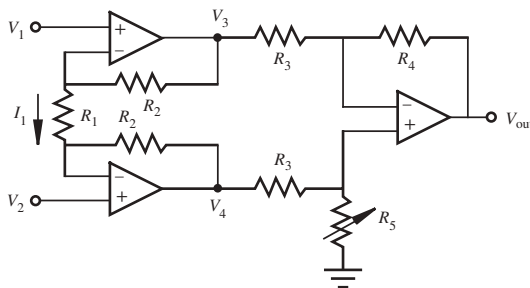


Figure 5.18 Instrumentation amplifier.

We first apply KCL and Ohm's law to the left portion of the circuit to express V_3 and V_4 in terms of V_1 and V_2 . Using the assumptions and rules for an ideal op amp, it is clear that the current I_1 passes through R_1 and both feedback resistors R_2 . Applying Ohm's law to the feedback resistors gives

$$V_3 - V_1 = I_1 R_2 \quad (5.26)$$

and

$$V_2 - V_4 = I_1 R_2 \quad (5.27)$$

Applying Ohm's law to R_1 gives

$$V_1 - V_2 = I_1 R_1 \quad (5.28)$$

To express V_3 and V_4 in terms of V_1 and V_2 , we eliminate I_1 by solving Equation 5.28 for I_1 and substituting it into Equations 5.26 and 5.27. The results are

$$V_3 = \left(\frac{R_2}{R_1} + 1 \right) V_1 - \frac{R_2}{R_1} V_2 \quad (5.29)$$

and

$$V_4 = -\frac{R_2}{R_1} V_1 + \left(\frac{R_2}{R_1} + 1 \right) V_2 \quad (5.30)$$

By analyzing the right portion of the circuit, it can be shown (Question 5.12) that

$$V_{\text{out}} = \frac{R_5(R_3 + R_4)}{R_3(R_3 + R_5)} V_4 - \frac{R_4}{R_3} V_3 \quad (5.31)$$

We can substitute the expressions for V_3 and V_4 from Equations 5.29 and 5.30 into Equation 5.31 to express the output voltage V_{out} in terms of the input voltages V_1 and V_2 . Assuming $R_5 = R_4$, the result is

$$V_{\text{out}} = \left[\frac{R_4}{R_3} \left(1 + 2 \frac{R_2}{R_1} \right) \right] (V_2 - V_1) \quad (5.32)$$

A design objective for the instrumentation amplifier is to maximize the CMRR by minimizing the common mode gain. For a common mode input, $V_1 = V_2$, Equation 5.32 yields an output voltage $V_{\text{out}} = 0$. Hence, the common mode gain is 0, and the CMRR is infinite if $R_5 = R_4$. In practice, the resistances never match exactly. Also, if the temperature varies within the discrete circuit, resistance mismatches are further exaggerated. Using a potentiometer for R_5 , the designer can minimize the mismatch between R_5 and R_4 , resulting in a maximum CMRR.

The problems of resistor matching with discrete components are avoided by using a monolithic instrumentation amplifier constructed with laser-trimmed resistors. These amplifiers have a very high CMRR not usually obtainable with discrete components. In addition, the gain is programmable by selecting an appropriate external resistor R_1 .

5.10 INTEGRATOR

If the feedback resistor of the inverting op amp circuit is replaced by a capacitor, the result is an **integrator** circuit. It is shown in Figure 5.19. Referring to the analysis for the inverting amplifier, Equation 5.9 is replaced by the relationship between voltage and current for a capacitor:

$$\frac{dV_{\text{out}}}{dt} = \frac{i_{\text{out}}}{C} \quad (5.33)$$

Integrating gives

$$V_{\text{out}}(t) = \frac{1}{C} \int_0^t i_{\text{out}}(\tau) d\tau \quad (5.34)$$

where τ is a dummy variable of integration. Since $i_{\text{out}} = -i_{\text{in}}$ and $i_{\text{in}} = V_{\text{in}}/R$,

$$V_{\text{out}}(t) = -\frac{1}{RC} \int_0^t V_{\text{in}}(\tau) d\tau \quad (5.35)$$

Therefore, the output signal is an inverted, scaled integral of the input signal.

■ CLASS DISCUSSION ITEM 5.5

Integrator Behavior

If a DC voltage is applied as an input to an ideal integrator, how does the output change over time? What is the output given a sinusoidal input? What would the result be if a small DC offset were added to the sinusoidal input?

A more practical integrator circuit is shown in Figure 5.20. The resistor R_s placed across the feedback capacitor is called a **shunt resistor**. Its purpose is to limit the low-frequency gain of the circuit. This is necessary because even a small DC offset at the input would be integrated over time, eventually saturating the op amp (see Section 5.14 and Class Discussion Item 5.8). The integrator is useful only when the scaled integral always remains below the maximum output voltage for the op amp. As a good rule of thumb, R_s should be greater than $10R_1$.

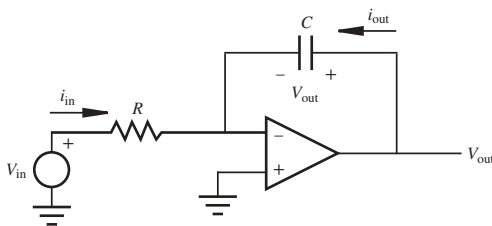


Figure 5.19 Ideal integrator.

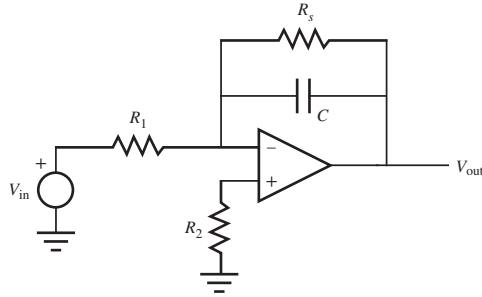


Figure 5.20 Improved integrator.



Lab Exercise

Lab 6

Operational
amplifier circuits



Video Demo

5.7 Op amp
integrator circuit
at different
frequencies

Because of the impedance and frequency response of the feedback circuit containing R_s and C , the circuit in Figure 5.20 acts as an integrator only for a range of frequencies. At very low frequencies, the circuit behaves as an inverting amplifier because the impedance of the feedback loop is effectively R_s because the impedance of C is large at low frequencies. At very high frequencies (i.e., $f \gg 1/R_1C$), the output is attenuated to zero because the R_1C current path is a low-pass filter (see Example 4.1 in Section 4.4). The limited bandwidth of the op amp can also be a factor at very high frequencies (see Section 5.14). Lab Exercise 6 explores, and Video Demo 5.7 demonstrates, how the response of the integrator changes over a large frequency range.

Any DC offset due to the input bias current (see item A in Section 5.14.1) is minimized by R_2 , which should be chosen to approximate the parallel combination of the input and shunt resistors:

$$R_2 = \frac{R_1 R_s}{R_1 + R_s} \quad (5.36)$$

The reason for this is that the input bias current flowing into the inverting terminal is a result of the currents through R_1 and R_s , and the input bias current flowing into the noninverting terminal flows through R_2 . If the voltages generated by the bias current are the same, they have no net effect on the output.

5.11 DIFFERENTIATOR

If the input resistor of the inverting op amp circuit is replaced by a capacitor, the result is a **differentiator** circuit. It is shown in Figure 5.21. Referring to the analysis for the inverting amplifier, Equation 5.8 is replaced by the relationship between voltage and current for a capacitor:

$$\frac{dV_{in}}{dt} = \frac{i_{in}}{C} \quad (5.37)$$

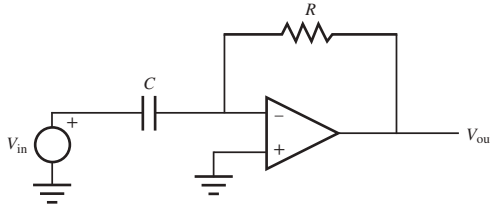


Figure 5.21 Differentiator.

Since $i_{\text{in}} = -i_{\text{out}}$ and $i_{\text{out}} = V_{\text{out}}/R$,

$$V_{\text{out}} = -RC \frac{dV_{\text{in}}}{dt} \quad (5.38)$$

Therefore, the output signal is an inverted, scaled derivative of the input signal.

One note of caution concerning using differentiation in signal processing is that any electrical noise in the input signal will be accentuated in the output. In effect, the differentiator amplifies the fast-changing noise. Integration, on the other hand, has a smoothing effect, so noise is not a concern when using an integrator.

■ CLASS DISCUSSION ITEM 5.6

Differentiator Improvements

Recommend possible improvements to the differentiator circuit in Figure 5.21. Consider the effects of high-frequency noise in the input signal.

■ CLASS DISCUSSION ITEM 5.7

Integrator and Differentiator Applications

Think of various applications for the integrator and differentiator circuits. Consider how a differential equation could be solved with an analog computer. Also consider how to convert between sawtooth and square-wave function generator outputs and how to process position and speed sensor signals.

5.12 SAMPLE AND HOLD CIRCUIT

A **sample and hold** circuit is used extensively in analog-to-digital conversion (discussed in Chapter 8), where a signal value must be stabilized while it is converted to a digital representation. The sample and hold circuit illustrated in Figure 5.22 consists of a voltage-holding capacitor and a voltage follower. With switch S closed,

$$V_{\text{out}}(t) = V_{\text{in}}(t) \quad (5.39)$$

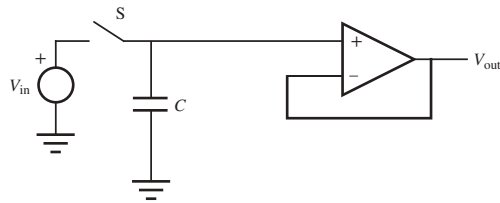


Figure 5.22 Sample and hold circuit.

When the switch is opened, the capacitor C holds the input voltage corresponding to the last sampled value, because negligible current is drawn by the follower. Therefore,

$$V_{\text{out}}(t - t_{\text{sampled}}) = V_{\text{in}}(t_{\text{sampled}}) \quad (5.40)$$

where t_{sampled} is the time when the switch was last opened. Often, an op amp buffer is also used on the V_{in} side of the switch to minimize current drain from the input voltage source V_{in} .

The type of capacitor (see Section 2.10.1) used for this application is important. A low-leakage capacitor such as a polystyrene or polypropylene type would be a good choice. An electrolytic capacitor would be a poor choice because of its high leakage. This leakage would cause the output voltage value to drop during the “hold” period.



Video Demo

4.2 Spectra of whistling and humming, and amplifier saturation

5.13 COMPARATOR

The comparator circuit illustrated in Figure 5.23 is used to determine whether one signal is greater than another. The **comparator** is an example of an op amp circuit where there is no negative feedback and the circuit exhibits infinite gain. The result is that the op amp **saturates**. Saturation implies that the output remains at its most positive or most negative output value. Video Demo 4.2 shows an interesting example of amplifier saturation where an audio amplifier is clipping the output of a sound wave from a microphone.

Certain op amps are specifically designed to operate in saturation as comparators. The output of the comparator is defined by

$$V_{\text{out}} = \begin{cases} +V_{\text{sat}} & V_{\text{in}} > V_{\text{ref}} \\ -V_{\text{sat}} & V_{\text{in}} < V_{\text{ref}} \end{cases} \quad (5.41)$$

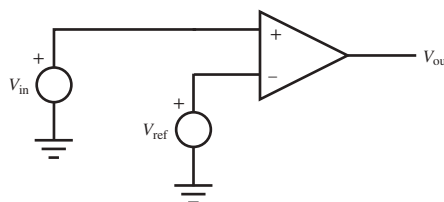


Figure 5.23 Comparator.

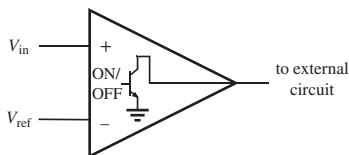


Figure 5.24 Comparator open-collector output.

where V_{sat} is the saturation voltage of the comparator and V_{ref} is the reference voltage to which the input voltage V_{in} is being compared. The positive saturation value is slightly less than the positive supply voltage, and the negative saturation value is slightly greater than the negative supply voltage.

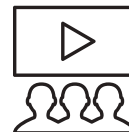
Often, comparators (e.g., LM339) have **open-collector outputs**, where the output states are controlled by an output transistor operating at cutoff or saturation. This type of output, illustrated in Figure 5.24, is called an open-collector output because the collector of the output transistor is not connected internally and requires an external powered circuit. The output transistor is ON (at saturation) and the output is effectively grounded when $V_{\text{in}} > V_{\text{ref}}$, and the output transistor is OFF (at cutoff) and the output is open circuited when $V_{\text{in}} < V_{\text{ref}}$.

5.14 THE REAL OP AMP

An actual operational amplifier deviates somewhat in characteristics from the ideal op amp model used throughout this chapter thus far. The best way to familiarize yourself with any IC, including an op amp, is to review its specifications in the data sheet provided by the manufacturer. Complete descriptions of op amps and many other analog ICs are found online or in manufacturers' *Linear* data books. Some of the more important parameters that can be found on op amp data sheets are described in the next section.

As the ideal operational amplifier model implies, real op amps have a very high input impedance, so very little current is drawn at the inputs. At the same time, there is very little voltage difference between the input terminals. However, the input impedance of a real op amp is not infinite, and its magnitude is an important terminal characteristic of the op amp.

Another important terminal characteristic of any real op amp is the maximum output voltage that can be obtained from the amplifier. Consider an op amp circuit with a gain of 100 set by the external resistors in a noninverting amplifier configuration. For a 1 V input, you would expect a 100 V output. In reality, the maximum voltage output will be about 1.4 V less than the supply voltage to the op amp for a large load impedance. So if a ± 15 V supply is being used, the maximum voltage output would be approximately 13.6 V, and the minimum would be -13.6 V. Attempts to drive the output beyond this range result in saturation and clipping at the maximum output-voltage-swing limits. Video Demo 4.2 shows a good example of amplifier saturation effects. Near the end of the video, a sound wave from a microphone-recorded whistle is being clipped due



Video Demo

4.2 Spectra of whistling and humming, and amplifier saturation

to amplifier saturation. As is clear in the spectrum shown in the video, the chopped corners of the clipped wave result in many added high-frequency components. If this amplified and clipped sound wave were sent to a speaker, it would sound very different from the original whistle sound being recorded.

Two other important characteristics of a real op amp are associated with its response to a step input. When you apply a step input to an amplifier circuit, you ideally would expect a step output. However, as illustrated in Figure 5.25, the output cannot change infinitely fast; instead, it exhibits a ramp from one level to the next. In order to quantify the op amp step response, two parameters are defined:

- **Slew rate**—The maximum time rate of change possible for the output voltage

$$SR = \frac{\Delta V}{\Delta t} \quad (5.42)$$

- **Rise time**—The time required for the output voltage to go from 10% to 90% of its final value. This parameter is specified by manufacturers for specific load and input parameters.

Another important characteristic of a real op amp is its frequency response. An ideal op amp exhibits infinite bandwidth. In practice, however, a real op amp has a finite bandwidth, which is a function of the gain established by external components. To quantify this dependence of bandwidth on the gain, another definition is used: the **gain bandwidth product (GBP)**. The GBP of an op amp is the product of the open-loop gain and the bandwidth at that gain. The GBP is constant over a wide range of frequencies because, as shown in Figure 5.26, typical op amps exhibit a linear loglog relationship between open-loop gain and frequency. Note how the op amp's gain decreases with input signal frequency. Higher-quality op amps have larger GBPs. The open-loop gain is a characteristic of the op amp without feedback. The closed-loop gain is the overall gain of an op amp circuit with feedback. The closed-loop gain is always limited by the open-loop gain of the op amp. For example, a noninverting amplifier with a closed-loop gain of 100 would have a bandwidth of 0 Hz to approximately 10,000 Hz as illustrated in Figure 5.26. The frequency where the open-loop gain curve first starts to limit the closed-loop gain is called the **fall-off frequency**. As you increase the gain of a circuit, you limit its bandwidth. Likewise, if your

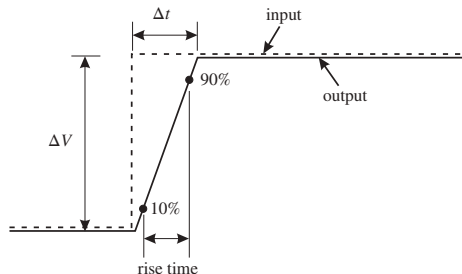


Figure 5.25 Effect of slew rate on a step response

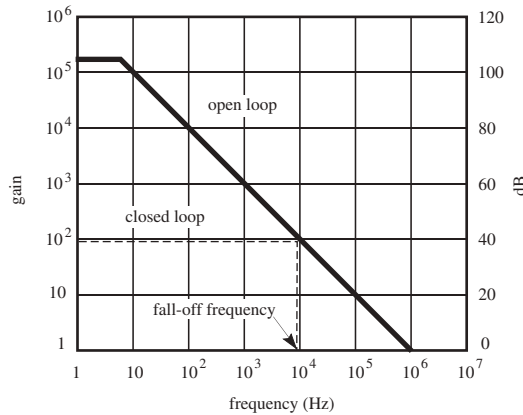


Figure 5.26 Typical op amp open- and closed-loop response.

application requires only a small bandwidth (e.g., in a low-frequency application), larger gains can be used without signal attenuation or distortion.

5.14.1 Important Parameters from Op Amp Data Sheets

Most of the parameters used to describe the characteristics of actual op amps are listed and described here. These parameters are important when designing and using op amp circuits.

A. Input Parameters

- **Input Voltage (V_{icm})**—This is the maximum input voltage that can be applied between either input and ground. In general, this voltage is equal to the supply voltage.
- **Input Offset Voltage (V_{io})**—This is the voltage that must be applied to one of the input terminals, with the other input being at 0 V, to give a zero output voltage. Remember, for an ideal op amp, the output voltage offset is 0.
- **Input Bias Current (I_{ib})**—This is the average of the currents flowing into both inputs when the output voltage is 0. Ideally, the two input currents are 0.
- **Input Offset Current (I_{io})**—This is the difference between the input currents when the output voltage is 0.
- **Input Voltage Range (V_{cm})**—This is the range of allowable common mode input voltage, where the same voltage is placed on both inputs.
- **Input Resistance (Z_i)**—This is the resistance “looking into” either input with the other input grounded.

B. Output Parameters

- **Output Resistance (Z_{oi})**—This is the internal resistance of the op amp’s output circuit (i.e., “looking into” the op amp).

- Output Short Circuit Current (I_{osc})—This is the maximum output current that the op amp can deliver to a load.
- Output Voltage Swing ($\pm V_{omax}$)—This is the maximum peak-to-peak output voltage that the op amp can supply without saturating or clipping.

C. Dynamic Parameters

- Open Loop Voltage Gain (A_{OL})—This is the ratio of the output to the differential input voltage of the op amp without external feedback.
- Large Signal Voltage Gain—This is the ratio of the maximum voltage swing to the change in the input voltage required to drive the output from 0 to a specified voltage.
- Slew Rate (SR)—This is the time rate of change of the output voltage, assuming a step input, with the op amp circuit having a voltage gain of 1.

D. Other Parameters

- Maximum Supply Voltage ($\pm V_s$)—This is the maximum positive and negative voltage permitted to power the op amp.
- Supply Current—This is the current that the op amp draws from the power supply.
- Common Mode Rejection Ratio (CMRR)—This is a measure of the ability of the op amp to reject signals of equal value at the inputs. It is the ratio of the difference mode gain (the output gain corresponding to the difference between the inputs) to the common mode gain (the output gain occurring when the same voltage is applied to both inputs), usually expressed in decibels (dB).
- Channel Separation—Whenever there is more than one op amp in a single package, such as the 747 op amp IC, a certain amount of **cross-talk** is present. That is, a signal applied to the input of one op amp produces a finite output signal in the second op amp, even though there is no direct connection.

Data for each of these parameters are usually provided in IC manufacturers' *Linear* data books, which are available online. Figure 5.27 is a reproduction of the LM741 data sheet from National Semiconductor. It is divided into a maximum ratings section and an electrical characteristics section. This data sheet is typical of those from other manufacturers. Figure 5.28 shows the frequency response characteristics of the TL071. These types of graphs are also typically provided on op amp data sheets. Internet Links 5.1 and 5.2 point to the complete data sheets for both the 741 and the TL071. Lab Exercise 6 explores how some of the parameters and information reported in the data sheets are important in understanding how various op amp circuits respond to various inputs.

As you gain practical experience with op amp circuits, you should develop an appreciation of the significance of the many parameters affecting op amp performance.



Internet Link

5.1 741 op amp data sheet

5.2 TL071 FET input op amp data sheet

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/
Distributors for availability and specifications.

(Note 5)

	LM741A	LM741E	LM741	LM741C
Supply Voltage	±22V	±22V	±22V	±18V
Power Dissipation (Note 1)	500 mW	500 mW	500 mW	500 mW
Differential Input Voltage	±30V	±30V	±30V	±30V
Input Voltage (Note 2)	±15V	±15V	±15V	±15V
Output Short Circuit Duration	Continuous	Continuous	Continuous	Continuous
Operating Temperature Range	–55°C to +125°C	0°C to +70°C	–55°C to +125°C	0°C to +70°C
Storage Temperature Range	–65°C to +150°C	–65°C to +150°C	–65°C to +150°C	–65°C to +150°C
Junction Temperature	150°C	100°C	150°C	100°C
Soldering Information				
N-Package (10 seconds)	260°C	260°C	260°C	260°C
J- or H-Package (10 seconds)	300°C	300°C	300°C	300°C
M-Package				
Vapor Phase (60 seconds)	215°C	215°C	215°C	215°C
Infrared (15 seconds)	215°C	215°C	215°C	215°C
See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" for other methods of soldering surface mount devices.				
ESD Tolerance (Note 6)	400V	400V	400V	400V

Electrical Characteristics (Note 3)

Parameter	Conditions	LM741A/LM741E			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	$T_A = 25^\circ\text{C}$ $R_S \leq 10\text{k}\Omega$ $R_S \leq 50\Omega$		0.8	3.0		1.0	5.0		2.0	6.0	mV mV
	$T_{\text{AMIN}} \leq T_A \leq T_{\text{AMAX}}$ $R_S \leq 50\Omega$ $R_S \leq 10\text{k}\Omega$			4.0			6.0			7.5	mV mV
Average Input Offset Voltage Drift				15							$\mu\text{V}/^\circ\text{C}$
Input Offset Voltage Adjustment Range	$T_A = 25^\circ\text{C}$, $V_S = \pm 20\text{V}$	±10				±15			±15		mV
Input Offset Current	$T_A = 25^\circ\text{C}$		3.0	30		20	200		20	200	nA
	$T_{\text{AMIN}} \leq T_A \leq T_{\text{AMAX}}$			70		85	500			300	nA
Average Input Offset Current Drift				0.5							$\text{nA}/^\circ\text{C}$
Input Bias Current	$T_A = 25^\circ\text{C}$		30	80		80	500		80	500	nA
	$T_{\text{AMIN}} \leq T_A \leq T_{\text{AMAX}}$			0.210			1.5			0.8	μA
Input Resistance	$T_A = 25^\circ\text{C}$, $V_S = \pm 20\text{V}$	1.0	6.0		0.3	2.0		0.3	2.0		$\text{M}\Omega$
	$T_{\text{AMIN}} \leq T_A \leq T_{\text{AMAX}}$ $V_S = \pm 20\text{V}$	0.5									$\text{M}\Omega$
Input Voltage Range	$T_A = 25^\circ\text{C}$							±12	±13		V
	$T_{\text{AMIN}} \leq T_A \leq T_{\text{AMAX}}$				±12	±13					V
Large Signal Voltage Gain	$T_A = 25^\circ\text{C}$, $R_L \geq 2\text{k}\Omega$ $V_S = \pm 20\text{V}$, $V_O = \pm 15\text{V}$ $V_S = \pm 15\text{V}$, $V_O = \pm 10\text{V}$	50			50	200		20	200		V/mV V/mV
	$T_{\text{AMIN}} \leq T_A \leq T_{\text{AMAX}}$ $R_L \geq 2\text{k}\Omega$ $V_S = \pm 20\text{V}$, $V_O = \pm 15\text{V}$ $V_S = \pm 15\text{V}$, $V_O = \pm 10\text{V}$ $V_S = \pm 15\text{V}$, $V_O = \pm 2\text{V}$	32			25			15			V/mV V/mV V/mV
		10									

Figure 5.27 Example op amp data sheet.

Source: National Semiconductor, Santa Clara, CA.

(continued)

Electrical Characteristics (Note 3) (Continued)

Parameter	Conditions	LM741A/LM741E			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Output Voltage Swing	$V_S = \pm 20V$ $R_L \geq 10k\Omega$ $R_L \geq 2k\Omega$	± 16 ± 15									V V
	$V_S = \pm 15V$ $R_L \geq 10k\Omega$ $R_L \geq 2k\Omega$				± 12 ± 10	± 14 ± 13		± 12 ± 10	± 14 ± 13		V V
Output Short Circuit Current	$T_A = 25^\circ C$	10	25	35		25			25		mA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$	10		40							mA
Common-Mode Rejection Ratio	$T_{AMIN} \leq T_A \leq T_{AMAX}$ $R_S \leq 10k\Omega$, $V_{CM} = \pm 12V$				70	90		70	90		dB
	$R_S \leq 50k\Omega$, $V_{CM} = \pm 12V$	80	95								dB
Supply Voltage Rejection Ratio	$T_{AMIN} \leq T_A \leq T_{AMAX}$ $V_S = \pm 20V$, to $V_S = \pm 15V$										
	$R_S \leq 50k\Omega$ $R_S \leq 10k\Omega$	86	96		77	96		77	96		dB dB
Transient Response Rise Time Overshoot	$T_A = 25^\circ C$, Unity Gain										
			0.25 6.0	0.8 20		0.3 5			0.3 5		μS %
Bandwidth (Note 4)	$T_A = 25^\circ C$,	0.437	1.5								MHz
Slew Rate	$T_A = 25^\circ C$, Unity Gain	0.3	0.7			0.5			0.5		V/ μS
Supply Current	$T_A = 25^\circ C$,					1.7	2.8		1.7	2.8	mA
Power Consumption	$T_A = 25^\circ C$, $V_S = \pm 20V$ $V_S = \pm 15V$		80	150		50	85		50	85	mW mW
	$V_S = \pm 20V$ $T_A = T_{AMIN}$ $T_A = T_{AMAX}$			165 135							mW mW
LM741E	$V_S = \pm 20V$ $T_A = T_{AMIN}$ $T_A = T_{AMAX}$			150 150							mW mW
	$V_S = \pm 15V$ $T_A = T_{AMIN}$ $T_A = T_{AMAX}$					60 45	100 75				mW mW

Note 1: For operation at elevated temperatures, these devices must be derated based on thermal resistance, and T_j max. (listed under "Absolute Maximum Ratings"). $T_j = T_A + (\theta_{JA} P_{DP})$.

Thermal Resistance	Cordip (J)	DIP (N)	HO8 (H)	SO-8 (M)
θ_{JA} (Junction to Ambient)	100°C/W	100°C/W	170°C/W	195°C/W
θ_C (Junction to Case)	N/A	N/A	25°C/W	N/A

- Note 2:** For supply voltages less than $\pm 15V$, the absolute maximum input voltage is equal to the supply voltage.
- Note 3:** Unless otherwise specified, these specifications apply for $V_S = \pm 15V$, $-55^\circ C \leq V_A + 125^\circ C$ (LM741/LM741A). For the LM741C/LM741E, these specifications are limited to $0^\circ C \leq T_A + 70^\circ C$.
- Note 4:** Calculated value from: BW (MHz) = $0.35/\text{Rise time}(\mu s)$
- Note 5:** For military specifications see RETS741X for LM741 and RETS741AX for LM741A.
- Note 6:** Human body model, 1.5 k Ω in series with 100pF.

Figure 5.27 (continued)

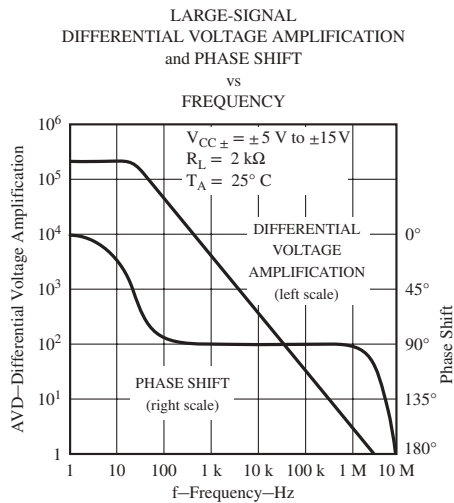


Figure 5.28 TL071 FET input op amp.
Source: Texas Instruments, Dallas, TX.



Lab Exercise

Lab 6

Operational
amplifier circuits

■ CLASS DISCUSSION ITEM 5.8

Real Integrator Behavior

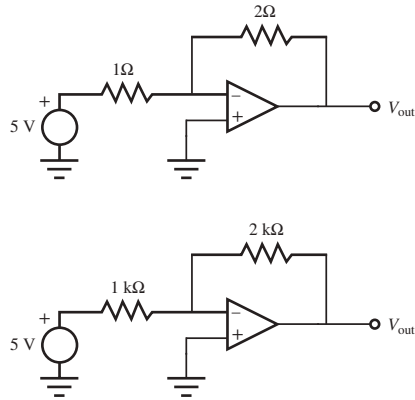
Reflecting back on Class Discussion Item 5.5, if the integrator is made with a real op amp, what happens to the output in contrast to that of the ideal integrator?

Sizing Resistors in Op Amp Circuits

EXAMPLE 5.1

The ideal model of the op amp would imply that if you constructed the following two op amp circuits in the laboratory, they would have the same gain. Ideally, each circuit would have a gain of -2 . However, the top circuit would be a very poor design and not function as expected. The reason for this can be found by considering the Output Short Circuit Current found on the specification sheet for the op amp. From Figure 5.27, the value for a LM741 is typically 25 mA. This is the largest current that the output can source. But, looking at the circuit, the output current is $V_{\text{out}} / 2 \Omega$, and because $V_{\text{out}} = -2V_{\text{in}} = -10 \text{ V}$, the output current would be 5 A! This is far above the current sourcing capability of the op amp. To avoid this problem, larger resistances such as the ones shown in the bottom circuit are used. Here, the output current is 5 mA ($10 \text{ V} / 2 \text{ k}\Omega$), which is well within the op amp specification.

(continued)

(concluded)

DESIGN EXAMPLE 5.1

Myogenic Control of a Prosthetic Limb

Interfacing prosthetic devices to the human body presents one of the most interesting and challenging problems for engineers. These problems pose a number of medical and engineering challenges in the fields of materials, fluids, electronics, control, and mechanics. Think of the artificial heart, dialysis machine, hip joint replacement, osmotic skin patch, and artificial retina as examples. As we develop improved technological products, we find very important applications in bioengineering. Let us consider one important problem that uses our knowledge of operational amplifiers.

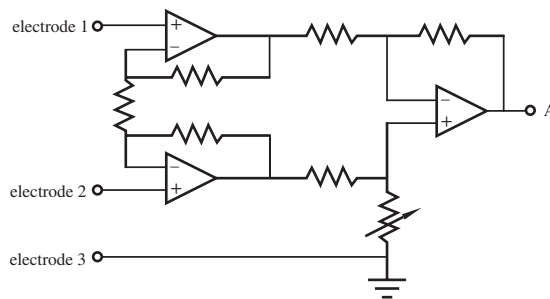
Suppose you would like to design a prosthetic limb (e.g., an artificial arm or leg) that could be controlled by the thoughts of the wearer. Early prosthetic limbs were either purely passive or somewhat mechanically controlled by contracting other muscles. A novel approach, however, would be to provide thought control of the limb. Two possibilities present themselves: neural control or myogenic control. For neural control we would have to electrically tap the nervous system, which still is a problem that has not been completely solved technically. Myogenic control is easier to realize. When a muscle is caused to move or twitch, the tiny movement of electrolytes in the muscles below the skin cause an electric field that induces a small voltage on the surface of the skin. This voltage is quite small, otherwise we would shock each other every time we touched. It ranges from microvolts to millivolts and may be mixed with other biopotential signals. The problem then is to sense and isolate this small voltage and convert it into a signal capable of switching something like an electric motor that could be attached to a prosthetic device. So here is our problem: How can we design a mechatronic system that uses the surface skin potential from a muscle as an input to control an actuator such as an electric motor?

Let us begin by outlining what the approach will be. First, we have to tap the skin potential with a special surface electrode. Then we have to amplify the signal and filter it to eliminate unwanted noise components and achieve the correct frequency response. Then we need to convert it to a form that allows setting different levels for a control strategy. Finally, we need to drive an electric motor that requires significant current. You currently have the

design capability to do all of these things. We start by looking at the transducer to sense the skin potential.

The electric fields that occur in living tissue are caused by charge separations in electrolytes and not by the movement of electrons. In order to sense the voltage at the skin, we need a transducer that converts subdermal (below the skin) electrolyte ion currents to electron currents in our electronic system. Silver–silver chloride electrodes have this property. So if we place a silver chloride electrode on the skin and couple it with a conducting gel, we can sense the body's voltage at that location. The magnitude of the voltage is related to how much a subcutaneous (beneath the skin) muscle contracts. This voltage is the myoelectric signal of interest. The problem that remains is that the electrode produces a very small signal, at best a few millivolts. Also, a considerable amount of 60-Hz background noise and other signals can obscure the signal associated with the muscle. Moreover, the electrode-skin connection has a high impedance.

This is an application where an instrumentation amplifier is necessary to provide the high input impedance, high common mode rejection ratio, and gain necessary to extract the biopotential signal produced by the contracting muscle. The following figure displays the preamplifier stage of our electromyogenic (EMG) detector. For the components shown, it should be easy to create a CMRR in excess of 60 dB and a gain of 125 with an input impedance of 10 M Ω . Note that two active (differential) electrodes 1 and 2 will be mounted close together above the muscle. The third electrode is a ground reference. This circuit is satisfactory in capturing the EMG signal.

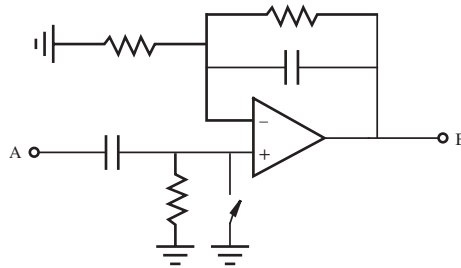


The instrumentation amplifier was chosen because it can extract a very small signal difference between the two signal electrodes (electrodes 1 and 2) while significantly attenuating noise common to both electrodes. This eliminates a considerable amount of 60-Hz common mode noise (resulting from electromagnetic interference) and other signals common to both electrodes. However, something called a *motion artifact* can still occur due to relative motion between the electrodes and the tissue. Relative motion can produce voltages sufficient to saturate the second-stage amplifier. The frequencies of the motion artifact are usually at the low end of the bandwidth of the EMG signals. Therefore, a 2-Hz high-pass filter on the input of the second stage of the amplifier that follows can be used to reduce these artifacts. Signal “A” is the output from the instrumentation amplifier circuit and signal “B” is the output of the op-amp-based filter. The filter circuit is a combination of an RC

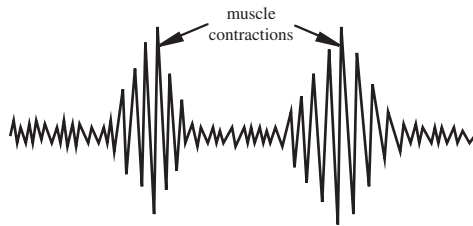
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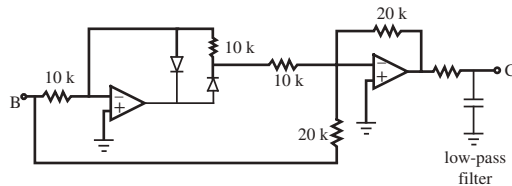
filter and a noninverting amplifier. The capacitor in the op amp feedback loop limits the gain at frequencies higher than those of interest.



At this point, the EMG signal (signal “B”) observed on an oscilloscope would look like the following, where the large amplitude bursts are associated with muscle contractions.

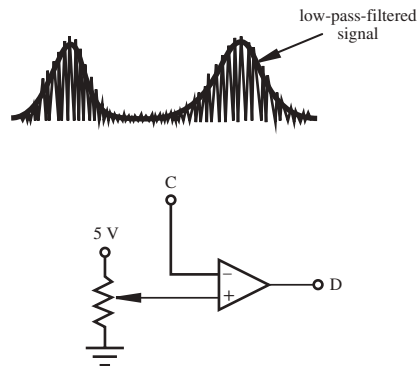


This is a rather high-frequency signal with components between a few Hz and 250 Hz. To make this signal more useful for control purposes, we need to extract the envelope of the signal between 0 V and its maximum positive amplitude. We can accomplish this with a rectifier and a low-pass filter. A normal silicon diode would not be satisfactory to rectify the signal because it requires a 0.7-V turn-on voltage, which is larger than the amplitude of the input signal. Because the signal is very small, we must use a *precision rectifier* circuit (see the figure that follows) that more closely approximates the action of an ideal diode.

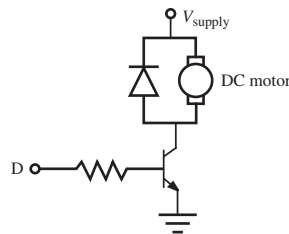


The precision-rectified EMG and the resulting low-pass-filtered signals look like those shown in the next figure. The low-pass-filtered signal is basically the envelope of the rectified signal. Now we have a signal that can be input to a comparator (see the figure that follows) to provide a binary control signal (signal “D”), which will be on when the muscle is

contracted and off when relaxed. The designer or user can adjust the reference voltage with the potentiometer for the desired sensitivity.



As shown in the final figure, the output of the rectifier can then be input to a power transistor circuit to control the current in a motor.



In summary, we have used a variety of op amp circuits to process an analog signal. It exemplifies the extraction of a very low level signal in the presence of noise, a variety of analog signal processing methods, and the interface to an actuator to control mechanical power. In this case, we have converted the EMG signal into a binary control signal for on–off control of a DC motor that could, for example, flex the elbow in a prosthetic arm. A more complete and detailed solution to a similar problem, where an EMG signal is used to control an industrial robot, is presented in Section 11.4.

■ CLASS DISCUSSION ITEM 5.9

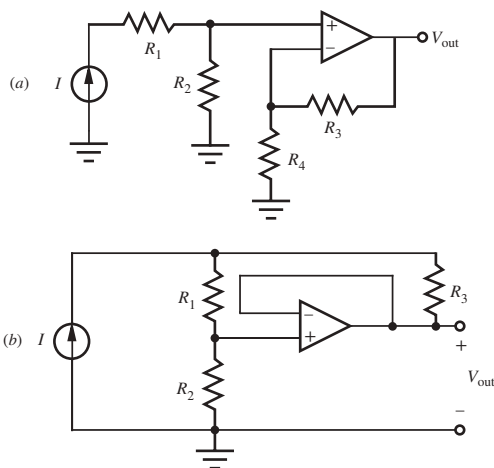
Bidirectional EMG Controller

In Design Example 5.1, we discussed turning on and off a motor via an EMG signal. Unfortunately, the controller can actuate the joint in one direction only. Discuss how you might change the design to allow bidirectional movement.

QUESTIONS AND EXERCISES

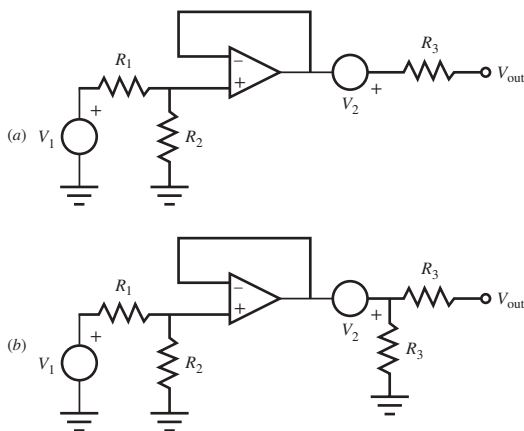
Section 5.5 Inverting Amplifier

- 5.1. An inverting op amp circuit is designed with $1/4\text{ W}$ resistors (i.e., they are capable of dissipating up to $1/4\text{ W}$ of energy without failure). If the input voltage is 5 V , what are the minimum required values for the input and feedback resistors if the gain is
- 1
 - 10
- 5.2. Determine V_{out} as a function of I (provided by a current source) and the resistor values for each of the op amp circuits that follows. Assume ideal op amp behavior.

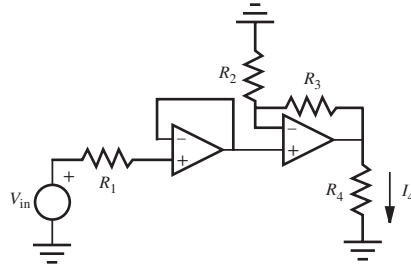


Section 5.6 Noninverting Amplifier

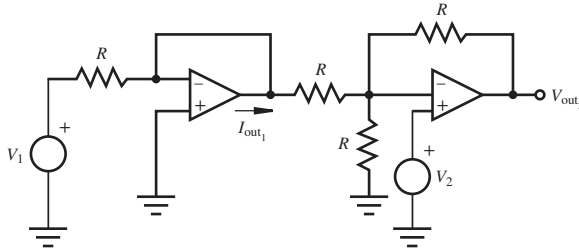
- 5.3. If resistor R_F shown in Figure 5.10 is replaced with a short (i.e., $R_F = 0$), what is the gain of the circuit?
- 5.4. Determine V_{out} in the following circuits with $R_1 = R_2 = R_3 = 1\text{ k}\Omega$, $V_1 = 10\text{ V}$, and $V_2 = 5\text{ V}$. Assume ideal op amp behavior.



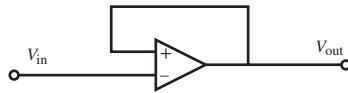
- 5.5. Determine I_4 in terms of V_{in} , R_1 , R_2 , R_3 , and R_4 in the following circuit. Assume ideal op amp behavior.



- 5.6. For the following circuit, express I_{out1} and V_{out2} in terms of V_1 , V_2 , and R .



- 5.7. Explain why $V_{out} \neq V_{in}$ in the following circuit.



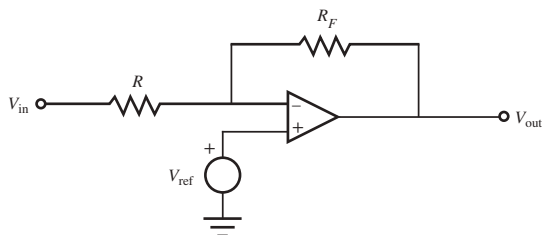
Section 5.7 Summer

- 5.8. Analyze the summer circuit in Figure 5.14 and determine an equation for the output voltage V_{out} in terms of the input voltages V_1 and V_2 and the resistances R_1 , R_2 , and R_F . Use this result to verify that Equation 5.19 is correct. Show and explain all work.
- 5.9. If a voltage source V_3 is inserted between ground and the noninverting input in the summer circuit shown in Figure 5.14, what is the resulting equation for the output voltage V_{out} in terms of the input voltages V_1 and V_2 if $R_1 = R_2 = R_F$?

Section 5.8 Difference Amplifier

- 5.10. Derive Equation 5.24 for the difference amplifier without using the principle of superposition.

- 5.11. Use the principle of superposition to derive an expression for the output voltage in the following circuit and explain why the circuit is called a **level shifter**.



Section 5.9 Instrumentation Amplifier

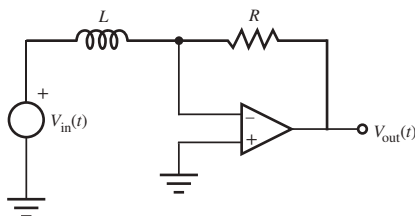
- 5.12. Derive Equation 5.31 that expresses V_{out} in terms of the V_3 and V_4 shown in Figure 5.18.

Section 5.10 Integrator

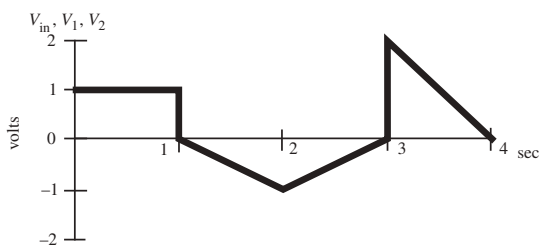
- 5.13. Solve and generate plots for Class Discussion Item 5.5 for a 100-Hz sine wave with an amplitude of 1 V and a DC offset of 0.1 V. Plot the output for 5 cycles of the sinusoid.

Section 5.11 Differentiator

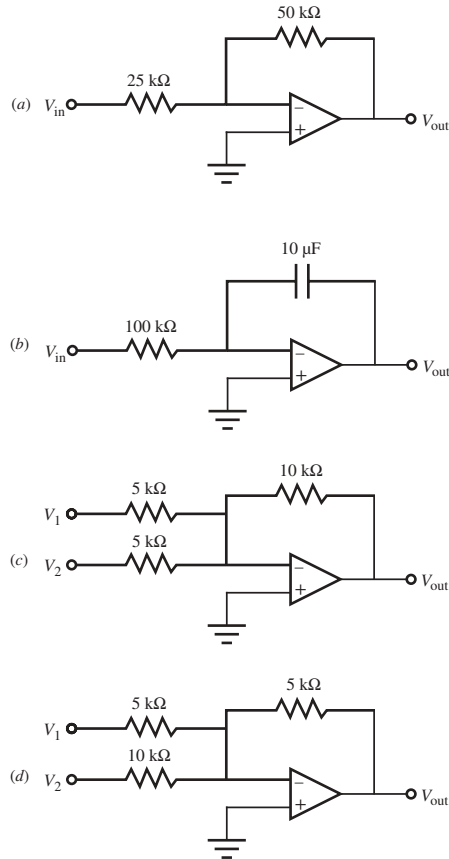
- 5.14. Find $V_{out}(t)$ given $V_{in}(t)$ in the op amp circuit that follows.



- 5.15. Derive Equation 5.36 assuming the input and output voltages are both zero and the currents flowing into each op amp input are equal.
- 5.16. Using the following input waveform, sketch the corresponding output waveform for each op amp circuit (a through d). Assume ideal op amp behavior.



(continued)

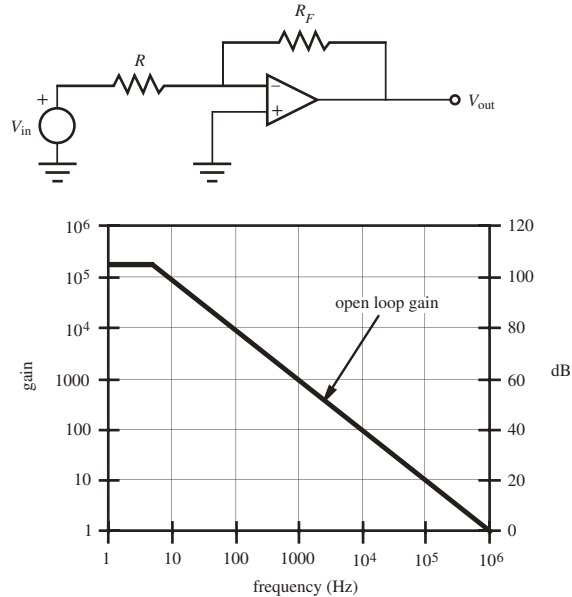


Section 5.13 Comparator

- 5.17.** Using a standard output (not open-collector) comparator, draw a circuit that could be used to turn on an LED when an input voltage exceeds 5 V .
- 5.18.** Using an open-collector output comparator, draw a circuit that could be used to turn on an LED when an input voltage exceeds 5 V .

Section 5.14 The Real Op Amp

- 5.19.** If the short-circuit output current of a real op amp is 10 mA , calculate the minimum resistance required for the feedback resistor in an inverting op amp circuit with a gain of 10 and a maximum output voltage of 10 V .
- 5.20.** For the 2nd circuit in Example 5.1, what is the maximum input voltage (above 5 V) that can be applied while still getting the full gain in the output voltage?
- 5.21.** Given the following circuit and op amp open loop gain curve, what is the fall-off frequency for the circuit when $R_F = 20\text{ k}\Omega$ and $R = 2\text{ k}\Omega$?



5.22. Document a complete and thorough answer to Class Discussion Item 5.8.

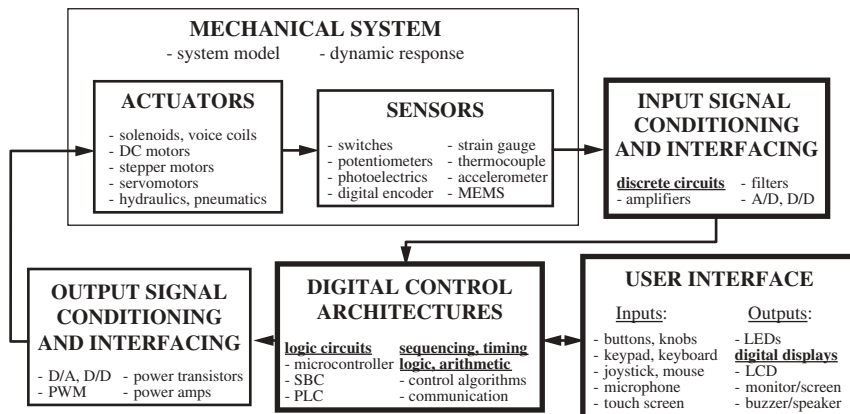
BIBLIOGRAPHY

- Coughlin, R. and Driscoll, F., *Operational Amplifiers and Linear Integrated Circuits*, 6th Edition, Prentice Hall, Englewood Cliffs, NJ, 2001.
- Horowitz, P. and Hill, W., *The Art of Electronics*, 3rd Edition, Cambridge University Press, New York, 2015.
- Johnson, D., Hilburn, J., and Johnson, J., *Basic Electric Circuit Analysis*, 2nd Edition, Prentice Hall, Englewood Cliffs, NJ, 1984.
- McWhorter, G. and Evans, A., *Basic Electronics*, Master Publishing, Richardson, TX, 2004.
- Mims, F., *Engineer's Mini-Notebook: Op Amp IC Circuits*, Radio Shack Archer Catalog No. 276-5011, 1985.
- Mims, F., *Getting Started in Electronics*, 3rd Edition, Master Publishing, Richardson, TX, 2003.
- Texas Instruments, *Linear Circuits Data Book, Volume 1—Operational Amplifiers*, Dallas, TX, 1992.

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Digital Circuits

This chapter presents digital electronic devices used for logic, display, sequencing, timing, and other functions in mechatronic systems. The fundamentals presented in this chapter are important in understanding the basic functioning of all digital components and systems used in the control of mechatronic systems. ■



CHAPTER OBJECTIVES

After you read, discuss, study, and apply ideas in this chapter, you will:

1. Be able to define a digital signal
2. Understand how the binary and hexadecimal number systems are used in coding digital data
3. Know the characteristics of different logic gates
4. Know the differences between combinational and sequential logic

5. Be able to draw a timing diagram for a digital circuit
6. Be able to use Boolean mathematics to analyze logic circuits
7. Be able to design logic networks
8. Be able to use a variety of flip-flops for storing data
9. Understand differences between TTL and CMOS logic devices
10. Know how to construct an interface between TTL and CMOS devices
11. Be able to use counters for different counting applications
12. Know how to display numerical data using LED displays

6.1 INTRODUCTION

In contrast to an analog signal that changes in a continuous manner, a digital signal exists only at specific levels or states and changes its level in discrete steps. An analog signal and a digital signal are illustrated in Figure 6.1. Most digital signals have only two states: high and low. A system using two-state signals allows the application of Boolean logic and binary number representations, which form the foundation for the design of all digital devices.

Digital devices convert digital inputs into one or more digital outputs. They are categorized according to their function as **combinational logic** or **sequential logic** devices. The difference between the two categories is based on signal timing. For sequential logic devices, the timing, or sequencing history, of the input signals plays a role in determining the output. This is not the case with combinational logic devices whose outputs depend only on the instantaneous values of the inputs.

Before we introduce the various digital devices, we will review the binary number system and the application of binary numbers in digital calculations. Then we discuss Boolean algebra, which is the mathematical basis for logic representation and manipulation. Finally, we discuss a number of specific combinational and sequential logic devices and their applications.

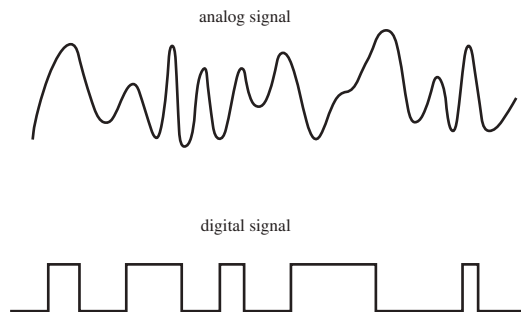


Figure 6.1 Analog and digital signals.

6.2 DIGITAL REPRESENTATIONS

We grow up becoming proficient using the base 10 decimal number system. The **base** of the number system indicates the number of different symbols that can be used to represent a digit. In base 10, the symbols are 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9. Each digit in a decimal number is a placeholder for different powers of 10 according to

$$d_{n-1} \dots d_3 d_2 d_1 d_0 = d_{n-1} \cdot 10^{n-1} + \dots + d_2 \cdot 10^2 + d_1 \cdot 10^1 + d_0 \cdot 10^0 \quad (6.1)$$

where n is the number of digits and each digit d_i is one of the ten symbols. Note that the highest power of 10 is $(n - 1)$, 1 less than the number of digits. As an example, the decimal number 123 can be expanded as

$$123 = 1 \times 10^2 + 2 \times 10^1 + 3 \times 10^0 \quad (6.2)$$

Fractions may also be included if digits for negative powers of 10 are included ($d_{-1}, d_{-2}, \dots$).

In order to represent and manipulate numbers with digital devices such as computers, we use a base 2 number system called the **binary number system**. The reason for this is that the operation of digital devices is based on transistors that switch between two states: the ON or saturated state and the OFF or cutoff state. These states are designated by the symbols 1 (ON) and 0 (OFF) in the base 2 system. The digits in a binary number, as with the base 10 system, correspond to different powers of the base. A binary number can be expanded as

$$(d_{n-1} \dots d_3 d_2 d_1 d_0)_2 = d_{n-1} \cdot 2^{n-1} + \dots + d_2 \cdot 2^2 + d_1 \cdot 2^1 + d_0 \cdot 2^0 \quad (6.3)$$

where each digit d_i is one of the two symbols 0 and 1. The trailing subscript 2 is used to indicate that the number is base 2 and not the normally assumed base 10. As an example of Equation 6.3, the binary number 1101 can be expanded as

$$1101_2 = 1 \cdot 2^3 + 1 \cdot 2^2 + 0 \cdot 2^1 + 1 \cdot 2^0 = 8_{10} + 4_{10} + 1_{10} = 13_{10} \quad (6.4)$$

The digits of a binary number are also called **bits**, and the first and last bits have special names. The first, or leftmost, bit is known as the **most significant bit** (MSB) because it represents the largest power of 2. The last, or rightmost, bit is known as the **least significant bit** (LSB) because it represents the smallest power of 2. A group of 8 bits is called a **byte**.

In general, the value of a number represented in any base can be expanded and computed with

$$(d_{n-1} \dots d_3 d_2 d_1 d_0)_b = (d_{n-1} \cdot b^{n-1} + \dots + d_2 \cdot b^2 + d_1 \cdot b^1 + d_0 \cdot b^0) \quad (6.5)$$

where b is the base and n is the number of digits. Often it is necessary to convert from one base system to another. Equation 6.5 provides a mechanism to convert from an arbitrary base to base 10. To convert a number from base 10 to some other base, the procedure is to successively divide the decimal number by the base and record the

Table 6.2 Hexadecimal symbols and equivalents

Binary	Hexadecimal	Decimal	Binary-Coded Decimal
0000	0	0	00000000
0001	1	1	00000001
0010	2	2	00000010
0011	3	3	00000011
0100	4	4	00000100
0101	5	5	00000101
0110	6	6	00000110
0111	7	7	00000111
1000	8	8	00001000
1001	9	9	00001001
1010	A	10	00010000
1011	B	11	00010001
1100	C	12	00010010
1101	D	13	00010011
1110	E	14	00010100
1111	F	15	00010101

Another base useful in representing binary numbers in concise form is octal (base 8). To convert a binary number to octal, divide the number into groups of three digits beginning with the least significant bit and replace each group with its octal equivalent. For example,

$$123_{10} = 001\ 111\ 011_2 = 173_8 \qquad (6.7)$$

■ CLASS DISCUSSION ITEM 6.1
Nerd Numbers

Why do geeky engineers sometimes confuse Halloween (OCT 31) and Christmas (DEC 25)?

In addition to numbers, alphanumeric characters can also be represented in digital (binary) form with **ASCII** codes. ASCII is short for the American Standard Code for *Information Interchange*. ASCII codes are 7-bit codes used to denote all of the alphanumeric characters. The 7-bit codes are usually stored in an 8-bit byte. There is a unique code for each alphanumeric character. Some example codes are

$$\begin{aligned} \text{A: } & 0100\ 0001 = 41_{16} = 65_{10} \\ \text{B: } & 0100\ 0010 = 42_{16} = 66_{10} \\ \text{0: } & 0011\ 0000 = 30_{16} = 48_{10} \\ \text{1: } & 0011\ 0001 = 31_{16} = 49_{10} \end{aligned}$$



Internet Link

The complete set of ASCII codes can be found at Internet Link 6.1.

6.1 ASCII codes

Binary coded decimal (BCD) is another type of digital representation sometimes used for input and output of numerical data. With BCD, 4 bits are used to represent a single, base 10 digit. BCD is a convenient mechanism for representing decimal numbers in a binary number format, but it is inefficient for storing or transmitting multiple-digit numbers because only 10 of the 16 (2^4) possible states of the 4-bit number are used. To convert a decimal number to BCD, assemble the 4-bit codes for each decimal digit. For example,

$$123_{10} = 0001\ 0010\ 0011_{bcd} \tag{6.8}$$

Note that this is different from the binary representation:

$$123_{10} = 0111\ 1011_2 \tag{6.9}$$

Table 6.2 list the two-decimal-digit BCD equivalents for all numbers between 00 and 15.

■ CLASS DISCUSSION ITEM 6.2

Computer Magic

How can a digital computer perform the complex operations it does given that its architecture and operation are based on simply manipulating bits (zeros and ones)?

6.3 COMBINATIONAL LOGIC AND LOGIC CLASSES

Combinational logic devices are digital devices that convert binary inputs into binary outputs based on the rules of mathematical logic. The basic operations, schematic symbols, and algebraic expressions for combinational logic devices are shown in Table 6.3. These devices are also called **logic gates**, because they control the flow of signals from the inputs to the single output. A small circle at the input or output of a digital device denotes signal inversion; that is, a 0 becomes a 1 or a 1 becomes a 0. For example, the **NAND** and **NOR** gates are AND and OR gates, respectively, with the output inverted, hence the circle is shown on the output. The **truth table** for each device is shown on the right. The truth table, in figure 6.3 below, is a compact means of displaying all combinations of inputs and their corresponding outputs. Usually, the combination of inputs is written as the ascending list of binary numbers whose number of bits corresponds to the number of inputs (e.g., 00, 01, 10, 11 for two inputs). Internet Link 6.2 provides a fun online digital circuit simulator allowing you to drag-and-drop and connect logic gates in different ways to interactively see how combinational logic circuits function.

The standard AND, NAND, OR, NOR, and XOR gates have only two inputs, but other forms are available with more than two inputs. In the case of a multiple-input **AND** gate, the output is 1 if and only if all inputs are 1; otherwise, the output is 0. In the case of the **OR** gate, the output is 0 if and only if all inputs are 0; otherwise, it is 1. In the case of the **XOR** gate, the output is 0 if all of the inputs are 0 or if all of



Internet Link

6.2 “Logicly”
combinational logic
online simulator

Table 6.3 Combinational logic operations

Gate	Operation	Symbol	Expression	Truth Table															
Inverter (INV, NOT)	Invert signal (complement)		$C = \overline{A}$	<table><tr><td><u>A</u></td><td><u>C</u></td></tr><tr><td>0</td><td>1</td></tr><tr><td>1</td><td>0</td></tr></table>	<u>A</u>	<u>C</u>	0	1	1	0									
<u>A</u>	<u>C</u>																		
0	1																		
1	0																		
AND gate	AND logic		$C = A \cdot B$	<table><tr><td><u>A</u></td><td><u>B</u></td><td><u>C</u></td></tr><tr><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>0</td></tr><tr><td>1</td><td>0</td><td>0</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table>	<u>A</u>	<u>B</u>	<u>C</u>	0	0	0	0	1	0	1	0	0	1	1	1
<u>A</u>	<u>B</u>	<u>C</u>																	
0	0	0																	
0	1	0																	
1	0	0																	
1	1	1																	
NAND gate	Inverted AND logic		$C = \overline{A \cdot B}$	<table><tr><td><u>A</u></td><td><u>B</u></td><td><u>C</u></td></tr><tr><td>0</td><td>0</td><td>1</td></tr><tr><td>0</td><td>1</td><td>1</td></tr><tr><td>1</td><td>0</td><td>1</td></tr><tr><td>1</td><td>1</td><td>0</td></tr></table>	<u>A</u>	<u>B</u>	<u>C</u>	0	0	1	0	1	1	1	0	1	1	1	0
<u>A</u>	<u>B</u>	<u>C</u>																	
0	0	1																	
0	1	1																	
1	0	1																	
1	1	0																	
OR gate	OR logic		$C = A + B$	<table><tr><td><u>A</u></td><td><u>B</u></td><td><u>C</u></td></tr><tr><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>1</td></tr><tr><td>1</td><td>0</td><td>1</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table>	<u>A</u>	<u>B</u>	<u>C</u>	0	0	0	0	1	1	1	0	1	1	1	1
<u>A</u>	<u>B</u>	<u>C</u>																	
0	0	0																	
0	1	1																	
1	0	1																	
1	1	1																	
NOR gate	Inverted OR logic		$C = \overline{A + B}$	<table><tr><td><u>A</u></td><td><u>B</u></td><td><u>C</u></td></tr><tr><td>0</td><td>0</td><td>1</td></tr><tr><td>0</td><td>1</td><td>0</td></tr><tr><td>1</td><td>0</td><td>0</td></tr><tr><td>1</td><td>1</td><td>0</td></tr></table>	<u>A</u>	<u>B</u>	<u>C</u>	0	0	1	0	1	0	1	0	0	1	1	0
<u>A</u>	<u>B</u>	<u>C</u>																	
0	0	1																	
0	1	0																	
1	0	0																	
1	1	0																	
XOR gate	Exclusive OR logic		$C = A \oplus B$ $= A \cdot \overline{B} + \overline{A} \cdot B$	<table><tr><td><u>A</u></td><td><u>B</u></td><td><u>C</u></td></tr><tr><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>1</td></tr><tr><td>1</td><td>0</td><td>1</td></tr><tr><td>1</td><td>1</td><td>0</td></tr></table>	<u>A</u>	<u>B</u>	<u>C</u>	0	0	0	0	1	1	1	0	1	1	1	0
<u>A</u>	<u>B</u>	<u>C</u>																	
0	0	0																	
0	1	1																	
1	0	1																	
1	1	0																	
Buffer	Increase output signal current		$C = A$	<table><tr><td><u>A</u></td><td><u>C</u></td></tr><tr><td>0</td><td>0</td></tr><tr><td>1</td><td>1</td></tr></table>	<u>A</u>	<u>C</u>	0	0	1	1									
<u>A</u>	<u>C</u>																		
0	0																		
1	1																		

the inputs are 1; otherwise, it is 1. The algebraic symbols used to represent the logic functions are: plus (+) for logic OR, dot (·) for the logic AND, and an overbar ($\bar{X}$) for logic NOT, denoting inversion.

A **buffer** is used to increase the current supplied at the output while retaining the digital state. This is important if you wish to drive multiple digital inputs from a single output. A normal digital gate has a limited **fan-out**, which defines the maximum number of similar digital inputs that can be driven by the gate's output (see Section 6.11.3). The buffer overcomes fan-out limitations by providing more output current.

**Video Demo**

5.1 Integrated circuits

5.2 Integrated circuit manufacturing process stages

5.3 Chip manufacturing process

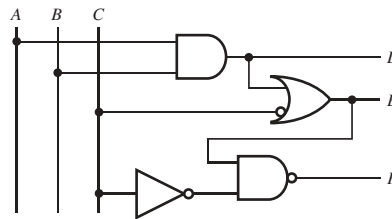
5.4 How a CPU is made

All the gates in Table 6.3 are manufactured as **integrated circuits** where transistors, resistors, and diodes exist on a single chip of silicon. Video Demo 5.1 shows various types of IC packages, and Video Demos 5.2 through 5.4 describe and illustrate all of the steps of the IC manufacturing process.

There are two families of digital integrated circuits: **TTL** (transistor-transistor logic) and **CMOS** (complementary metal-oxide semiconductors). Specific voltage ranges define **logic low** (0) and **logic high** (1) at the inputs and outputs. The ranges for the logic levels vary depending on the device family. A designer must be careful when mixing different types of digital integrated circuits because different digital devices have specified current source and sink capabilities that affect how much fan-out is allowed and how they may be mixed with each other. The TTL and CMOS families are described in detail in Section 6.11.

EXAMPLE 6.2**Combinational Logic**

This example illustrates how to determine signal expressions and values in a logic diagram. Here is an example logic circuit:



Signals A , B , and C are inputs and signals D , E , and F are outputs. Each of the signals can be high (1) or low (0). When analyzing a logic circuit, start by writing out logic expressions for all signals in the circuit. D is the most straightforward because it is simply the AND combination of signals A and B :

$$D = A \cdot B$$

Signal E depends on signal D and uses the circle inversion symbol on the C input to the OR gate, so

$$E = D + \overline{C}$$

This can also be written as

$$E = (A \cdot B) + \overline{C}$$

Finally, signal F is the result of a NAND combination of signal E and the inverse of C :

$$F = \overline{E \cdot \overline{C}}$$

Note that the inversion bar goes over the entire expression $E \cdot \overline{C}$ because the NAND gate inverts the output of the AND combination of E and $\overline{C}$.

Another way to express the functionality of the logic circuit is to summarize all the possible input and output combinations in a truth table as follows. Each output value can be determined from the logic expressions. For example, for input combination $A = 0$, $B = 0$, and $C = 0$, $D = 0 \cdot 0 = 0$, $E = 0 + \overline{0} = 0 + 1 = 1$, $F = \overline{1 \cdot \overline{0}} = \overline{1 \cdot 1} = \overline{1} = 0$.

A	B	C	D	E	F
0	0	0	0	1	0
0	0	1	0	0	1
0	1	0	0	1	0
0	1	1	0	0	1
1	0	0	0	1	0
1	0	1	0	0	1
1	1	0	1	1	0
1	1	1	1	1	1

When you become comfortable with logic expressions and truth tables, you will be able to construct the table very quickly using some short-cuts. For example, because D is the AND combination of A and B , D is 1 only if A is 1 *and* B is 1; otherwise, D is 0. Therefore, you can quickly fill in column D with all zeros except where A and B are both 1. Similarly, with column E , which is an OR combination, the output is 1 if D is 1 *or* if $\overline{C}$ is 1 (i.e., C is 0). Another way to interpret this is that E is 0 only if both D is 0 and $\overline{C}$ is 0 (i.e., C is 1). F is 0 (1 inverted) if E is 1 and $\overline{C}$ is 1 (i.e., C is 0).

6.4 TIMING DIAGRAMS

In order to analyze complex logic circuits it helps to sketch a timing diagram, which shows the simultaneous levels of the inputs and outputs in a circuit vs. time. The timing diagram can be used to illustrate every possible combination of input values and corresponding outputs, providing a graphical summary of the input/output relationships. Timing diagrams for the AND and OR gates are shown in Figures 6.2 and 6.3, respectively, as examples. Multiple-input digital oscilloscopes and logic analyzers have the capability to display timing diagrams for digital circuits.

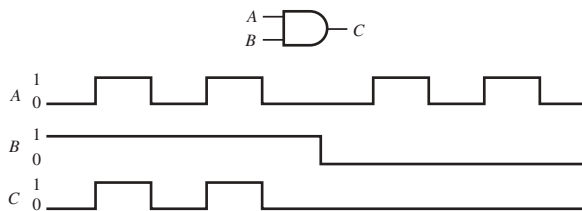


Figure 6.2 AND gate timing diagram.

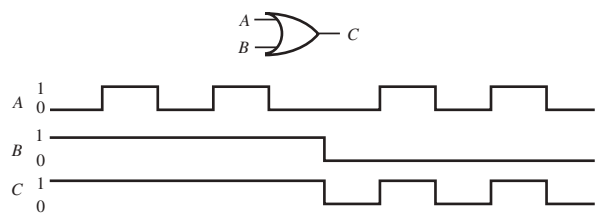


Figure 6.3 OR gate timing diagram.

6.5 BOOLEAN ALGEBRA

In formulating mathematical expressions for logic circuits, it is important to have knowledge of Boolean algebra (developed by George Boole in the 1840s), which defines the rules for expressing and simplifying binary logic statements. The basic Boolean laws and identities follow. A bar over a symbol indicates the Boolean operation NOT, which corresponds to inversion of a signal.

Boolean Algebra Laws and Identities

Fundamental Laws

OR	AND	NOT	
$A + 0 = A$	$A \cdot 0 = 0$		
$A + 1 = 1$	$A \cdot 1 = A$	$\overline{\overline{A}} = A$	(6.10)
$A + A = A$	$A \cdot A = A$	(double inversion)	
$A + \overline{A} = 1$	$A \cdot \overline{A} = 0$		

Commutative Laws

$A + B = B + A$ (6.11)

$A \cdot B = B \cdot A$ (6.12)

Associative Laws

$(A + B) + C = A + (B + C)$ (6.13)

$(A \cdot B) \cdot C = A \cdot (B \cdot C)$ (6.14)

Distributive Laws

$A \cdot (B + C) = (A \cdot B) + (A \cdot C)$ (6.15)

$A + (B \cdot C) = (A + B) \cdot (A + C)$ (6.16)

Other Useful Identities

$A + (A \cdot B) = A$ (6.17)

$A \cdot (A + B) = A$ (6.18)

$$A + (\bar{A} \cdot B) = A + B \quad (6.19)$$

$$(A + B) \cdot (A + \bar{B}) = A \quad (6.20)$$

$$(A + B) \cdot (A + C) = A + (B \cdot C) \quad (6.21)$$

$$A + B + (A \cdot \bar{B}) = A + B \quad (6.22)$$

$$(A \cdot B) + (B \cdot C) + (\bar{B} \cdot C) = (A \cdot B) + C \quad (6.23)$$

$$(A \cdot B) + (A \cdot C) + (\bar{B} \cdot C) = (A \cdot B) + (\bar{B} \cdot C) \quad (6.24)$$

De Morgan's laws are also useful in rearranging or simplifying longer Boolean expressions or in converting between AND and OR gates:

$$\overline{A + B + C + \dots} = \bar{A} \cdot \bar{B} \cdot \bar{C} \cdot \dots \quad (6.25)$$

$$\overline{A \cdot B \cdot C \cdot \dots} = \bar{A} + \bar{B} + \bar{C} + \dots \quad (6.26)$$

If we invert both sides of these equations and apply the double NOT law from Equation 6.10, we can write De Morgan's laws in the alternative form:

$$A + B + C + \dots = \overline{\bar{A} \cdot \bar{B} \cdot \bar{C} \cdot \dots} \quad (6.27)$$

$$A \cdot B \cdot C \cdot \dots = \overline{\bar{A} + \bar{B} + \bar{C} + \dots} \quad (6.28)$$

Truth tables can be very helpful in verifying an identity. For example, to show that Equation 6.19 is valid, we can construct the following truth table where each term in the identity is evaluated for all input combinations:

A	$\bar{A}$	B	$\bar{A} \cdot B$	$A + (\bar{A} \cdot B)$	$A + B$
1	0	0	0	1	1
1	0	1	0	1	1
0	1	0	0	0	0
0	1	1	1	1	1

Because both sides of the identity are equal for every input combination, the identity is valid.

Simplifying a Boolean Expression

EXAMPLE 6.3

Simplify the following expression using Boolean laws and identities:

$$X = (A \cdot B \cdot C) + (B \cdot C) + (\bar{A} \cdot B)$$

First, we can rewrite this equation using the associative law and the fundamental law that $Z \cdot 1 = Z$:

$$X = A \cdot (B \cdot C) + 1 \cdot (B \cdot C) + (\bar{A} \cdot B) \quad (continued)$$

(continued)

In this form, it is clear that we can use the distributive law to factor out the $(B \cdot C)$ term:

$$X = (A + 1) \cdot (B \cdot C) + (\bar{A} \cdot B)$$

Because $A + 1 = 1$ and $1 \cdot (B \cdot C) = B \cdot C$,

$$X = (B \cdot C) + (\bar{A} \cdot B)$$

Furthermore, using the associative and distributive laws we can factor out B :

$$X = B \cdot (C + \bar{A})$$

We have reduced the number of operators from seven in the original expression (including the inversion) to three in the final expression. This is important because it reduces the number of gates required to build the circuit.

6.6 DESIGN OF LOGIC NETWORKS

As an example illustrating the application of combinational logic to a real engineering problem, suppose you are asked to design a circuit for a simple home security system. The homeowner wants an alarm to sound if someone breaks into the house through a door or window or if something is moving around in the house while the occupants are away. Under certain conditions, the users may also want to disable portions of the alarm system. We assume that there are sensors to detect if windows or doors are disturbed and to detect motion. To accomplish the goals of this security system, we design a combinational logic circuit using two switches that can be set by the owner.

The following steps facilitate the design of a digital circuit to solve this type of problem:

1. Define the problem in words.
2. Write quasi-logic statements in English that can be translated into Boolean expressions.
3. Write the Boolean expressions.
4. Simplify and optimize the Boolean expressions, if possible.
5. Write an all-AND, all-NAND, all-OR, or all-NOR realization of the circuit to minimize the number of required logic gate IC components.
6. Draw the logic schematic for the electronic realization of the circuit.

Each of these steps is carried out for the home security system example in the following sections.

6.6.1 Define the Problem in Words

We begin our logic design by translating the problem into a series of word statements that reflect what should be happening in the system. We want the alarm system to create a high signal, sounding the alarm for certain combinations of the

house sensors. Also, we want the user to be able to select one of three operating states:

1. An active state where the alarm will sound only if the windows or doors are disturbed. This state is useful when the occupants are sleeping.
2. An active state where the alarm will sound if the windows or doors are disturbed or if there is motion in the house. This state is useful when the occupants are away.
3. A disabled state where the alarm will not sound. This state is useful during normal household activity.

At this time, we must define Boolean variables that will represent the inputs and outputs of the circuit. The following Boolean variables are used to design the security system logic:

- A : state of the door and window sensors
- B : state of the motion detector
- Y : output used to sound the alarm
- CD : 2-bit code set by the user to select the operating state defined by

$$CD = \begin{cases} 01 & \text{operating state 1} \\ 10 & \text{operating state 2} \\ 00 & \text{operating state 3} \end{cases}$$

The inputs to the system are A , B , C , and D , and the output is Y . We assume **positive logic** for A , B , and Y , where a 1 implies active or ON and a 0 implies inactive or OFF.

6.6.2 Write Quasi-Logic Statements

We further translate the word statements into logic-like statements. The quasi-logic statements for the security system are

Activate the alarm ($Y = 1$) if A is high *and* the code CD is 01 *or* activate the alarm if A *or* B is high *and* the code is 10.

Note the italicized logic operators, which should aid in writing the Boolean expression.

6.6.3 Write the Boolean Expression

Now we write the Boolean expression based on the quasi-logic statement. To create a product of 1 for the active control code 01, we need to form the expression $\overline{C} \cdot D$; to create a product of 1 for the other active control code 10, we need to form the expression $C \cdot \overline{D}$. Based on this, the complete Boolean expression for the security system is

$$Y = A \cdot (\overline{C} \cdot D) + (A + B) \cdot (C \cdot \overline{D}) \quad (6.29)$$

The alarm will sound ($Y = 1$) if the expression $A \cdot (\overline{C} \cdot D)$ is 1 or if the expression $(A + B) \cdot (C \cdot \overline{D})$ is 1; otherwise, the alarm will not sound ($Y = 0$). The first

expression will be 1 if and only if A is 1 *and* C is 0 *and* D is 1; the second expression will be 1 if and only if A *or* B is 1 *and* C is 1 *and* D is 0.

For this particular problem, we can simplify Equation 6.29 by looking at a truth table for the C and D terms for the different control code combinations.

C	D	$(\overline{C} \cdot D)$	$(C \cdot \overline{D})$
0	0	0	0
1	0	0	1
0	1	1	0

Note that $(\overline{C} \cdot D) = D$ and $(C \cdot \overline{D}) = C$ for the given control code combinations. If we disallow the state $C D = 1 1$ (see Question 6.23), Equation 6.29 can be simplified as

$$Y = (A \cdot D) + (A + B) \cdot C \quad (6.30)$$

6.6.4 AND Realization

Once a Boolean expression is simplified, it may be desirable to manipulate the result further in order to convert all operations to a preferred type of gate (e.g., AND or OR). The reason for this is that logic gates come packaged on integrated circuits (logic ICs) in groups of four, six, or eight, depending on the number of gate inputs and the number of IC pins. Therefore, we may be able to reduce the total number of ICs required by using all of one type of gate. Converting from one gate type to another is easily accomplished with a repeated application of De Morgan's laws. For the security system example, an all-AND representation is achieved by applying Equation 6.27 to convert each OR gate to an AND gate. Starting with Equation 6.30:

$$Y = (A \cdot D) + (A + B) \cdot C \quad (6.31)$$

First, we convert the second OR gate expression $A + B$:

$$Y = (A \cdot D) + (\overline{\overline{A} \cdot \overline{B}}) \cdot C \quad (6.32)$$

Now we have one expression OR-ed into another. Again, Equation 6.30 states that to convert the OR gate to an AND gate, invert each expression, change the gate, and invert the whole expression:

$$Y = \overline{\overline{A \cdot D} \cdot \overline{\overline{A} \cdot \overline{B}}} \cdot C \quad (6.33)$$

6.6.5 Draw the Circuit Diagram

Now it is relatively straightforward to draw the circuit using only AND gates and inverters from inspection of the final Boolean expression in Equation 6.33, by building the subexpressions one at a time and connecting them as shown in Figure 6.4. It is a good idea to label intermediate signals in a logic circuit with their corresponding Boolean expressions, as shown. This will help you prevent or find errors in your logic.

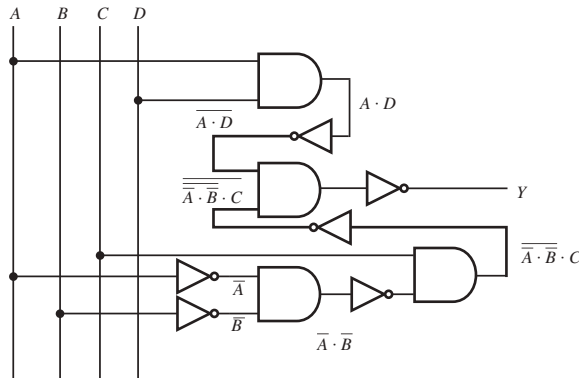


Figure 6.4 AND realization schematic of the security system.

Because there are a total of four AND gates and six inverters, the circuit can be constructed with two ICs: one quad AND gate IC (e.g., the 7408), which contains four AND gates, and one hex inverter IC (e.g., the 7404), which contains six inverters. Equation 6.30 could also be implemented using two ICs because only two OR gates and two AND gates are required. Therefore, for the security system, the all-AND realization did not reduce the number of ICs. However, for more complex Boolean expressions, a single-type gate realization will usually reduce the number of ICs.

The solution just presented is known as a hardware solution because it uses integrated circuit gates to provide the desired logic. An alternative is to implement the logic using a program running on a microcontroller. This solution, called a software solution, is presented in Example 7.5 in Section 7.5.2.

■ CLASS DISCUSSION ITEM 6.3

Everyday Logic

Make a list of devices that you interact with on a daily basis that use logic for control purposes. For each, describe what logic is being performed.

6.7 FINDING A BOOLEAN EXPRESSION GIVEN A TRUTH TABLE

As an alternative to the method presented in Sections 6.6.1 and 6.6.2, where we defined a logic problem in words and then wrote quasi-logic statements, sometimes it is more convenient to express the complete input/output combinations with a truth table. In these situations, there are two methods for directly obtaining the Boolean expression that performs the logic specified in the truth table. Both methods are described here, and an example is given to demonstrate their application.

The first method is known as the **sum-of-products method**. It is based on the fact that we can represent an output as a sum of products containing combinations of the inputs. For example, if we have three inputs A , B , and C and an output X , the sum of products would be a Boolean expression containing input terms AND-ed together to form product terms that are OR-ed together to define the output X as a Boolean sum. The following equation is an example of what a sum-of-products expression looks like:

$$X = (\overline{A} \cdot B \cdot C) + (\overline{A} \cdot \overline{B} \cdot C) + (A \cdot B \cdot \overline{C}) \tag{6.34}$$

If we form a product for every row in the truth table that results in an output of 1 and take the sum of the products, we can represent the complete logic of the table. For rows whose output values are 1, we must ensure that the product representing that row is 1. In order to do this, any input whose value is 0 in the row must be inverted in the product. By expressing a product for every input combination whose value is 1, we have completely modeled the logic of the truth table because every other combination will result in a 0.

The second method is known as the **product-of-sums method**. It is based on the fact that we can represent an output as a product of sums containing combinations of the inputs. For example, if we have three inputs A , B , and C and an output X , the product of sums would be a Boolean expression containing input terms OR-ed together to form sum terms that are AND-ed together to define the output X as a Boolean product. The following equation is an example of what a product-of-sums expression looks like:

$$X = (\overline{A} + B + C) \cdot (\overline{A} + \overline{B} + C) \cdot (A + B + \overline{C}) \tag{6.35}$$

If we form a sum for every row in the truth table that results in an output of 0 and take the product of the sums, we can represent the complete logic of the table. For rows whose output values are 0, we must ensure that the sum representing that row is 0. In order to do this, any input whose value is 1 in the row must be inverted in the sum. By expressing a sum for every input combination (row) whose value is 0, we have completely modeled the logic of the truth table because every other combination will result in a 1.

EXAMPLE 6.4

Sum of Products and Product of Sums

In performing binary arithmetic, the simplest operation is summing the two least significant bits resulting in a sum bit and a carry bit. The four possible combinations for adding two bits are shown below.

			1	C
0	0	1	1	A
<u>+0</u>	<u>+1</u>	<u>+0</u>	<u>+1</u>	<u>+B</u>
0	1	1	0	S

The last column shows the terminology used. The two input bits are labeled A and B , the sum of the two bits is labeled S , and the carry bit is labeled C . Only in the last case ($1 + 1$) is the carry bit 1; otherwise it is 0.

The truth table for this operation is

<i>A</i>	<i>B</i>	<i>S</i>	<i>C</i>
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

We apply the sum-of-products and product-of-sums methods to both of the outputs (*S* and *C*) to illustrate how the methods differ.

Using the procedure in the paragraph after Equation 6.34, the sum-of-products method applied to output *S* yields

$$S = (\bar{A} \cdot B) + (A \cdot \bar{B})$$

The product (AND) terms represent rows two and three where *S* is 1.

Using the procedure in the paragraph after Equation 6.35, the product-of-sums method applied to output *S* yields

$$S = (A + B) \cdot (\bar{A} + \bar{B})$$

The sum (OR) terms represent rows one and four where *S* is 0.

The sum-of-products method applied to output *C* yields

$$C = (A \cdot B)$$

The product (AND) term represents row four where *C* is 1.

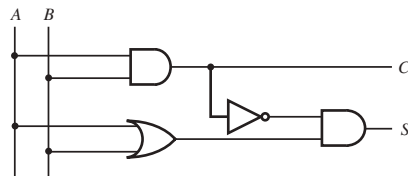
The product-of-sums method applied to output *C* yields

$$C = (A + B) \cdot (A + \bar{B}) \cdot (\bar{A} + B)$$

The sum (OR) terms represent rows one, two, and three, where *C* is 0.

Note that the sum-of-products method was easier to apply to output *C* because only a single row has an output of 1. You can verify all of the derived expressions by testing each with a truth table, comparing the results to the desired truth table (Question 6.31).

If we use the product-of-sums result for *S* and the sum-of-products result for *C*, we obtain a circuit (see Question 6.32) using the fewest number of gates:



This circuit is known as a **half adder** because it applies only to the two least significant bits of a sum of two multiple-bit numbers. The higher-order bits require a lower-order carry bit as an additional input, and the circuit is called a **full adder** (see Question 6.34).

■ CLASS DISCUSSION ITEM 6.4

Equivalence of Sum of Products and Product of Sums

Draw the logic circuits for S and C in Example 6.4 using only the product-of-sums results and then do the same for the sum-of-products results. Compare your circuits to the one shown in the example. Also, show that the sum-of-products and product-of-sums results are equivalent.



Internet Link

6.3 Karnaugh Mapping

An alternative to the sum-of-products and product-of-sums methods is Karnaugh mapping. This method results in a simplified Boolean expression through truth table manipulation. Internet Link 6.3 describes the method and provides examples.

6.8 SEQUENTIAL LOGIC

Combinational logic devices generate an output based on the input values, independent of the input timing. With **sequential logic** devices, however, the timing or sequencing of the input signals is important. Devices in this class include flip-flops, counters, monostables, latches, and more complex devices such as microprocessors. Sequential logic devices usually respond to inputs when a separate trigger signal transitions from one level to another. The trigger signal is usually referred to as the **clock** (CK) signal. The clock signal can be a periodic square wave or an aperiodic collection of pulses. Figure 6.5 illustrates edge terminology in relation to a clock pulse, where an arrow is used to indicate edges where state transitions occur. **Positive-edge-triggered** devices respond to a low-to-high (0 to 1) transition, and **negative-edge-triggered** devices respond to a high-to-low (1 to 0) transition. This topic is addressed again in Section 6.9.1 where it is applied to flip-flops.

6.9 FLIP-FLOPS

Because digital data is stored in the form of bits, digital memory devices such as computer random access memory (RAM) require a means for storing and switching between the two binary states. A **flip-flop** is a sequential logic device that can perform this function. The flip-flop is called a **bistable** device, because it has two and only two possible stable output states: 1 (high) and 0 (low). It has the capability to remain in a particular output state (i.e., storing a bit) until input signals cause it to change state. This is the basis of all semiconductor information storage and processing in digital computers; in fact, flip-flops perform many of the basic functions critical to the operation of almost all digital devices.

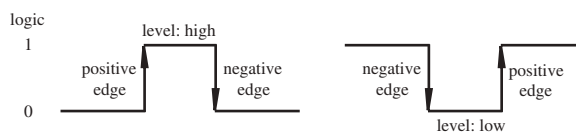


Figure 6.5 Clock pulse edges.

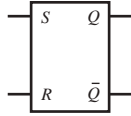


Figure 6.6 RS flip-flop.

A fundamental flip-flop, an **RS flip-flop**, is schematically shown in Figure 6.6. S is the **set** input, R is the **reset** input, and Q and $\bar{Q}$ are the **complementary outputs**. Most flip-flops include both outputs, where one output is the inverse (NOT) of the other. The RS flip-flop operates based on the following rules:

1. As long as the inputs S and R are both 0, the outputs of the flip-flop remain unchanged.
2. When S is 1 and R is 0, the flip-flop is *set* to $Q = 1$ and $\bar{Q} = 0$.
3. When S is 0 and R is 1, the flip-flop is *reset* to $Q = 0$ and $\bar{Q} = 1$.
4. It is “not allowed” (NA) to place a 1 on S and R simultaneously because the output will be unpredictable.

A truth table is a valuable tool for describing the functionality of a flip-flop. The truth table for a basic RS flip-flop is given in Table 6.4. The first row shows the memory state where the flip-flop retains the last value set or reset. Q_0 is the value of the output Q before the indicated input conditions were established; 1 is logic high and 0 is logic low. The NA in the last row indicates that the input condition for that row is not allowed. Because we are precluded from applying the $S = 1, R = 1$ input condition, the RS flip-flop is seldom used in actual designs. Other more versatile flip-flops that avoid the NA limitation are presented in subsequent sections.

To understand how flip-flops and other sequential logic circuits function, we will look at the internal design of an RS flip-flop illustrated in Figure 6.7a. It consists of combinational logic gates with internal feedback from the outputs to the inputs of the NAND gates. Figure 6.7b illustrates the timing of the various signals, which are affected by very short propagation delays through the NAND gates. Immediately after signal R transitions from 0 to 1, the inputs to the lower NAND gate are 0 and Q , which is still 1. This changes $\bar{Q}$ to 1 after a slight propagation delay Δt_1 . Feedback of $\bar{Q}$ to the top NAND gate drives Q to 0 after a slight delay Δt_2 . Now the flip-flop is reset, and it remains in this state even after R returns to 0. The set operation functions

Table 6.4 Truth table for the RS flip-flop

Inputs		Outputs	
S	R	Q	$\bar{Q}$
0	0	Q_0	$\bar{Q}_0$
1	0	1	0
0	1	0	1
1	1	NA	

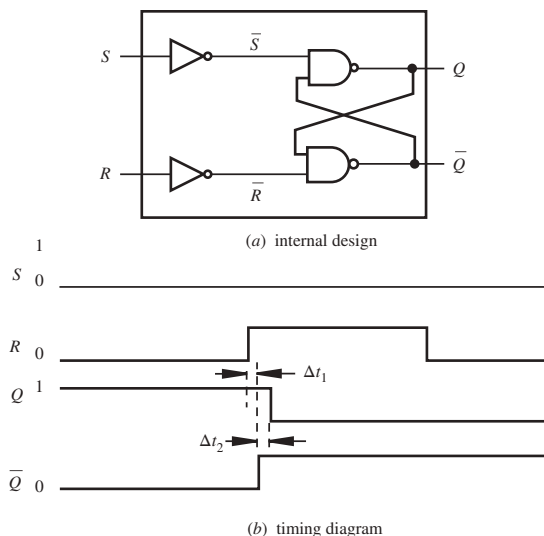


Figure 6.7 RS flip-flop internal design and timing.

in a similar manner. The propagation delays Δt_1 and Δt_2 are usually in the nano-second or picosecond range. All sequential logic devices depend on feedback and propagation delays for their operation.

6.9.1 Triggering of Flip-Flops

Flip-flops are usually **clocked**; that is, a signal designated “clock” coordinates or synchronizes the changes of the output states of the device. This allows the design of complex circuits such as a microprocessor where all system changes are triggered by a common clock signal. This is called **synchronous** operation because changes in state are coordinated by the clock pulses. The outputs of different types of clocked flip-flops can change on either a positive edge or a negative edge of a clock pulse. These flip-flops are termed **edge-triggered** flip-flops. Positive-edge triggering is indicated schematically by a small angle bracket on the clock input to the flip-flop (see Figure 6.8a). Negative-edge triggering is indicated schematically by a small circle and angle bracket on the clock input (see Figure 6.8b).

The function of the edge-triggered RS flip-flop is defined by the following rules:

1. If S and R are both 0 when the clock edge is encountered, the output state remains unchanged.
2. If S is 1 and R is 0 when the clock edge is encountered, the flip-flop output is **set** to 1. If the output is at 1 already, there is no change.
3. If S is 0 and R is 1 when the clock edge is encountered, the flip-flop output is **reset** to 0. If the output is at 0 already, there is no change.
4. S and R should never both be 1 when the clock edge is encountered.

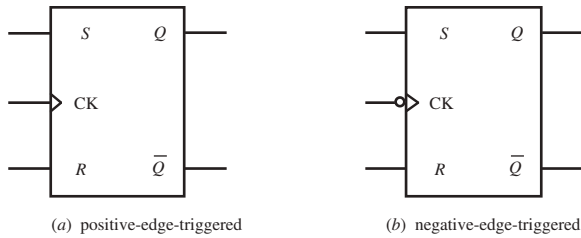


Figure 6.8 Edge-triggered RS flip-flops.

The truth table for a positive-edge-triggered RS flip-flop (Figure 6.8a) is given in Table 6.5. The up-arrow $\uparrow$ in the clock (CK) column represents the positive edge transition from 0 to 1. The NA in the second to last row indicates that the input condition for that row is not allowed. As long as there is no positive edge transition, the values of S and R have no effect on the output as shown by the X symbols in the last row of the table. An example timing diagram is shown in Figure 6.9. The output is reset ($Q = 0$) at the first positive edge of the clock signal, where $R = 1$ and $S = 0$, and the output is set ($Q = 1$) at the second positive edge, where $S = 1$ and $R = 0$.

There are special devices that are not edge triggered in the way just described. An important example is called a **latch**. Its schematic symbol is shown in Figure 6.10. The output Q tracks the input D as long as CK is high. When a negative edge occurs (i.e., when CK goes low), the flip-flop will store (latch) the value that D had at the negative edge, and that value will be retained at the output. Because the output follows the input when the clock is high, we say the latch is **transparent** during this

Table 6.5 Positive-edge-triggered RS flip-flop truth table

S	R	CK	Q	$\bar{Q}$
0	0	$\uparrow$	Q_0	$\bar{Q}_0$
1	0	$\uparrow$	1	0
0	1	$\uparrow$	0	1
1	1	$\uparrow$	NA	
X	X	0,1, $\downarrow$	Q_0	$\bar{Q}_0$

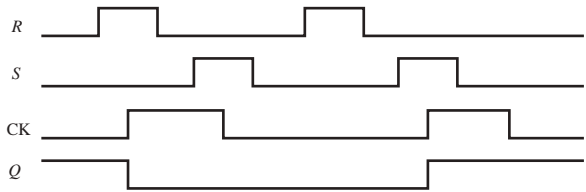


Figure 6.9 Positive-edge-triggered RS flip-flop timing diagram.

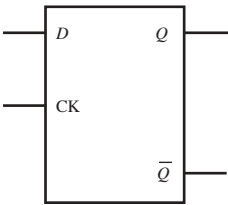


Figure 6.10 Latch.

Table 6.6 Latch truth table

<i>D</i>	<i>CK</i>	<i>Q</i>	$\overline{Q}$
0	1	0	1
1	1	1	0
X	0	Q_0	$\overline{Q}_0$

time. The latch can also be referred to as a positive-level-triggered device. The truth table for a latch is given in Table 6.6, and a timing diagram example is shown in Figure 6.11. Note how the output (*Q*) tracks the input (*D*) while the clock level is high (*CK* = 1). The X in the last row of the table indicates that the value of *D* has no effect on the output as long as *CK* is low.

6.9.2 Asynchronous Inputs

Flip-flops usually also have preset and clear functions that instantaneously override any other inputs. They are called **asynchronous inputs**, because their effect may be asserted at any time. They are not triggered by a clock signal. The **preset** input is used to set or initialize the output *Q* of the flip-flop to high (1). The **clear** input is used to clear or reset the output *Q* of the flip-flop to low (0). The small inversion symbols shown at the asynchronous inputs in Figure 6.12 are typical of most devices and imply that the function is asserted when the asynchronous input signal is low. Such an input is referred to as an **active low** input. Both preset and clear should not be asserted simultaneously. Either of these inputs can be used to define the state of a flip-flop after power-up; otherwise, at power-up the output of a flip-flop may be uncertain or default to some manufacturer-specified value.

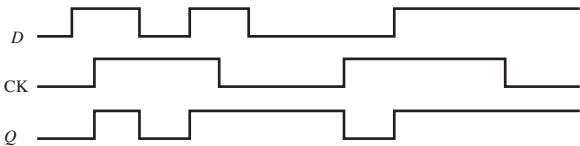


Figure 6.11 Latch timing diagram.

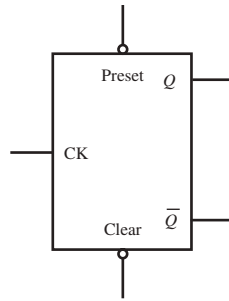


Figure 6.12 Preset and clear flip-flop functions.

6.9.3 D Flip-Flop

The **D flip-flop**, also called a data flip-flop, has a single input D whose value is stored and presented at the output Q at the edge of a clock pulse. A positive-edge-triggered D flip-flop is illustrated in Figure 6.13, and its truth table is given in Table 6.7. Unlike a latch, a D flip-flop does not exhibit transparency. The output changes only when triggered by the appropriate clock edge (in this case, a positive edge, indicated by the $\uparrow$ symbol).

Lab Exercise 7 explores latches and D flip-flops and shows how their functions differ. The exercise also deals with logic gates and shows how to wire switches for input into logic circuits.



Lab Exercise

Lab 7 Digital circuits—logic and latching

6.9.4 JK Flip-Flop

The **JK flip-flop** is similar to the RS flip-flop where the J is analogous to the S (set) input and the K is analogous to the R (reset) input. The major difference is that the J and K inputs may both be high simultaneously. This state causes the output to **toggle**, which means the output changes value (i.e., a 1 would become 0, and a 0 would become 1). The schematic representation and truth table for a negative edge-triggered JK flip-flop are shown in Figure 6.14 and Table 6.8. The first two rows of the table describe the preset or clear functions that can be used to initialize the output of the flip-flop. Recall that these features are active low and override the other inputs. The third row precludes presetting and clearing simultaneously. The symbol $\downarrow$ represents the negative edge of the clock signal, which causes the change in the

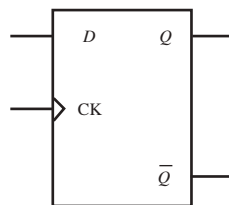


Figure 6.13 Positive-edge-triggered D flip-flop.

Table 6.7 Positive-edge-triggered D flip-flop truth table

D	CK	Q	$\overline{Q}$
0	$\uparrow$	0	1
1	$\uparrow$	1	0
X	0,1, $\downarrow$	Q_0	$\overline{Q}_0$

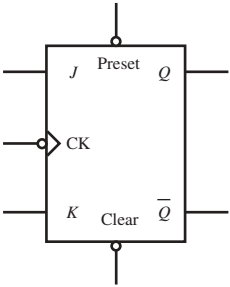


Figure 6.14 Negative-edge-triggered JK flip-flop.

Table 6.8 Truth table for a negative-edge-triggered JK flip-flop

Preset	$\overline{\text{Clear}}$	CK	J	K	Q	$\overline{Q}$
0	1	X	X	X	1	0
1	0	X	X	X	0	1
0	0			NA		
1	1	$\downarrow$	0	0	Q_0	$\overline{Q}_0$
1	1	$\downarrow$	1	0	1	0
1	1	$\downarrow$	0	1	0	1
1	1	$\downarrow$	1	1	$\overline{Q}_0$	Q_0
1	1	0,1, $\uparrow$	X	X	Q_0	$\overline{Q}_0$

output. The last row describes the memory feature of the flip-flop in the absence of a negative edge.

The JK flip-flop has a wide range of applications, and all flip-flops can easily be constructed from it with proper external wiring. The **T (toggle) flip-flop** serves as a good example of this. The symbol for a positive-edge-triggered T flip-flop and the equivalent JK flip-flop implementation are shown in Figure 6.15. The T flip-flop simply toggles the output (i.e., changes the value from 1 to 0 or from 0 to 1) every time it is triggered. The preset and clear functions are necessary to provide direct control over the output because the *T* input alone provides no mechanism for initializing the output value. The truth table is given in Table 6.9.

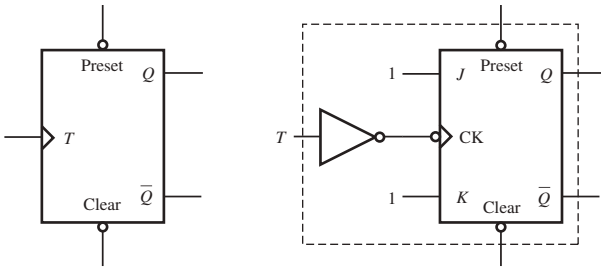


Figure 6.15 Positive-edge-triggered T flip-flop.

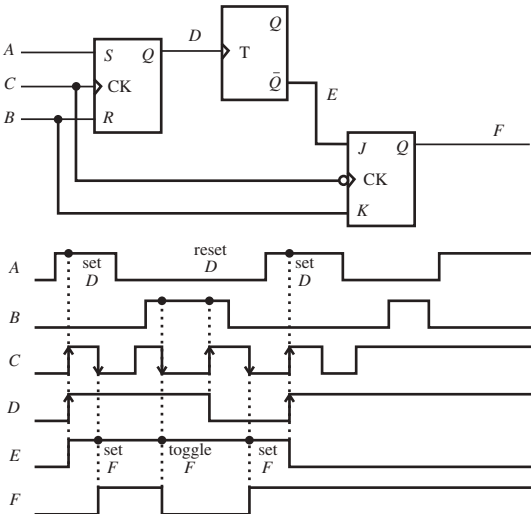
Table 6.9 Positive-edge-triggered T flip-flop truth table

T	Preset	Clear	Q	$\bar{Q}$
$\uparrow$	1	1	$\bar{Q}_0$	Q_0
0	1	1	Q_0	$\bar{Q}_0$
1	1	1	Q_0	$\bar{Q}_0$
$\downarrow$	X	X	Q_0	$\bar{Q}_0$
X	0	1	1	0
X	1	0	0	1

Flip-Flop Circuit Timing Diagram

EXAMPLE 6.5

Given the following sequential logic circuit that includes RS, T, and JK flip-flops with the inputs as indicated in the timing diagram, the digital outputs D , E , and F will be as shown. The signals D , E , and F are assumed to be low at the beginning of the timing diagram. Observe how signal D updates (sets or resets) at positive edges of C , signal E updates (toggles) at positive edges of D , and signal F updates (sets, resets, or toggles) at negative edges of C .



■ CLASS DISCUSSION ITEM 6.5

JK Flip-Flop Timing Diagram

Construct a timing diagram for the negative-edge-triggered JK flip-flop illustrating its complete functionality.

■ CLASS DISCUSSION ITEM 6.6

Computer Memory

With your knowledge of flip-flops, discuss how you think computer random access memory (RAM) works. What do you think happens to the RAM when you first turn on a computer?

6.10 APPLICATIONS OF FLIP-FLOPS

We have just seen that there are a variety of flip-flops. In the subsections below, we illustrate a number of applications that use flip-flops as their functional units.



Video Demo

6.2 Switch bounce

6.3 High-voltage disconnect switch

6.10.1 Switch Debouncing

When mechanical switches are opened or closed, there are brief current oscillations due to mechanical bouncing or electrical arcing. This phenomenon is called **switch bounce**. As illustrated in Figure 6.16, a single closing of a switch can result in multiple voltage transitions that usually occur within a few milliseconds. Video Demo 6.2 shows how switch bounce can be visualized on an oscilloscope. As is the case with the switch in Video Demo 6.2, sometimes bounce occurs more during the “make” action of the switch (where both mechanical and electrical bounce are likely to occur) as compared to the “break” action (where often only electrical bounce occurs, if any). Video Demo 6.3 shows a very dramatic example of the arcing that occurs when a high-voltage switch is opened or closed. In this case, a power transmission line is being shut down by a large disconnect switch, and a very large arc forms in the process.

The sequential logic circuit shown in Figure 6.17 can provide an output that is free from multiple transitions associated with switch bounce. As the switch breaks contact with *B*, signal bounce can occur on the *B* line. There is a small delay as the

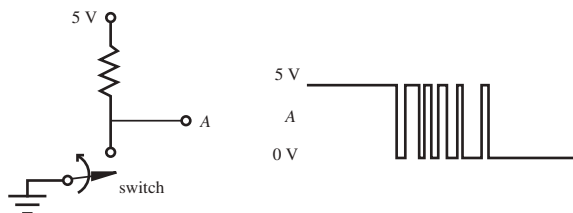


Figure 6.16 Switch bounce.

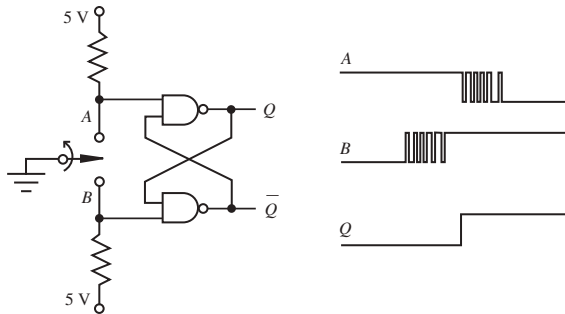


Figure 6.17 Switch debouncer circuit.

switch moves from contact *B* to *A*, and then signal bounce can occur on the *A* line as contact is established with *A*. However, as a result of the feedback and logic, the output signal (*Q*) experiences only a single transition from low to high (i.e., the output is bounce free). The circuit functions very much like a flip-flop (see Class Discussion Item 6.7).

■ CLASS DISCUSSION ITEM 6.7

Switch Debouncer Function

Track the inputs and outputs of the two NAND gates in Figure 6.17 as the switch moves from contact *B* to contact *A* and create a timing diagram. Also, draw an equivalent circuit for the debouncer using an RS flip-flop. Hint: Consider the gate switch delay as was done in Figure 6.7.

The switch shown in Figure 6.17 is called an SPDT switch, which is short for single-pole, double-throw (see Section 9.2.1 for more information). An SPDT switch has three leads. Section 6.12.2 shows a circuit that can be used to debounce SPST (single-pole, single-throw) switches, which only have two leads. Class Discussion Item 7.9 will also explore how microcontroller software can be used to debounce switch inputs directly. This is the most efficient solution if a design happens to include a microcontroller.

6.10.2 Data Register

Figure 6.18 shows a 4-bit **data register** that uses negative-edge-triggered D flip-flops to transfer data from four data lines to the outputs of four AND gates. It does this in two distinct steps. First, the data values D_i are transferred to the outputs Q of the flip-flops on the negative edge of the *load* signal. Then a pulse on the *read* line presents the data at the register outputs R_i of the AND gates. Data registers are used in microprocessors to hold data for arithmetic calculations. Data registers can be cascaded to store as many bits as are required.

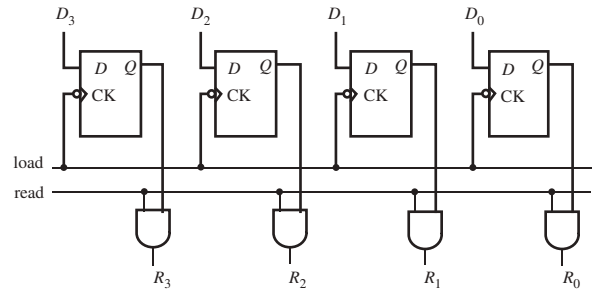


Figure 6.18 4-bit data register.

6.10.3 Binary Counter and Frequency Divider

Figure 6.19 shows a 4-bit **binary counter** consisting of four negative-edge-triggered toggle flip-flops connected in sequence. The timing diagram is also shown for the first 10 input pulses. The four output bits B_i change according to the binary number counting sequence, counting from 0 ($B_3B_2B_1B_0 = 0000$), to 1 ($B_3B_2B_1B_0 = 0001$), up to 15 ($B_3B_2B_1B_0 = 1111$), and then return back to 0. This circuit may also be used as a **frequency divider**. Output B_0 is a divide-by-2 output because its frequency is $1/2$ the input pulse train frequency. B_1 , B_2 , and B_3 are divide-by-4, -8, and -16 outputs, respectively.

6.10.4 Serial and Parallel Interfaces

Figures 6.20 and 6.21 show flip-flop circuits that convert between serial and parallel data. **Serial data** consists of a sequence of bits, or train of pulses, that occurs on a single data line. **Parallel data** consist of a set of bits that occurs simultaneously in

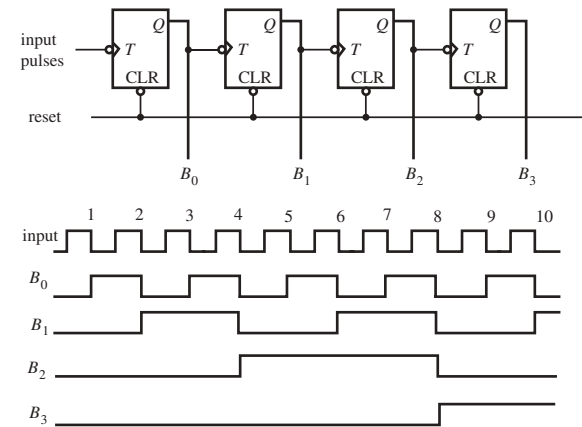


Figure 6.19 4-bit binary counter.

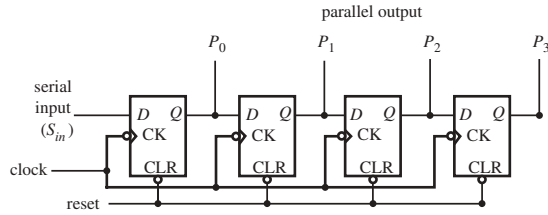


Figure 6.20 Serial-to-parallel converter.

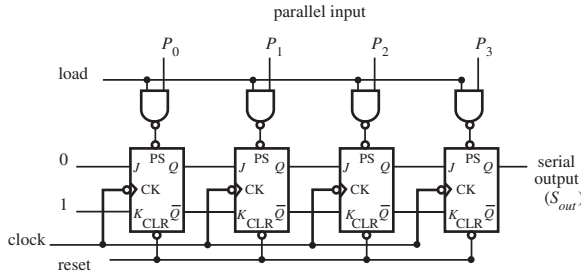


Figure 6.21 Parallel-to-serial converter.

parallel on a set of data lines. These circuits are useful in serial interfaces where binary data stored as a collection of bits is sent or received serially (1 bit at a time, through one wire) or in parallel (a group of bits all at once, through a set of wires or a computer bus). The serial-to-parallel converter utilizes negative-edge-triggered D flip-flops, and the parallel-to-serial converter utilizes negative-edge-triggered JK flip-flops. In both circuits, the serial input or output is synchronized by a *clock* signal. A *reset* line is used to clear the flip-flops prior to loading a set of bits. The *reset* line is active low, meaning that, when the line goes low, the flip-flops are cleared, causing the outputs Q to go low (0). The *load* line for the parallel-to-serial converter passes the data through the NAND gates, storing the data-line values in the flip-flops using the active-low flip-flop preset. When the *load* line goes high and a parallel bit (P_i) is high (1), then the respective flip-flop is preset, resulting in a high (1) output Q . The figures show 4-bit converters, but the flip-flops can be cascaded for a larger number of bits.

■ CLASS DISCUSSION ITEM 6.8

Converting Between Serial and Parallel Data

Looking at the Figures 6.20 and 6.21, explain in detail the function of the circuits that convert between serial and parallel data. Also, how is the **baud rate** (bits per second) for serial transmission related to the converter's clock speed?

■ CLASS DISCUSSION ITEM 6.9
Everyday Use of Logic Devices

Discuss the use of combinational and sequential logic functions in items you use every day. For each, identify the purpose of the logic function and what type you think it is (combinational or sequential).

6.11 TTL AND CMOS INTEGRATED CIRCUITS

Now that we have discussed digital signals, Boolean algebra, the formulation of digital logic expressions, and logic devices, we are prepared to present the characteristics of the actual integrated circuits that perform the various digital functions. There are two families of logic devices called *TTL* and *CMOS*. *TTL* stands for **transistor-transistor logic** and *CMOS* stands for **complementary metal-oxide semiconductor**. In general, any combinational or sequential logic circuit can be constructed with either family or with a mix of the two families, but to do this correctly, we need to understand the differences in the electronic characteristics of each family.

In Chapter 3, we described bipolar junction transistors that are the building blocks for *TTL* logic, and MOSFETs that are the building blocks for *CMOS* logic. The two states of a digital device are defined by voltages occurring within specified acceptable ranges. The states and voltages for the two families are shown in Figure 6.22. For comparison purposes, we assume that both families are powered by a 5 V DC supply, although *CMOS*, unlike *TTL*, can be powered with a DC supply between 3 V and 18 V. For a *TTL* digital input, **logic zero** (0) or **low** (*L*) is defined as a value less than 0.8 V, and **logic one** (1) or **high** (*H*) is defined as a value greater than 2.0 V. The digital output of a *TTL* device typically ranges between 0 and 0.5 V for low and between 2.7 V and 5 V for high. The input voltage range 0.8 V to 2.0 V

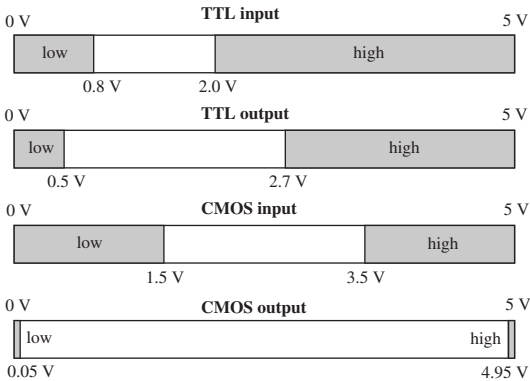


Figure 6.22 TTL and CMOS input and output levels.

between the logic 0 and logic 1 states is a dead zone where the input state is undefined. For a CMOS digital input, logic zero (0) or low (*L*) is defined as a value less than 1.5 V, and logic high is defined as a value greater than 3.5 V. The digital output of a CMOS device typically ranges between 0 and 0.05 V for low and between 4.95 V and 5 V for high. The input voltage range from 1.5–3.5 V is a dead zone where the input state is undefined.

When interfacing digital devices, in addition to understanding the voltage levels, it is also important to know the input and output current characteristics of the devices. Important characteristics are the amount of current a device can **source** (produce) when the output is high and the amount of current the device can **sink** (draw) when the output voltage is low. In manufacturer data sheets for digital devices, these characteristics are usually labeled as I_{OH} or “high-level output current” for the sourcing capability and I_{OL} or “low-level output current” for the sinking capability. Example data sheets for TTL and CMOS devices are presented later in the section.

We now examine the equivalent output circuits for TTL and CMOS devices. Referring to Figure 6.23, TTL logic switches between states by forward biasing one of the two output transistors. This output circuit is called a **totem pole** configuration, where two bipolar junction transistors are stacked between power and ground. When the upper transistor is forward biased and the bottom transistor is off, the output is high. The resistor, transistor, and diode drop the actual output voltage to a value typically about 3.4–4 V. When the lower transistor is forward biased and the top transistor is off, the output is low. You can see that the TTL device must source current when there is a high output and sinks current when the output is low. The values of the sink and source currents depend on the TTL subfamily. When the output of a TTL device is connected to the input of another, the TTL device dissipates power continuously regardless of whether the output is high or low.

CMOS logic ICs employ complementary pairs of p-type and n-type enhancement-mode MOS transistors at their outputs, hence the name **complimentary MOS (CMOS)**. Referring to the CMOS output circuit in Figure 6.23, if the input signal to this output stage is high, the p-type transistor (top) is off and the n-type transistor (bottom) is on, so the output is pulled low. When the input is low, the top

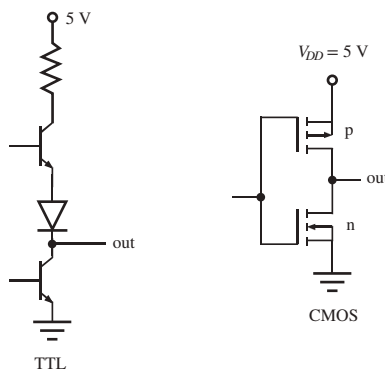


Figure 6.23 TTL and CMOS output circuits.

transistor is on and the bottom transistor is off, so the output is pulled high. When the output is high, the device sources current; and when the output is low, the device sinks current if there is a load attached to the output. Because the MOSFET gates are insulated, CMOS devices consume power only when switching between states or when there is a load attached. Therefore, a major difference between CMOS and TTL devices is that TTL devices require power continuously (see Class Discussion Item 6.10).

CMOS is often recommended over TTL for the following reasons:

- When an output is unloaded or connected to other CMOS devices, CMOS requires power only when an output switches its logic state. Therefore, CMOS is useful in battery-operated applications where power is limited.
- The wide power supply range of CMOS (3–18 V) provides more design flexibility and allows use of less tightly regulated power supplies.

There are some disadvantages of CMOS:

- CMOS is sensitive to static discharge even with internal protective diodes. Protective packaging and static discharge during handling and assembly are necessary; otherwise, the devices would easily be damaged.
- CMOS requires negligible input current, but its output current is also small compared to TTL. This limits the ability of CMOS to drive large TTL fan-out or other high-current devices.

■ CLASS DISCUSSION ITEM 6.10
CMOS and TTL Power Consumption

Figure 6.23 shows the output circuits for TTL and CMOS devices. Study these circuits and convince yourself why TTL devices require power to maintain output levels when connected to other TTL devices and CMOS devices do not require power when connected to other CMOS devices.

6.11.1 Using Manufacturer IC Data Sheets

Manufacturers provide **data books** that contain **data sheets** for all the devices they manufacture. The data sheets contain all the information you might need to use the devices in your designs, including internal schematics, pin-out connections, maximum ratings, operating conditions, and electrical and switching characteristics. The labeling system used in TTL data books is usually in the form AAxxyyzz, where AA is the manufacturer's prefix (SN for TI and others; DM for National Semiconductor); xx distinguishes between military (xx = 54) and industrial (xx = 74) quality; y distinguishes between different internal designs (no letter: standard TTL; L: low-power dissipation; H: high-power dissipation; S: Schottky type; AS: advanced Schottky, LS: low-power Schottky; ALS: advanced low-power Schottky); and zz is the device number in the data book. Schottky devices have faster switching speeds and require less power. CMOS devices are available in the 40XXB series and the 74CXX series.

The latter is pin compatible with the TTL 74XX series. There are also different varieties of the 74CXX family that provide different speed and power characteristics. They include the 74HCXX (high-speed CMOS), 74ACXX (advanced CMOS), and 74HCTXX and 74ACTXX (high-speed CMOS with TTL threshold).

Figures 6.24 through 6.26 illustrate some of the information available in a TTL data book. The 74LS00 QUAD NAND IC is the specific example shown here. Internet Link 6.4 points to the entire datasheet that contains a wealth of information, much of which you might find superfluous. Similar to other gates, the internal design is composed of transistors, resistors, and diodes, which are easily manufactured as an integrated circuit on a silicon chip. The IC is manufactured as a **dual in-line package (DIP)**, suitable for plugging into a breadboard, or a **small outline package (SOP)**, suitable for surface-mount soldering to a production circuit board. The pin connections (AKA pin-out) are shown in Figure 6.25. This particular IC has four NAND gates on a single silicon chip, hence the name QUAD NAND gate. All logic gates are active devices that require power via the V_{cc} and GND pins. The V_{cc} pin, which connects to the collector side of the internal bipolar junction transistors (hence the “cc” subscript), requires 5 V. As mentioned previously, two important parameters in Figure 6.26 are the current sourcing and sinking capacities. The TTL-LS NAND gate shows an output current sourcing limit (I_{OH}) of -0.4 mA and an output current sinking limit (I_{IH}) of 8 mA. The standard convention is to use a positive number for current entering the device. TTL devices can usually sink much more current than they can source.



Internet Link

6.4 74LS00 TTL QUAD NAND data sheet

■ CLASS DISCUSSION ITEM 6.11

NAND Magic

Even though the NAND gate circuit shown in Figure 6.24 is much more complicated than basic transistor circuits we’ve seen previously, convince yourself that it results in NAND logic.

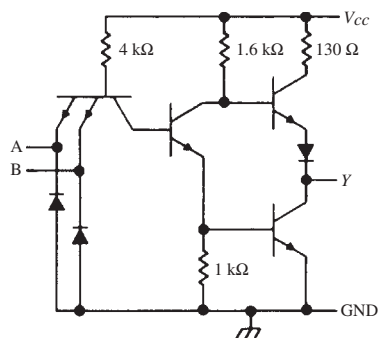


Figure 6.24 NAND gate internal design.

Source: Texas Instruments, Dallas, TX.

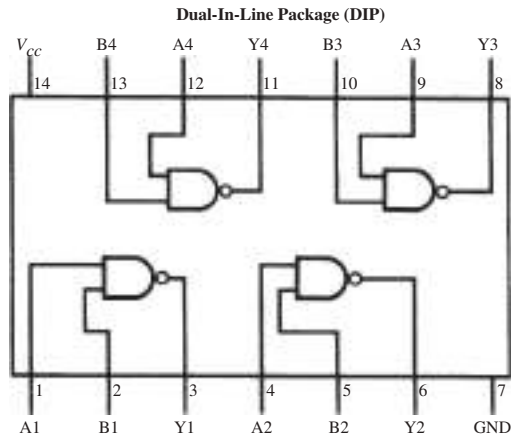


Figure 6.25 QUAD NAND gate IC pin-out.

Source: National Semiconductor, Santa Clara, CA.



Internet Link

6.5 4011B CMOS
QUAD NAND data
sheet

Figures 6.27 and 6.28 illustrate some of the information available in a CMOS databook. The 4011B QUAD NAND IC is the specific example shown. Internet Link 6.5 points to the entire data sheet. A CMOS output is composed of two complementary FETs, and the high output is at the supply voltage (usually 5 V) and the low output at ground. The positive supply voltage is denoted as V_{DD} (on the drain sides of the internal MOSFETs); and the low side, usually ground, is denoted as V_{SS} (on the source side of the internal MOSFETs). In Figure 6.28, the CMOS NAND operating with a supply voltage of 5 V can sink or source 1 mA.

6.11.2 Digital IC Output Configurations

Three different types of output circuits are used in TTL devices. The most common is the **totem pole** configuration, where two transistors are stacked between power and ground as shown in Figures 6.23 and 6.24. The second type of output circuit is known as an **open-collector output**. As shown in Figure 6.29, this configuration requires an external **pull-up resistor** connected to a power supply to produce the output states. When the output transistor is saturated (ON), V_{out} is low; and when it is in cutoff (OFF), V_{out} is high. Some devices that include this type of output include the 7401, 7403, 7405, and 7406. The third type of output circuit is known as the **tristate output**, where an additional input signal controls a third output state. When enabled, the third state produces a high-output impedance that effectively disconnects the output from any circuit to which it is attached. This permits attaching multiple devices to a single line where only one output would be enabled at a time (e.g., in the bus of a computer).

Some CMOS devices, instead of having a full CMOS output stage as shown in Figures 6.23 and 6.27, have an **open-drain** output, which is analogous to the TTL open-collector output.

Absolute Maximum Ratings (Note)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	7V
Input Voltage	7V
Operating Free Air Temperature Range	
DM54LS and 54LS	–55°C to +125°C
DM74LS	0°C to +70°C
Storage Temperature Range	–65°C to +150°C

Note: The “Absolute Maximum Ratings” are those values beyond which the safety of the device cannot be guaranteed. The device should not be operated at these limits. The parametric values defined in the “Electrical Characteristics” table are not guaranteed at the absolute maximum ratings. The “Recommended Operating Conditions” table will define the conditions for actual device operation.

Recommended Operating Conditions

Symbol	Parameter	DM54LS00			DM74LS00			Units
		Min	Nom	Max	Min	Nom	Max	
V_{CC}	Supply Voltage	4.5	5	5.5	4.75	5	5.25	V
V_{IH}	High Level Input Voltage	2			2			V
V_{IL}	Low Level Input Voltage			0.7			0.8	V
I_{OH}	High Level Output Current			–0.4			–0.4	mA
I_{OL}	Low Level Output Current			4			8	mA
T_A	Free Air Operating Temperature	–55		125	0		70	°C

Electrical Characteristics over recommended operating free air temperature range (unless otherwise noted)

Symbol	Parameter	Conditions	Min	Typ (Note 1)	Max	Units
V_I	Input Clamp Voltage	$V_{CC} = \text{Min}$, $I_I = -18 \text{ mA}$			–1.5	V
V_{OH}	High Level Output Voltage	$V_{CC} = \text{Min}$, $I_{OH} = \text{Max}$, $V_{IL} = \text{Max}$	DM54	2.5	3.4	V
			DM74	2.7	3.4	
V_{OL}	Low Level Output Voltage	$V_{CC} = \text{Min}$, $I_{OL} = \text{Max}$, $V_{IH} = \text{Min}$	DM54		0.25	0.4
			DM74		0.35	0.5
		$I_{OL} = 4 \text{ mA}$, $V_{CC} = \text{Min}$	DM74		0.25	0.4
I_I	Input Current @ Max Input Voltage	$V_{CC} = \text{Max}$, $V_I = 7 \text{ V}$			0.1	mA
I_{IH}	High Level Input Current	$V_{CC} = \text{Max}$, $V_I = 2.2 \text{ V}$			20	μA
I_{IL}	Low Level Input Current	$V_{CC} = \text{Max}$, $V_I = 0.4 \text{ V}$			–0.36	mA
I_{OS}	Short Circuit Output Current	$V_{CC} = \text{Max}$ (Note 2)	DM54	–20	–100	mA
			DM74	–20	–100	
I_{CCH}	Supply Current with Outputs High	$V_{CC} = \text{Max}$		0.8	1.6	mA
I_{CCL}	Supply Current with Outputs Low	$V_{CC} = \text{Max}$		2.4	4.4	mA

Switching Characteristics at $V_{CC} = 5 \text{ V}$ and $T_A = 25^\circ\text{C}$ (See Section 1 for Text Waveforms and Output Load)

Symbol	Parameter	R _L = 2 kΩ				Units
		C _L = 15 pF		C _L = 50 pF		
		Min	Max	Min	Max	
t _{PLH}	Propagation Delay Time Low to High Level Output	3	10	4	15	ns
t _{PHL}	Propagation Delay Time High to Low Level Output	3	10	4	15	ns

Figure 6.26 DM74LS00 NAND gate IC data sheet.

Source: National Semiconductor, Santa Clara, CA.

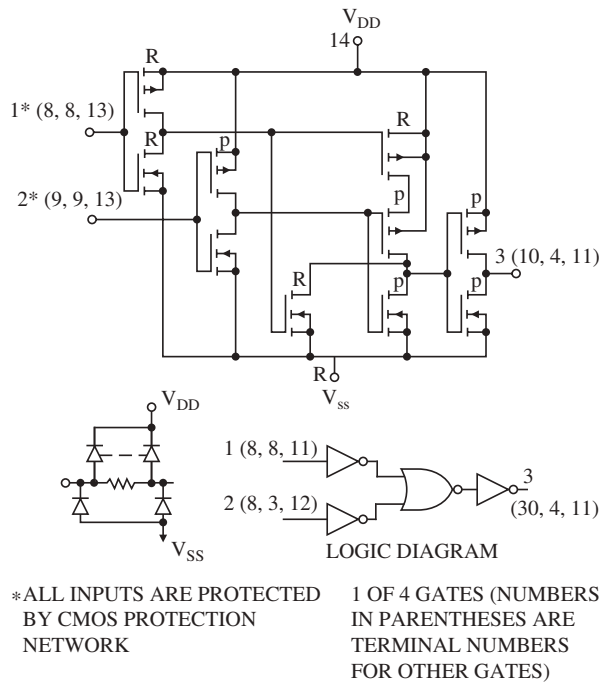


Figure 6.27 CMOS 4011B NAND gate internal design.

Source: Texas Instruments, Dallas, TX.

■ CLASS DISCUSSION ITEM 6.12

Driving an LED

There are three different ways to drive an LED with a TTL digital device, depending on whether the output type is totem pole or open collector and whether or not the device sinks or sources current through the LED. Sketch the three possible output circuits. Which of these three circuits exhibits positive logic (i.e., when the output of the device is HI, the LED is ON and when the output is LOW, the LED is OFF)? For each of the three circuits, indicate whether it is sourcing or sinking current. In which circuit would you expect the LED to be the brightest? Why?

6.11.3 Interfacing TTL and CMOS Devices

There may be situations where we need to connect devices from the same and/or different families. We consider connecting a TTL device to other TTL and CMOS devices and connecting a CMOS device to other CMOS and TTL devices. When designing digital systems, it is generally recommended to use only one family of devices (TTL or CMOS), but sometimes you may be required to interface between families.

STATIC ELECTRICAL CHARACTERISTICS

CHARACTER- ISTIC	CONDITIONS			LIMITS AT INDICATED TEMPERATURES (°C)							UNITS
	V _O (V)	V _{IN} (V)	V _{DD} (V)					+ 25			
				−55	−40	+85	+125	Min.	Typ.	Max.	
Quiescent Device Current, I _{DD} Max.	–	0.5	5	0.25	0.25	7.5	7.5	–	0.01	0.25	mA
	–	0.10	10	0.5	0.5	15	15	–	0.01	0.5	
	–	0.15	15	1	1	30	30	–	0.01	1	
	–	0.20	20	5	5	150	150	–	0.02	5	
Output Low (Sink) Current, I _{OL} Min.	0.4	0.5	5	0.64	0.61	0.42	0.36	0.51	1	–	mA
	0.5	0.10	10	1.6	1.5	1.1	0.9	1.3	2.6	–	
	1.5	0.15	15	4.2	4	2.8	2.4	3.4	6.8	–	
Output High (Source) Current, I _{OH} Min.	4.6	0.5	5	−0.64	−0.61	−0.42	−0.36	−0.51	−1	–	
	2.5	0.5	5	−2	−1.8	−1.3	−1.15	−1.6	−3.2	–	
	9.5	0.10	10	−1.6	−1.5	−1.1	−0.9	−1.3	−2.6	–	
	13.5	0.15	15	−4.2	24	−2.8	−2.4	−3.4	−6.8	–	
Output Voltage: Low-Level, V _{OL} Max.	–	0.5	5	0.05				–	0	0.05	V
	–	0.10	10	0.05				–	0	0.05	
	–	0.15	15	0.05				–	0	0.05	
Output Voltage: High-Level, V _{OH} Min.	–	0.5	5	4.95				4.95	5	–	
	–	0.10	10	9.95				9.95	10	–	
	–	0.15	15	14.95				14.95	15	–	
Input Low Voltage, V _{IL} Max.	4.5	–	5	1.5				–	–	1.5	V
	9	–	10	3				–	–	3	
	13.5	–	15	4				–	–	4	
Input High Voltage, V _{IH} Min.	0.5, 4.5	–	5	3.5				3.5	–	–	
	1.9	–	10	7				7	–	–	
	1.5, 13.5	–	15	11				11	–	–	
Input Current, I _{IN} Max.		0.18	18	±0.1	±0.1	±1	±1	–	± 10 ²⁵	± 0.1	mA

Figure 6.28 CMOS 4011B NAND gate IC data sheet.

Source: Texas Instruments, Dallas, TX.

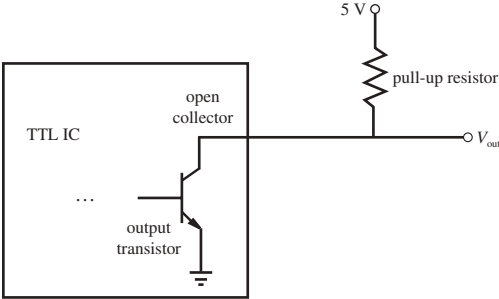


Figure 6.29 Open-collector output with pull-up resistor.

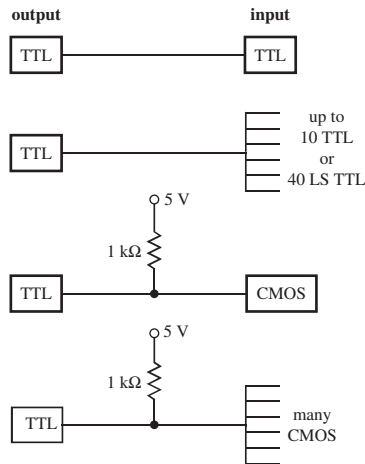


Figure 6.30 Interfacing TTL to digital devices.

Figure 6.30 shows how to interface TTL to different combinations of digital ICs. The output of a TTL device sinks current when it is low and sources current when it is high. The TTL low sink current (I_{OL}) is the limiting factor when interfacing to multiple TTL inputs. A TTL output can drive up to 10 standard TTL inputs or up to 40 Low-power Schottky (LS) TTL inputs. TTL outputs are easy to interface to CMOS due to the insulating gate input, which draws no steady-state current. It is necessary only to ensure voltages match when connecting TTL outputs to CMOS inputs. Referring back to Figure 6.22, a TTL low output will match a CMOS low input just fine. However, a TTL high may be as low as 2.7 V, which is not enough to match the 3.5 V input required by CMOS. As shown in Figure 6.30, using a pull-up resistor on the TTL output will raise the output voltage above the 3.5 V required by a CMOS input. The pull-up resistor must be large enough (e.g., 1 kΩ) that the TTL low sink current (I_{OL}) for the device is not exceeded. If power consumption is a concern, the pull-up resistor can be even larger.

Figure 6.31 shows how to interface CMOS to different combinations of digital ICs. A CMOS device neither sources nor sinks current at its input due to the insulating gate at the input. Therefore, CMOS can interface to multiple CMOS inputs. If CMOS is powered by a 5 V supply voltage (V_{DD}) and is used to drive TTL devices, a CMOS high is no problem because the CMOS device can source enough current to drive the TTL input. However, a CMOS low can sink only enough current to drive one LS TTL input. A CMOS 4049 buffer can be used to provide adequate fan-out for up to two standard TTL inputs or approximately 10 LS TTL inputs.

Section 7.9 provides additional information on how to interface TTL and CMOS inputs and outputs to various types of devices. Although the material is specific to the PIC microcontroller, it applies to any TTL and CMOS device. Included are interfaces to sensors, switches, keyboards, Schmitt triggers, power transistors, and relays.

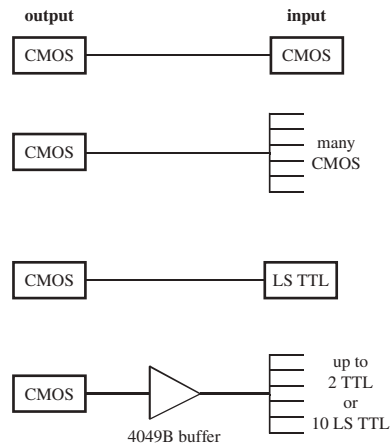


Figure 6.31 Interfacing CMOS to digital devices.

In summary, when using ICs of one logic family exclusively, you need not be concerned with voltage levels and current drives as long as the fan-out is less than 10 for TTL (CMOS can be higher). CMOS is better for general use because it draws no current unless switching, and the output swings from nearly ground to the positive supply value. However, at high frequency, CMOS can dissipate nearly the power required by an equivalent TTL circuit.

6.12 SPECIAL PURPOSE DIGITAL INTEGRATED CIRCUITS

This section presents some important special purpose ICs useful for digital design. They include the decade counter, the Schmitt trigger, and the 555 timer ICs.

6.12.1 Decade Counter

Section 6.10.3 presented a flip-flop circuit that can be used to perform binary counting. Another common counter, called a **decade counter**, can be constructed using a 7490 IC (Question 6.52). It is a negative-edge-triggered counter, and the output is in binary coded decimal (BCD) consisting of 4 bits, making it useful for decimal counting applications. Table 6.10 shows the output sequence for the 4 bits as the counter increments from 0 to 9. The timing diagram for the input and four outputs of the decade counter are shown in Figure 6.32. Note that the counter output cycles back to 0000 (0_{10}) after 1001 (9_{10}).

As illustrated in Figure 6.33, BCD counters can be cascaded in order to count in powers of 10. Output *D* can be used as the clock input for a second 7490, thus cascading the two together to raise the range for counting from 0 to 99. Further cascading allows counting of higher powers of 10. The 7490 is a versatile IC and can

Table 6.10 7490 decade counter BCD coding

Decimal Count	BCD Output			
	D	C	B	A
0	0	0	0	0
1	0	0	0	1
2	0	0	1	0
3	0	0	1	1
4	0	1	0	0
5	0	1	0	1
6	0	1	1	0
7	0	1	1	1
8	1	0	0	0
9	1	0	0	1
0	0	0	0	0

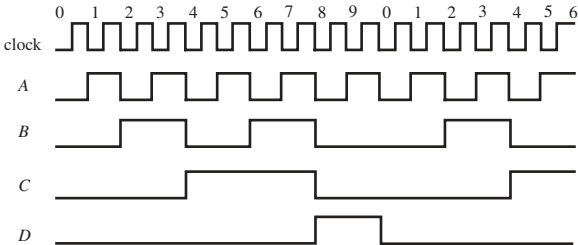


Figure 6.32 Decade counter timing.

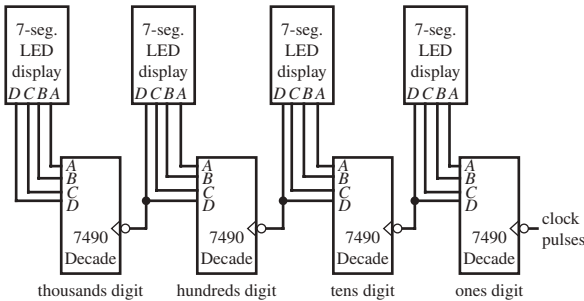


Figure 6.33 Cascaded decade counters.



Internet Link

6.6 7490 decade counter data sheet

be wired in a variety of useful ways. Examples include binary counters, divide-by-2 counters, and divide-by-4 counters. Internet Link 6.6 points to the entire data sheet for the 7490. The data sheet provides instructions for wiring the IC for the various configurations it supports.

A convenient device for viewing a BCD output is a seven-segment LED display (see Figure 6.34) driven by a 7447 BCD-to-seven-segment decoder. Figure 6.35 shows a two-segment LED display that can display numbers ranging from 0 to 99. Also shown in the photograph is the 7447 display-decoder IC. The 7447 converts the 4 BCD bits at its inputs into a 7-bit code to drive the LED segments properly. The function table describing the input (BCD) to output (negative logic seven-segment LED code) relationship for the 7447 is shown in Table 6.11. You can verify some of the rows in this table by drawing the digits with the appropriate segments. Figure 6.36 illustrates the internal design of the 7447, which consists of combinational logic circuits. Internet Link 6.7 points to the full data sheet for the 7447.



Internet Link

6.7 7447 seven-segment display decoder data sheet

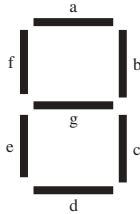


Figure 6.34 Seven-segment LED display.

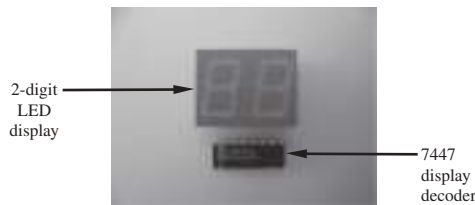


Figure 6.35 Two-digit LED display and a 7447 display decoder.

©David Alciatore

Table 6.11 7447 BCD to seven-segment decoder

Decimal digit	Input				Output						
	D	C	B	A	$\bar{a}$	$\bar{b}$	$\bar{c}$	$\bar{d}$	$\bar{e}$	$\bar{f}$	$\bar{g}$
0	0	0	0	0	0	0	0	0	0	0	1
1	0	0	0	1	1	0	0	1	1	1	1
2	0	0	1	0	0	0	1	0	0	1	0
3	0	0	1	1	0	0	0	0	1	1	0
4	0	1	0	0	1	0	0	1	1	0	0
5	0	1	0	1	0	1	0	0	1	0	0
6	0	1	1	0	1	1	0	0	0	0	0
7	0	1	1	1	0	0	0	1	1	1	1
8	1	0	0	0	0	0	0	0	0	0	0
9	1	0	0	1	0	0	0	0	1	0	0

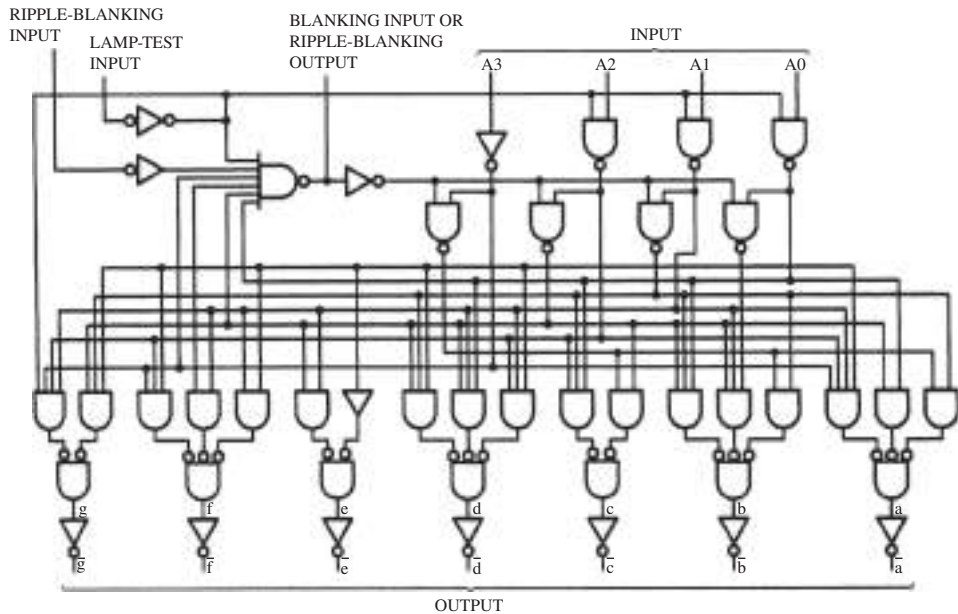


Figure 6.36 7447 internal design.

Source: National Semiconductor, Santa Clara, CA.

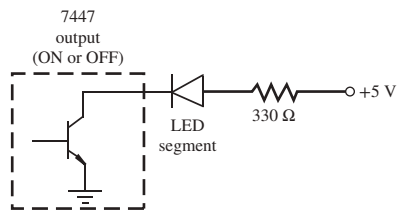


Figure 6.37 7447 output circuit.



Video Demo

6.4 Decade counter and display circuit driven by a 555 timer

If the 7447 decoder driver is properly connected to a seven-segment LED display, the output from a counter can be displayed in numerical digit form. Note that the decoder driver does not actually drive the segment LEDs by supplying current to them; rather, it sinks current from them as illustrated in Figure 6.37. The outputs of the 7447 are open-collector outputs. The resistor and LED segment complete the circuit for each 7447 output. Therefore, the LED is ON (i.e., illuminated) when the 7447 output is low (0), allowing current to flow to ground. 330 Ω resistors are used in series with the segments to limit the current into the decoder driver, thus preventing damage to the segments.

Lab Exercise 8 involves building a counter circuit with an LED digit display. Video Demo 6.4 shows the final functioning circuit.

■ CLASS DISCUSSION ITEM 6.13

Up-Down Counters

Using a TTL logic handbook or an online search, look up the digital IC known as an **up-down counter**. Note that the device can be used as a binary, hexadecimal, or decimal counter. Discuss the purpose of counting both up and down and give examples of devices that might use the different configurations.



Lab Exercise

Lab 8 Digital circuits—counter and LED display

6.12.2 Schmitt Trigger

In some applications, digital pulses may not exhibit sharp edges; instead, the signal may ramp from 0 to 5 V over a finite time period, and it may do so in a “noisy” (jumpy) fashion as illustrated in Figure 6.38. The Schmitt trigger is a device that can convert such a signal into a sharp pulse using the threshold hysteresis effect illustrated in the figure. The output goes high when the input exceeds the high threshold and remains high until the input falls below the low threshold. The hysteresis between the low and high thresholds results in the distinct edges in the output. Six Schmitt triggers are usually packaged on a single IC (e.g., the 7414 Hex Schmitt Trigger Inverter). A complete demonstration and explanation of how a Schmitt trigger works and how it is useful can be found in Video Demo 6.5.

Section 6.10.1 presented a circuit that can be used to debounce an SPDT switch, which has three leads. That circuit cannot be used to debounce signals from an SPST switch, which only has two leads. Common pushbutton switches are normally of this variety (see Section 9.2.1 for more information). Figure 6.39 shows a Schmitt trigger *RC* circuit that can be used to debounce an SPST switch. As the inversion circle on the output of the 7414 indicates, the 7414 is a Schmitt trigger inverter, meaning the output will be the inverse of the input. With the switch open, as shown, the capacitor is fully charged to 5 V, and the output of the 7414 is low. When the switch is closed, the capacitor is shorted to ground, and the 7414’s output goes high. Depending on the capacitor value, the capacitor voltage might discharge below the low threshold of the 7414 on first contact. If not, the capacitor will eventually discharge as any



Video Demo

6.5 Schmitt trigger

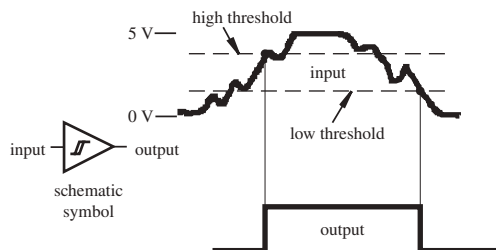


Figure 6.38 Input and output of a Schmitt trigger.

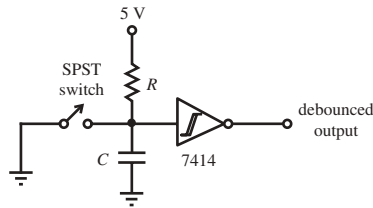


Figure 6.39 Schmitt trigger SPST debounce circuit.

bouncing occurs and continual contact is established. When the switch is opened, the capacitor again begins to charge. Any switch bounce occurring when the switch is opened just momentarily interrupts the charging. When the charge on the capacitor exceeds the high threshold of the 7414, the output again goes low. The result is a clean, bounce-free, output pulse.

6.12.3 555 Timer



Internet Link

6.8 NE555 timer
data sheet

The 555 integrated circuit is known as the “time machine” because it performs a wide variety of timing tasks. It is a combination of digital and analog circuits. The block diagram for the 555, including pin terminology and numbering, is shown in Figure 6.40. Two packages and pin configurations for the 555 are shown in Figure 6.41. Manufacturers usually list 555 ICs (e.g., TI’s NE555) in the special function section of their *Linear* data books. Internet Link 6.8 points to the complete data sheet for the 555 IC. Applications for the 555 include bounce-free switches, cascaded timers, frequency dividers, voltage-controlled oscillators, pulse generators, LED flashers, and many other useful circuits.

A circuit easily built with a 555 IC is the **monostable multivibrator** shown in Figure 6.42. It is constructed by adding an external capacitor and resistor to a 555.

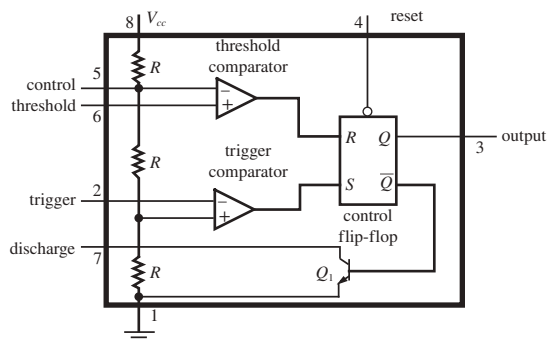


Figure 6.40 Block diagram of the 555 IC.

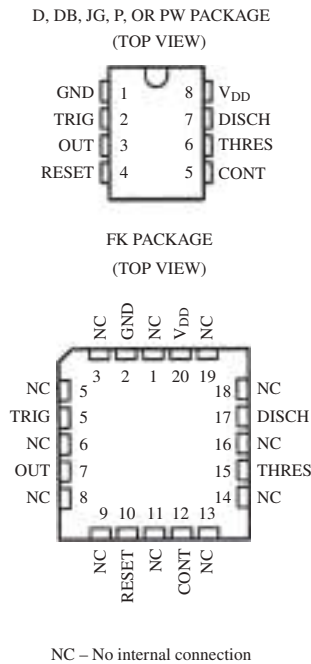


Figure 6.41 555 pin-out.
Source: Texas Instruments, Dallas, TX.

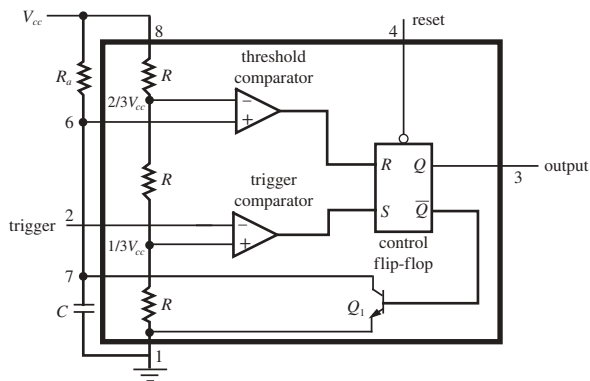


Figure 6.42 Monostable multivibrator (one-shot).

The circuit generates a single pulse of desired duration when it receives a trigger signal, hence it is also called a **one-shot**. The time constant of the resistor-capacitor combination determines the length of the pulse. In Figure 6.43, the sequence of operation is as follows: When the circuit is powered up or after the reset is activated,

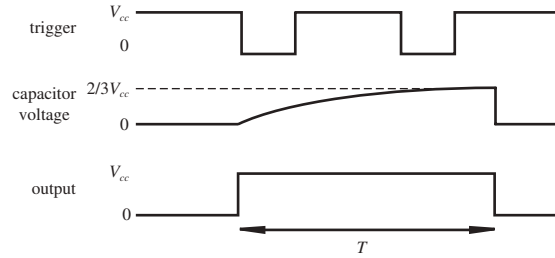


Figure 6.43 One-shot timing.

the output will be low ($Q = 0$), transistor Q_1 is saturated (ON) shorting capacitor C , and the outputs of both comparators are low. When the trigger pulse goes below $(1/3)V_{cc}$, the trigger comparator goes high, setting the flip-flop. Now that the output is high ($Q = 1$), transistor Q_1 cuts off, and the capacitor begins to charge with time constant $\tau = R_a C$. The time constant is the time required for the capacitor voltage to reach 63.2% of its full charge value V_{cc} (see Section 4.9). When the capacitor voltage reaches $(2/3)V_{cc}$, the threshold comparator resets the flip-flop, which resets the output low ($Q = 0$) and discharges the capacitor again. If the trigger is pulsed while the output is high, it has no effect. The length of the pulse is given approximately (Question 6.55) by

$$\Delta T \approx 1.1R_a C \quad (6.36)$$

As alternatives to the 555 one-shot circuit, the TTL logic family also includes devices that can be used as one-shots. Examples are the 74121 and the 74123. They also require an external resistor and capacitor to control the pulse width.

Another important circuit that can be constructed with a 555 timer is an **astable multivibrator**, also called a square-wave generator or an oscillator. The schematic for this circuit is shown in Figure 6.44. When the circuit is powered, the capacitor C charges through the series resistors R_1 and R_2 with a time constant $(R_1 + R_2)C$. When the voltage on C reaches $(2/3)V_{cc}$, the flip-flop resets, turning on the discharge transistor that discharges the capacitor through resistor R_2 with time constant $R_2 C$. When the voltage on C drops to $(1/3)V_{cc}$, the flip-flop sets causing the cycle to repeat. The result is a signal consisting of repeating and regular pulses.

Figure 6.45 shows how the capacitor voltage (V_C) and the output signal (Q) vary over time as the astable multivibrator cycle repeats. From Section 4.9, an RC circuit, which is a first-order system with time constant $\tau = RC$, charges in response to a step input V_{cc} as follows:

$$V_C(t) = V_{cc} \left(1 - e^{-\frac{t}{RC}} \right) \quad (6.37)$$

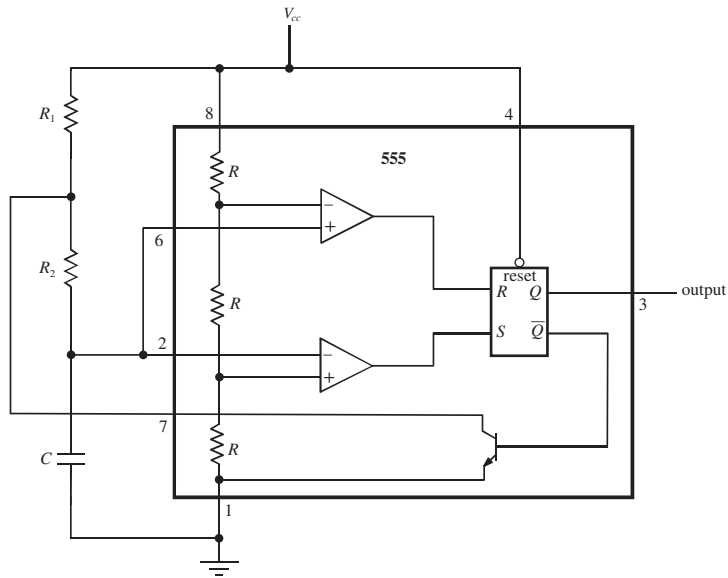


Figure 6.44 Astable multivibrator.

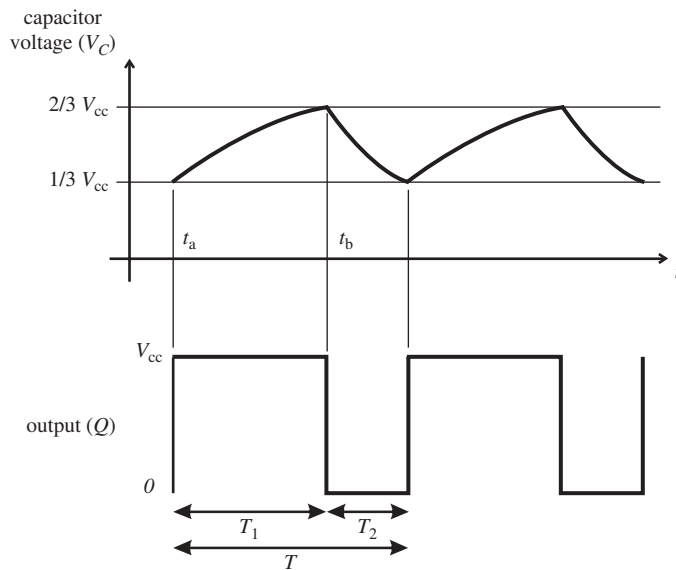


Figure 6.45 Astable multivibrator capacitor voltage and output signal.

The time it would take the capacitor to charge from 0 V to $2/3V_{cc}$, through series resistors R_1 and R_2 , can be found from:

$$\frac{2}{3}V_{cc} = V_{cc} \left(1 - e^{\frac{-t_b}{(R_1 + R_2)C}}\right) \quad (6.38)$$

Solving this equation gives:

$$t_b = -(R_1 + R_2)C \ln\left(\frac{1}{3}\right) \quad (6.39)$$

Similarly, the time to charge from 0 V to $1/3V_{cc}$ would be:

$$t_a = -(R_1 + R_2)C \ln\left(\frac{2}{3}\right) \quad (6.40)$$

Therefore, the period of charging through series resistors R_1 and R_2 from $1/3V_{cc}$ to $2/3V_{cc}$, during which time the output is high, is:

$$T_1 = t_b - t_a = (R_1 + R_2)C \ln(2) \quad (6.41)$$

Similarly, the period of discharge through resistor R_2 from $2/3V_{cc}$ to $1/3V_{cc}$, during which time the output is low, can be found to be (Question 6.57):

$$T_2 = R_2C \ln(2) \quad (6.42)$$

Therefore, the total period for the pulse cycle is:

$$T = T_1 + T_2 = \ln(2)(R_1 + 2R_2)C \approx 0.693 (R_1 + 2R_2)C \quad (6.43)$$

and the cycle frequency is:

$$f = \frac{1}{T} = \frac{1}{\ln(2)(R_1 + 2R_2)C} \approx \frac{1.443}{(R_1 + 2R_2)C} \quad (6.44)$$

To obtain a near-symmetrical square wave, the ON and OFF times for the pulse widths, T_1 and T_2 , need to be as close to equal as possible. This can be achieved by making resistance value R_2 much larger than resistance value R_1 (see Class Discussion Item 6.14).

■ CLASS DISCUSSION ITEM 6.14

Astable Square-Wave Generator

How could you attempt to produce a perfectly symmetric square wave with the circuit in Figure 6.44? Are there any potential problems with this approach? Also, if the capacitor has a partial charge on it before power is applied to the circuit, what effect would this have on the circuit output?

6.13 INTEGRATED CIRCUIT SYSTEM DESIGN

For most digital design applications, integrated circuits can be used as building blocks to create the desired functionality. A myriad of ICs on the market provide almost every conceivable digital function. Listings of ICs along with data sheets describing their functionality can be found online or in manufacturer TTL or logic data books. The digital tachometer example in Design Example 6.1 illustrates a digital design solution employing several commercially available ICs. Internet Link 6.9 is an excellent resource providing a review of digital electronics fundamentals, logic devices, circuit analysis and design, and application examples.



Internet Link

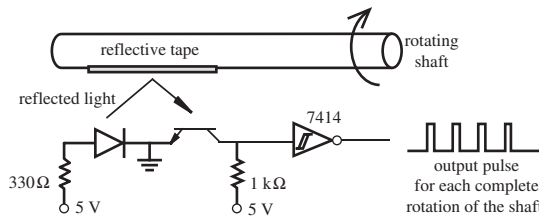
6.9 All about circuits — Vol. IV — digital

Digital Tachometer

DESIGN EXAMPLE 6.1

The objective is to design a system to measure and display the rotational speed of a shaft. A simple method to measure rotational speed is to count the number of shaft rotations during a given period of time. The resulting count will be directly proportional to the shaft speed.

A number of different sensors can detect shaft rotation. A proximity sensor that uses magnetic, optical, or mechanical principles to detect some feature on the shaft is one example. We can use an LED-phototransistor pair as an optical sensor and place a small piece of reflective tape on the shaft. Each time the tape passes by the photo-optic pair, the 7414 Schmitt trigger inverter provides a single pulse to a counting circuit. The following figure illustrates the sensor and signal conditioning circuit.



Now we need a circuit to count and display the pulses over a given interval of time T . The following figure illustrates all the required components. The 7490 decade counter counts the pulses and is reset by a negative edge on signal R after the time period T . The period T is set by a resistor-capacitor combination using a 555 oscillator circuit. If the count can exceed nine during the period T , additional 7490s must be cascaded to provide the full count. Just prior to counter reset, the output is stored by 7475 data latches that are enabled by a brief pulse on signal L . The latches are necessary to hold the previous count for display while the counter begins a new count cycle. One of the two 74123 one-shots is positive-edge triggered by the clock signal CK to generate a latch pulse L of length Δt . Note that the latch and reset pulse widths must be small ($\Delta t \ll T$) to maintain count accuracy (see Class Discussion Item 6.15). The trailing edge of the latch pulse triggers the second one-shot, which is negative-edge triggered, to produce a delayed reset pulse R for the counter. The 7447 LED decoder and driver converts

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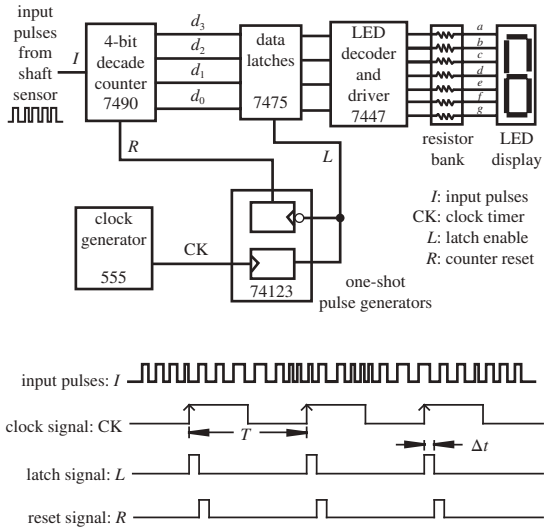
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the latched BCD count into the seven signals required to drive the LED display. The display reports the number of pulses that have occurred during the counting period T .

The shaft speed in revolutions per minute is related to the displayed pulse count by

$$\text{rpm} = \frac{\text{pulse count/ppr}}{T} 60$$

where ppr is the number of pulses per revolution generated by the sensor (e.g., 1 for a single piece of reflective tape).



■ CLASS DISCUSSION ITEM 6.15
Digital Tachometer Accuracy

What effect does the choice of Δt have on the accuracy of the counts displayed by the digital tachometer presented in Design Example 6.1?

■ CLASS DISCUSSION ITEM 6.16
Digital Tachometer Latch Timing

One potential problem with the digital tachometer circuit in Design Example 6.1 could occur if latching happens at the exact instant when the counter is incrementing in response to an input pulse. Explain why. This problem can be resolved by blocking the input pulses during the latch with a logic gate. What would you need to add to the circuit schematic to accomplish this?

■ CLASS DISCUSSION ITEM 6.17

Using Storage and Bypass Capacitors in Digital Design

It is standard practice to include one or more large tantalum or electrolytic **storage capacitors** (e.g., 10–100 μf) across the power supply lines within a digital system and to include a small ceramic **bypass** or **decoupling capacitor** (e.g., 0.1 μf) between the V_{cc} and ground leads supplying power to each IC. Why?

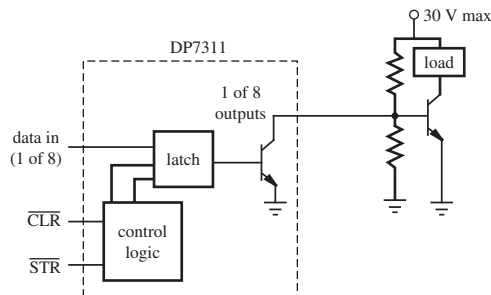
Digital Control of Power to a Load Using Specialized ICs

DESIGN EXAMPLE 6.2

In Design Example 3.4, we introduced a discrete-component power driver for mechatronic system peripheral devices. The large semiconductor manufacturers provide specialized integrated circuits that vastly aid the mechatronic designer in many applications. Example ICs include relay drivers, lamp drivers, motor drivers, and solenoid drivers. In this chapter, we learned how to design logic circuits to provide digital control outputs. These outputs can then be interfaced to peripheral power devices to control mechanical power. Peripheral power requirements are quite varied, creating a need for interface ICs that have a large degree of adaptability. Specialized interface ICs offer some benefits that are difficult for the designer to include using discrete components. Example features include short circuit protection at outputs, glitch-free power-up, inductive flyback protection, and negative transient protection.

Consider a situation where digital outputs are provided via an 8-bit bus that could be used, for example, to control eight separate devices. A good choice for a peripheral driver is the National Semiconductor DP7311 octal latched peripheral driver. This device can provide up to 100 mA DC at each output at a maximum operating voltage of 30 V to drive LEDs, motors, sensors, solenoids, or relays. It has open-collector outputs that require external pull-up resistors when interfaced to high-current external discrete drivers capable of controlling much higher currents than the IC itself. Let us consider two possible configurations.

The first configuration shows a typical output (one of eight) for a high-side (load between supply and collector), large-current bipolar power transistor driver. The *data in* line is active high, and the clear (CLR) and strobe (STR) lines are active low. The latches are cleared (the outputs are turned off) when CLR goes low, and the *data in* values are latched when STR goes low.



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An alternative high-current n-channel MOSFET design is shown below:

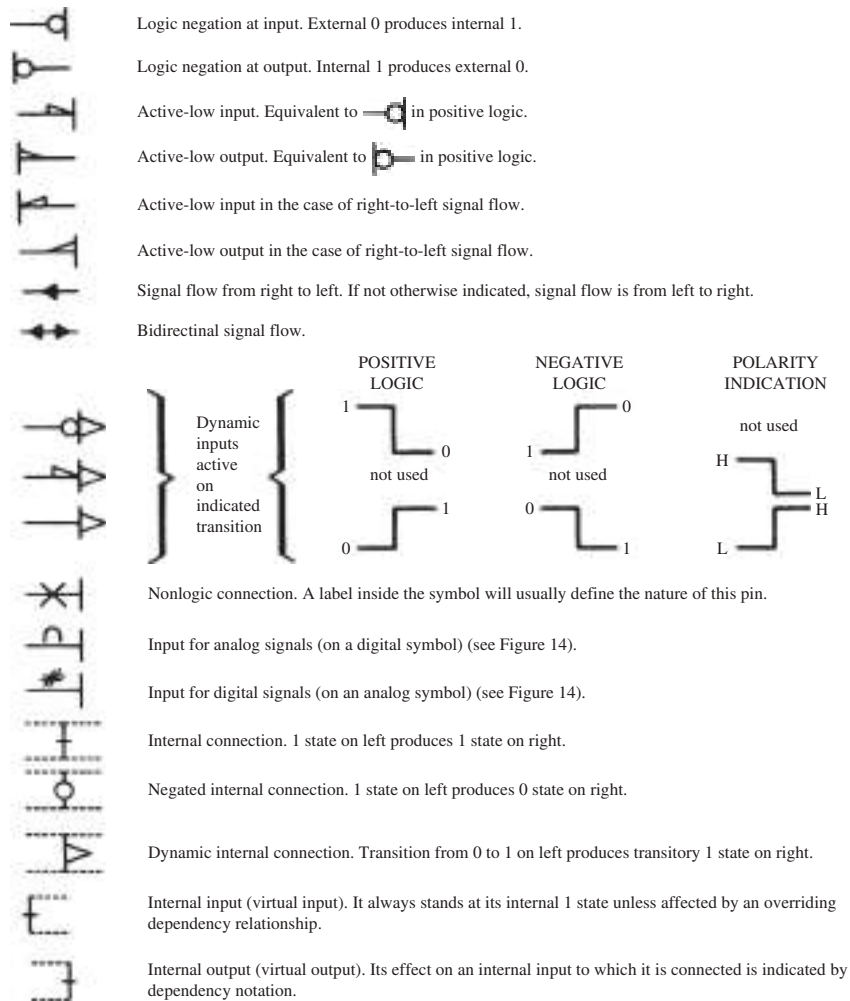
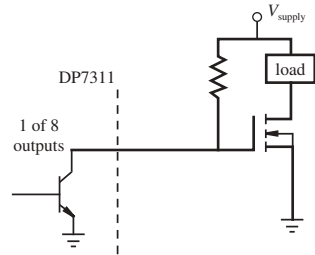


Figure 6.46 IEEE standard symbols for digital ICs.

Source: Texas Instruments, Dallas, TX.

6.13.1 IEEE Standard Digital Symbols

The IEEE standard symbols for illustrating digital input and output conditions are shown in Figure 6.46. When drawing or reading digital schematics, it is important to recognize these conventions. You will find these symbols used in some manufacturers' TTL data books and on-line datasheets.

QUESTIONS AND EXERCISES

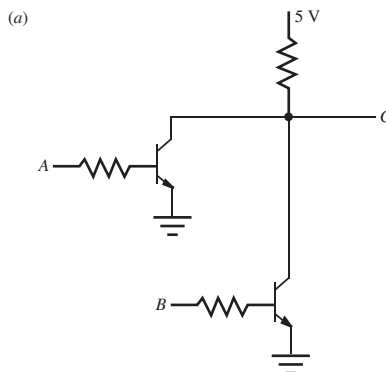
Section 6.2 Digital Representations

- 6.1. In computers, integers are sometimes represented by 16 bits. What is the largest positive base 10 integer that can be represented by a 16 bit binary number?
- 6.2. Convert each of the following base 10 integers to their equivalent binary representations. Show your work.
 - a. 128
 - b. 127
- 6.3. Convert each of the following base 10 integers to their equivalent hexadecimal representations. Show your work.
 - a. 128
 - b. 127
- 6.4. Perform each of the following binary arithmetic operations and check your results with decimal equivalents. Show your work.
 - a. $1101 + 1001$
 - b. $1101 - 1001$
 - c. 1101×1001
 - d. $111 + 111$
 - e. 111×111

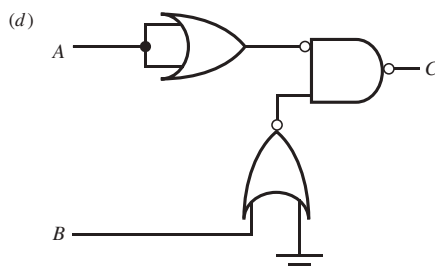
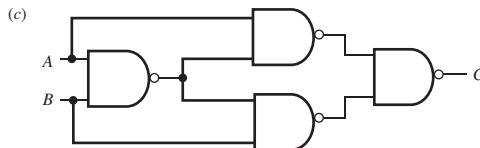
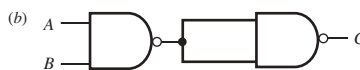
Section 6.3 Combinational Logic and Logic Classes

- 6.5. Draw the schematics of logic circuits that produce the following logic expressions:
 - a. $\overline{A} + \overline{B}$
 - b. $\overline{A} \cdot \overline{B}$
- 6.6. Create an inverter using a single NAND gate. Draw the schematic.

- 6.7.** Write out a simplified Boolean expression and construct a truth table for each of the following circuits. Assume 0 = low = 0 V and 1 = high = 5 V.



Hint: Try to write out a quasi-logic statements (see Sections 6.6.1 and 6.6.2) or a truth table first, based on how the transistors function. Assume ideal transistors operating either in cutoff or saturation.



Section 6.4 Timing Diagrams

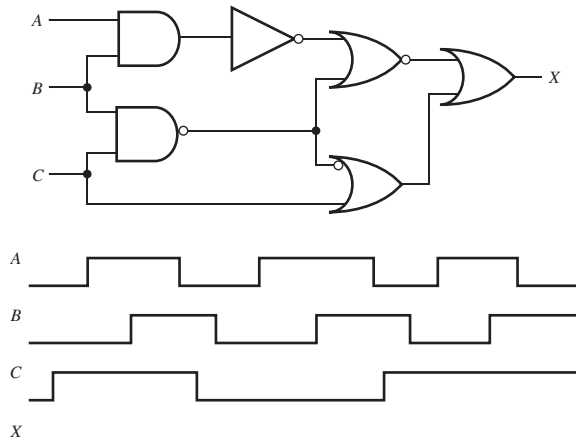
- 6.8.** Construct a timing diagram showing the complete functionality of a NOR gate.
6.9. Construct a timing diagram showing the complete functionality of an XOR gate.
6.10. Construct a timing diagram showing the results of the truth table in Example 6.2.

Section 6.5 Boolean Algebra

6.11. Find the result of each of the following expressions:

- $\overline{1 \cdot 0} + 1 \cdot (0 + 1) + \overline{0} \cdot (1 + \overline{0})$
- $A \cdot \overline{B} + A \cdot (A + B)$

6.12. Determine a simplified Boolean expression for X in the combinational logic circuit that follows. Also, complete the timing diagram.



6.13. Prove Equation 6.19 using the basic Boolean algebra laws.

6.14. Prove Equation 6.20 using the basic Boolean algebra laws.

6.15. Prove Equation 6.21 using the basic Boolean algebra laws.

6.16. Verify that Equation 6.22 is correct using a truth table.

6.17. Prove Equation 6.23 using a truth table.

6.18. Prove that the following Boolean identity is correct:

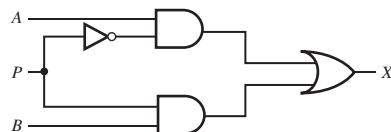
$$AB + AC + \overline{B}C = AB + \overline{B}C$$

6.19. Prove whether the following Boolean equations are valid or not:

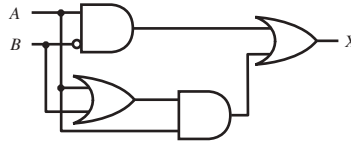
- $(A \cdot B) + (B \cdot C) + (\overline{B} \cdot C) = (A \cdot B) + \overline{C}$
- $A \cdot B \cdot C = \overline{A + B + C}$
- $(A \cdot B) + (B \cdot C) + (\overline{B} \cdot C) = (A \cdot B) + C$

6.20. Use a truth table to prove the validity of De Morgan's laws (Equations 6.25 and 6.26) for two signals (A and B).

6.21. The following circuit is called a **multiplexer**. Construct a truth table and write out a Boolean expression for X . Also, explain why the circuit is termed a multiplexer.



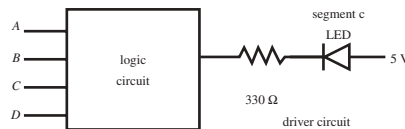
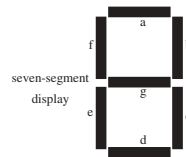
- 6.22. Find the simplest possible Boolean expression representing X in the circuit below, and draw an equivalent simplified circuit diagram.



- 6.23. For the security system simplified Boolean expression derived in Section 6.6.3, if the input state $CD = 11$ resulted from a malfunction, explain how the alarm system would respond in different situations?

Section 6.6 Design of Logic Networks

- 6.24. Create an all-AND and an all-OR representations for the simplified Boolean expression in Example 6.3. Given that AND and OR gates are available on ICs in groups of four per IC and inverters are available on ICs in groups of six per IC, how many ICs would be required to implement the original and each of the two alternative representations?
- 6.25. Create an all-OR realization for Equation 6.30 and draw the resulting circuit.
- 6.26. Design and draw a logic circuit that will drive segment c of a seven-segment LED display given the 4-bit BCD input DCBA representing decimal numbers from 0 to 9. Note that the logic circuit will be used in the driver circuit that follows.

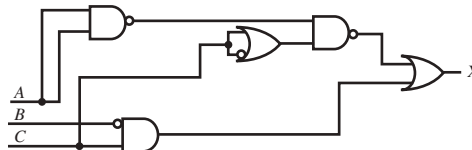


- 6.27. Draw a logic circuit for the following Boolean expression using NAND gates and inverters only:

$$X = \bar{A} \cdot B \cdot C + (A + B) \cdot \bar{C}$$

The NAND gates may only have two inputs each. Do not attempt to simplify the expression first before converting the gates. Convert the expression as is.

- 6.28. Determine a simplified Boolean expression for the following circuit and draw an equivalent circuit using NOR gates and inverters only:



The NOR gates may only have two inputs each.

- 6.29. Design a logic circuit for a simple automobile door and seat belt buzzer system. Assume that sensors are available to provide digital signals representing the door and seat belt states. Signal A is from the door, where high implies the door is closed;

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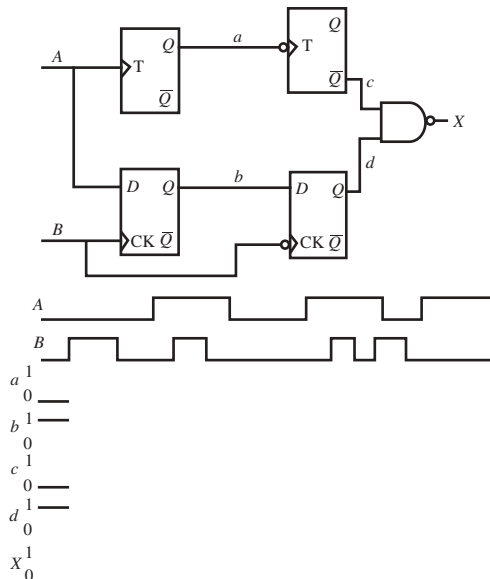
signal B is from the seat belt, where high implies the seat belt is fastened; and signal C indicates whether the ignition switch is turned on. Your circuit should output a signal X that can be used to turn a buzzer on or off, where high implies on. The buzzer should be on if the ignition is on and if the door is open or the seat belt is not fastened. Write out your Boolean expression, draw the logic circuit, construct a truth table, and draw a timing diagram illustrating all functionality.

Section 6.7 Finding a Boolean Expression Given a Truth Table

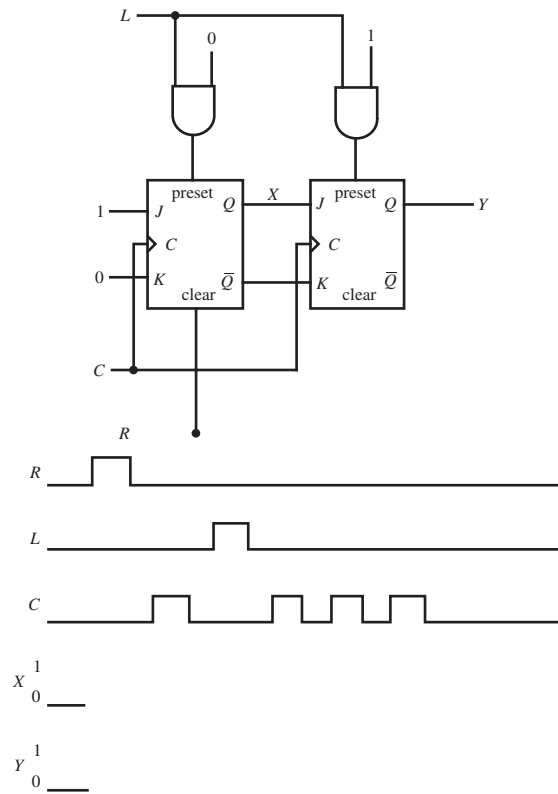
- 6.30. Derive the simplified Boolean expression for X in Question 6.21 using the sum-of-products method.
- 6.31. Verify the four expressions for S and C (two each) from Example 6.4 by testing each with a truth table.
- 6.32. Prove that the logic circuit in Example 6.4 is a valid representation of the selected product-of-sums and sum-of-products equations.
- 6.33. Document a complete and thorough answer to Class Discussion Item 6.4.
- 6.34. Design and draw a **full-adder** circuit that has two sum bits A_i and B_i and a lower-order carry bit C_{i-1} as inputs (see Example 6.4). Include a complete truth table and include sum-of-products Boolean expressions for the output sum bit S_i and carry bit C_i .

Section 6.9 Flip-Flops

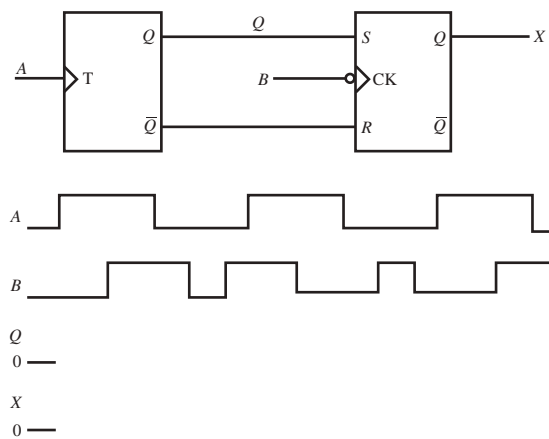
- 6.35. Answer CDI 6.5, demonstrating the results of every row in Table 6.8.
- 6.36. Construct a complete truth table for a negative-edge-triggered T flip-flop including preset and clear inputs.
- 6.37. Construct a complete truth table and timing diagram for a negative-edge-triggered D flip-flop including preset and clear inputs.
- 6.38. Complete the timing diagram for the following circuit.



6.39. Complete the timing diagram (see below) for the following circuit.



6.40. Complete the timing diagram (see below) for the following circuit.



Section 6.10 Applications of Flip-Flops

- 6.41. Document a complete and thorough answer to Class Discussion Item 6.7.
- 6.42. Design a circuit that will store data from four binary sensors (presenting either a high or low value) when an enable pulse from a digital source first goes high. Assume that the enable input is normally low and the pulse is high for 1 sec.
- 6.43. Draw a timing diagram for all of the signals in Figure 6.20, showing all steps in the transmission of the nibble (4-bit string) 1011, starting with the MSB first.
- 6.44. Draw a timing diagram for all of the signals in Figure 6.21, showing all steps in the transmission of the nibble (4-bit string) 1011, starting with the MSB first.
- 6.45. Using JK flip-flops, design a circuit that will produce a clock signal of half the frequency of an input clock signal. If the input clock signal is asymmetric, will the output clock also be asymmetric?
- 6.46. You have a digital sensor such as a photo-interrupter that is normally low, but when activated will go high for a short but unspecified period of time. Design a circuit that will capture the output from the sensor and hold it until you apply a reset signal.
- 6.47. Design a sequential logic circuit to store the state of an SPDT switch when a bounce-free NO button (see Section 9.2.1 for details) is first pressed down and increment a counter when the button is released if the switch was down when the button was first pressed. Assume the bounce-free button and counter are purchased off the shelf and need not be designed. Draw a complete circuit diagram of your solution and show a timing diagram, assuming the SPDT switch exhibits switch bounce.

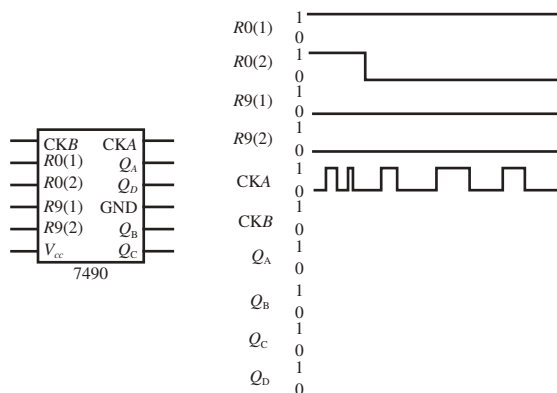
Section 6.11 TTL and CMOS Integrated Circuits

- 6.48. Document a complete and thorough answer to Class Discussion Item 6.12.
- 6.49. You are constrained in a digital design to interface a 74LS00 NAND gate to a 4011B NAND gate. Draw the schematic of a circuit necessary to do this properly.
- 6.50. Why can you not have large TTL fan-out from the output of a CMOS device?

Section 6.12 Special Purpose Digital Integrated Circuits

- 6.51. Derive a Boolean expression for the output columns $\bar{c}$ and $\bar{e}$ of Table 6.11 using either the product-of-sums or sum-of-products techniques presented in Section 6.7. Use whichever method results in the fewest number of terms. You don't need to attempt to simplify the resulting expressions.

- 6.52.** Using the information in a TTL data book, draw a complete schematic for a 7490 decade counter with BCD output. Include a reset feature using the four R lines in the timing diagram that follows. Also, complete the timing diagram.



- 6.53.** How does the decade counter differ from the 4-bit binary counter presented in Figure 6.19?
- 6.54.** Given a Schmitt trigger operating between 0 and 5 V, assume that the lower threshold is 1 V and the upper threshold is 4 V. Given the following input signals applied to the Schmitt trigger, sketch the corresponding output for one cycle of each of the signals:
- $2.5 + 1.0 \sin(2\pi t)$ V
 - $2.5 + 2.0 \sin(2\pi t)$ V
 - $1.5 + 1.5 \sin(2\pi t)$ V
 - $3.0 + 1.5 \sin(2\pi t)$ V
- 6.55.** Determine the exact pulse width as a function of the resistance and capacitance in a one-shot circuit (see Equation 6.36).
- 6.56.** Design and draw the schematic for a 555 oscillator that generates a 1-Hz clock signal.
- 6.57.** Show all of the detailed algebraic steps necessary to derive Equation 6.42.
- 6.58.** Document a complete and thorough answer to Class Discussion Item 6.14.

Section 6.13 Integrated Circuit System Design

- 6.59.** Document a complete and thorough answer to Class Discussion Item 6.16.
- 6.60.** Look up the 74LS90 decade counter in a digital handbook. Using the information found there, design a circuit that will turn on an LED after 100 occurrences of a digital event. The design should be a schematic. Include details of input codes to the IC necessary for decade counting.
- 6.61.** For the circuit you designed in Question 6.47, or for a design provided by your instructor, verify whether or not switch bounce (from the SPDT switch) has an effect. Also, would the circuit still work if the NO button were not bounce-free? If not, how could the design be modified to deal with this?

- 6.62.** You are provided with a coin slot through which people push coins. The bottom of the coin always slides along the bottom of the slot. People feed dimes, nickels, and quarters into the slot. Photo sensors are available and can be placed at any height to detect when portions of coins pass through the slot. The output of a sensor is high when its beam is interrupted; otherwise, it is low. Design a system that will light a red LED when a dime passes through, a yellow LED when a nickel passes through, and a green LED when a quarter passes through.
- 6.63.** Assuming you have been successful in Question 6.62, extend the design to also count the number of dimes, nickels, and quarters passing through the slot.

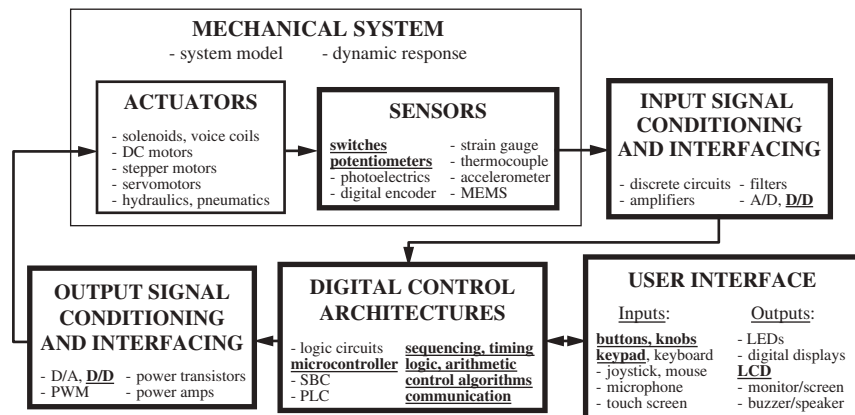
BIBLIOGRAPHY

- Horowitz, P. and Hill, W., *The Art of Electronics*, 3rd Edition, Cambridge University Press, New York, 2015.
- Mano, M., *Digital Logic and Computer Design*, Prentice-Hall, Englewood Cliffs, NJ, 1979.
- McWhorter, G. and Evans, A., *Basic Electronics*, Master Publishing, Richardson, TX, 2004.
- Mims, F., *Getting Started in Electronics*, 3rd Edition, Master Publishing, Richardson, TX, 2003.
- Mims, F., *Engineers Mini-Notebook: 555 Circuits*, Radio Shack Archer Catalog No. 276-5010, 1984.
- Mims, F., *Engineer's Mini-Notebook: Digital Logic Circuits*, Radio Shack Archer Catalog No. 276-5014, 1986.
- Stiffler, A., *Design with Microprocessors for Mechanical Engineers*, McGraw-Hill, New York, 1992.
- Texas Instruments, *Operational Amplifiers and Comparators*, Volume B, Dallas, TX, 1995.
- Texas Instruments, *TTL Linear Circuits Data Book*, Volume 3, Dallas, TX, 1992.
- Texas Instruments, *TTL Logic Data Book*, Dallas, TX, 1988.

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Microcontroller Programming and Interfacing

This chapter describes how to program and interface a microcontroller. Various input and output devices are also presented. ■



CHAPTER OBJECTIVES

After you read, discuss, study, and apply ideas in this chapter, you will:

1. Understand the differences among microprocessors, microcomputers, and microcontrollers
2. Know the terminology associated with a microcomputer and microcontroller
3. Understand the architecture and principles of operation of a microcontroller

4. Understand the basic concepts of assembly language programming
5. Understand the basics of high-level programming languages such as PicBasic Pro and Arduino C
6. Be able to write programs to control PIC microcontrollers and Arduino prototyping boards
7. Be able to interface microcontrollers to input and output devices
8. Be able to design microcontroller-based mechatronic systems
9. Be aware of several practical considerations that will help you prototype, program, and debug microcontroller-based systems
10. Be able to select an appropriate source of power for a microcontroller-based system

7.1 MICROPROCESSORS AND MICROCOMPUTERS

The digital circuits presented in Chapter 6 allow the implementation of combinational and sequential logic operations by interconnecting ICs containing gates and flip-flops. This is considered a **hardware** solution because it consists of a selection of specific ICs, which when hardwired on a circuit board, carry out predefined functions. To make a change in functionality, the hardware circuitry must be modified and may require a redesign. This is a satisfactory approach for simple design tasks (e.g., the home security system presented in Section 6.6 and the digital tachometer presented in Design Example 6.1). However, in many mechatronic systems, the control tasks may involve complex relationships among many inputs and outputs, making a strictly hardware solution impractical. A more satisfactory approach in complex digital design involves the use of a microprocessor-based system to implement a **software** solution. Software is a procedural program consisting of a set of instructions to execute logic and arithmetic functions and to access input signals and control output signals. An advantage of a software solution is that, without making changes in hardware, the program can be easily modified to alter a mechatronic system's functionality.

A **microprocessor** is a single, very-large-scale-integration (VLSI) chip that contains many digital circuits that perform arithmetic, logic, communication, and control functions. When a microprocessor is packaged on a printed circuit board with other components, such as interface and memory chips, the resulting assembly is referred to as a **microcomputer** or **single-board computer**. The overall architecture of a typical microcomputer system using a microprocessor is illustrated in Figure 7.1.

The microprocessor, also called the **central processing unit** (CPU) or **microprocessor unit** (MPU), is where the primary computation and system control operations occur. The **arithmetic logic unit** (ALU) within the CPU executes mathematical functions on data structured as binary words. A **word** is an ordered set of bits, usually 8, 16, 32, or 64 bits long. The instruction decoder interprets instructions fetched sequentially from memory by the control unit and stored in the instruction

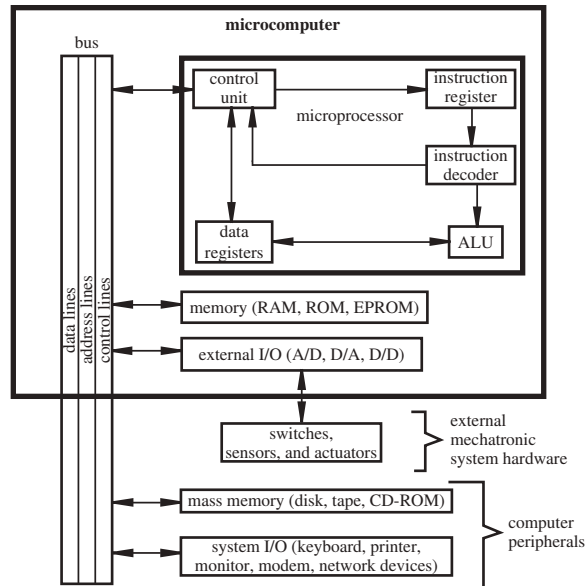


Figure 7.1 Microcomputer architecture.

register. Each instruction is a set of coded bits that commands the ALU to perform bit manipulation, such as binary addition and logic functions, on words stored in the CPU data registers. The ALU results are also stored in data registers and then transferred to memory by the control unit.

The **bus** is a set of shared communication lines that serves as the central nervous system of the microcomputer. Data, address, and control signals are shared by all system components via the bus. Each component connected to the bus communicates information to and from the bus via its own bus controller. The data lines, address lines, and control lines allow a specific component to access data addressed to that component. The **data lines** are used to communicate words to and from data registers in the various system components such as memory, the CPU, and input/output (I/O) peripherals. The **address lines** are used to select devices on the bus or specific data locations within memory. Devices usually have a combinational logic address decoder circuit that identifies the address code and activates the device. The **control lines** transmit read and write signals, the system clock signal, and other control signals such as system interrupts, which are described in subsequent sections.

A key to a CPU's operation is the storage and retrieval of data from a memory device. Different types of memory include **read-only memory (ROM)**, **random-access memory (RAM)**, and **erasable-programmable ROM (EPROM)**. ROM is used for permanent storage of data that the CPU can read, but the CPU cannot write data to ROM. ROM does not require a power supply to retain its data and therefore is called nonvolatile memory. RAM can be read from or written to at any time, provided power is maintained. The data in RAM is considered volatile because it is lost when power is removed. There are two main types of RAM: **static RAM (SRAM)**,

which retains its data in flip-flops as long as the memory is powered, and **dynamic RAM** (DRAM), which consists of capacitor storage of data that must be refreshed (rewritten) periodically because of charge leakage. Data stored in an EPROM can be erased with ultraviolet light applied through a transparent quartz window on top of the EPROM IC. Then new data can be stored on the EPROM. Another type of EPROM is **electrically erasable (EEPROM)**. Data in EEPROM can be erased electrically and rewritten through its data lines without the need for ultraviolet light. Because data in RAM are volatile, ROM, EPROM, EEPROM, and peripheral mass memory storage devices such as magnetic, optical, and solid-state drives are sometimes needed to provide permanent data storage.

Communication to and from the microprocessor occurs through I/O devices connected to the bus. External computer peripheral I/O devices include keyboards, printers, displays, and network devices. For mechatronic applications, analog-to-digital (A/D), digital-to-analog (D/A), and digital I/O (D/D) devices provide interfaces to switches, sensors, and actuators.

The instructions that can be executed by the CPU are defined by a binary code called **machine code**. The instructions and corresponding codes are microprocessor dependent. Each instruction is represented by a unique binary string that causes the microprocessor to perform a low-level function (e.g., add a number to a register or move a register's value to a memory location). Microprocessors can be programmed using **assembly language**, which has a mnemonic command corresponding to each instruction (e.g., *ADD* to add a number to a register and *MOV* to move a register's value to a memory location). However, assembly language must be converted to machine code, using software called an **assembler**, before it can be executed on the microprocessor. When the set of instructions is small, the microprocessor is known as a **RISC** (reduced instruction-set computer) microprocessor. RISC microprocessors are cheaper to design and manufacture and are usually faster. However, more programming steps may be required for complex algorithms, due to the limited set of instructions.

Programs can also be written in a high-level language such as BASIC or C, provided that a compiler is available that can generate machine code for the specific microprocessor being used. The advantages of using a high-level language are that it is easier to learn and use, programs are easier to **debug** (the process of finding and removing errors), and programs are easier to comprehend. A disadvantage is that the resulting machine code may be less efficient (i.e., slower and require more memory) than a corresponding well-written assembly language program.

7.2 MICROCONTROLLERS

There are two branches in the ongoing evolution of the microprocessor. One branch supports CPUs for the personal computer and workstation industry, where the main constraints are high speed and large word size (32 and 64 bits). The other branch includes development of the **microcontroller**, which is a single IC containing specialized circuits and functions that are applicable to mechatronic system design. It contains a microprocessor, memory, I/O capabilities, and other on-chip resources. It is basically a microcomputer on a single IC. Two commonly used microcontrollers are



Internet Link

7.1 Microcontroller online resources and manufacturers

7.2 List of common microcontrollers

the Microchip PIC (featured in this book) and the Atmel ATmega (used on Arduino boards). Many semiconductor companies offer a wide range of microcontroller products. A comprehensive list of common models can be found at Internet Link 7.2. A microcontroller is sometimes called an **MCU** (microcontroller units) or a μC .

Internet Link 7.1 points to various microcontroller online resources and manufacturers. A wealth of information is available online, and it is constantly changing as manufacturers continually release products with faster speeds, larger memories, and more functionality. Factors that have driven development of the microcontroller are low cost, versatility, ease of programming, and small size. Microcontrollers are attractive in mechatronic system design because their small size and broad functionality allow them to be physically embedded in a system to perform all of the necessary control functions.

Microcontrollers are used in a wide array of applications including home appliances, entertainment equipment, telecommunication equipment, automobiles, trucks, airplanes, toys, and office equipment. All these products involve devices that require some sort of intelligent control based on various inputs. For example, the microcontroller in a microwave oven monitors the control panel for user input, updates the graphical displays when necessary, and controls the timing and cooking functions. In an automobile, there are many microcontrollers to control various subsystems, including cruise control, antilock braking, ignition control, keyless entry, environmental control, and air and fuel flow. An office copy machine controls actuators to feed paper, uses photo sensors to scan a page, sends or receives data via a network connection, and provides a user interface complete with menu-driven controls. A toy robot dog has various sensors to detect inputs from its environment (e.g., bumping into obstacles, being patted on the head, light and dark, voice commands), and an onboard microcontroller actuates motors to mimic actual dog behavior (e.g., bark, sit, and walk) based on this input. All of these powerful and interesting devices are controlled by microcontrollers and the software running on them.

Figure 7.2 is a block diagram for a typical full-featured microcontroller. Also included in the figure are lists of typical external devices that might interface to the microcontroller. The components of a microcontroller include the CPU, RAM, ROM, digital I/O ports, a serial communication interface, timers, analog-to-digital (A/D) converters, and digital-to-analog (D/A) converters. The CPU executes the software stored in ROM and controls all the microcontroller components. The RAM is used to store settings and values used by an executing program. The ROM is used to store the program and any permanent data. A designer can have a program and data permanently stored in ROM by the chip manufacturer, or the ROM can be in the form of EPROM or EEPROM, which can be reprogrammed by the user. Software permanently stored in ROM is referred to as **firmware**. Microcontroller manufacturers offer programming devices that can download compiled machine code from a PC directly to the EEPROM of the microcontroller, usually via a PC USB port and special-purpose pins on the microcontroller. These pins can usually be used for other purposes once the device is programmed. Additional EEPROM may also be available and used by the program to store settings and parameters generated or modified during execution. The data in EEPROM is nonvolatile, which means the program can access the data when the microcontroller power is turned off and back on again.

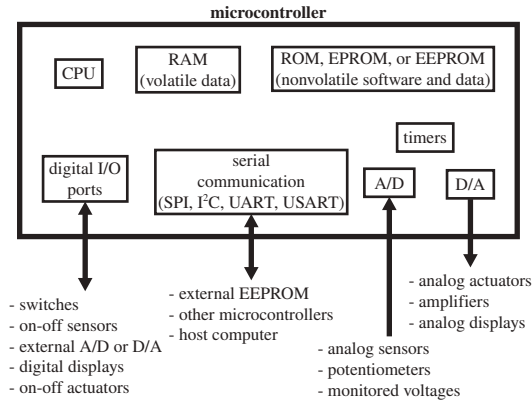


Figure 7.2 Components of a typical full-featured microcontroller.

The digital I/O **ports** allow binary data to be transferred to and from the microcontroller using external pins on the IC. These pins can be used to read the state of switches and on-off sensors, to interface to external A/D and D/A converters, to control digital displays, and to control on-off actuators. The I/O ports can also be used to transmit signals to and from other microcontrollers to coordinate various functions. The microcontroller can also use a serial port to transmit data to and from external devices, provided these devices support the same serial communication protocol. Examples of such devices include external EEPROM memory ICs that might store a large block of data for the microcontroller, other microcontrollers that need to share data and coordinate control, and a host computer that might download a program into the microcontroller's onboard EEPROM. There are various standards or protocols for serial communication including SPI (serial peripheral interface), I²C (interintegrated circuit), UART (universal asynchronous receiver-transmitter), USART (universal synchronous-asynchronous receiver-transmitter), and USB (Universal Serial Bus).

The A/D converter allows the microcontroller to convert an external analog voltage (e.g., from a sensor) to a digital value that can be processed or stored by the CPU. The D/A converter allows the microcontroller to output an analog voltage to a nondigital device (e.g., a motor amplifier). A/D and D/A converters and their applications are discussed in Chapter 8. Onboard timers are usually provided to help create delays or ensure events occur at precise time intervals (e.g., reading the value of a sensor).

Microcontrollers typically have limited program memory measured in kilobytes, compared with microcomputers whose RAM memory is measured in megabytes or gigabytes. Also, microcontroller clock speeds are slower than those used for microcomputers (MHz range vs. GHz range). For some applications, a selected microcontroller may not have enough speed or memory to satisfy the needs of the application. Fortunately, microcontroller manufacturers usually provide a wide range of products to accommodate different applications. Also, when more memory or I/O capability

is required, the functionality of the microcontroller can be expanded with additional external components (e.g., RAM or EEPROM chips, external A/D and D/A converters, and other microcontrollers).

In the remainder of this chapter, we focus on the Microchip PIC microcontroller due to its popularity, abundant information resources and support products, low cost, and ease of use. Section 7.7 introduces Arduino prototyping boards, which are popular alternatives to PIC programming, especially in the hobby and engineering-education worlds. **PIC** is an acronym for peripheral interface controller, the phrase Microchip once used to refer to its line of microcontrollers. Microchip offers a large and diverse family of low-cost PIC products. They vary in footprint (physical size), the number of I/O pins available, the size of the EEPROM and RAM space for storing programs and data, and the availability of A/D and D/A converters. Obviously, the more features and capacity a microcontroller has, the higher the cost. Information for Microchip's entire line of products can be found on its website at www.microchip.com (see Internet Link 7.3). We focus specifically on the **PIC16F84**, which is a low-cost 8-bit microcontroller with EEPROM flash memory for program and data storage. It has no built-in A/D, D/A, or serial communication capability, but it supports 13 digital I/O lines and serves as a good learning platform because it is low cost and easy to program. Once you know how to interface and program one microcontroller, it is easy to extend that knowledge to other microcontrollers with different features and programming options.

Another good reason to focus on the PIC16F84 is that many other PIC microcontrollers are upward-compatible and pin-compatible with the PIC16F84. Examples include the PIC16F84A, PIC16F88, PIC16F819, and PIC16F1827. These and other PIC microcontrollers can be configured to mimic the PIC16F84, and everything learned on the PIC16F84 can be directly applied to these and many other Microchip microcontrollers. So what are the differences that distinguish the 84A, 88, 819, 1827 and others from the 84? First, newer models can be run at faster clock speeds (e.g., up to 20 MHz for the 84A, 88, and 819; and up to 32MHz for the 1827). The 88, 819, and 1827 have internal oscillators (that can provide the clock signal without external components), allowing for more I/O lines, and they have more memory and additional software-configurable functionality (e.g., onboard comparators and pulse-width-modulation generators). The 88, 819, and 1827 also include software-configurable A/D converters, which allow one to interface the PIC to analog sensors that output a continuously varying voltage rather than a digital signal. The 1827 also includes a D/A converter for outputting a variable voltage (e.g., to control the speed of a motor via a power amp) based on a digital value calculated in the PIC.



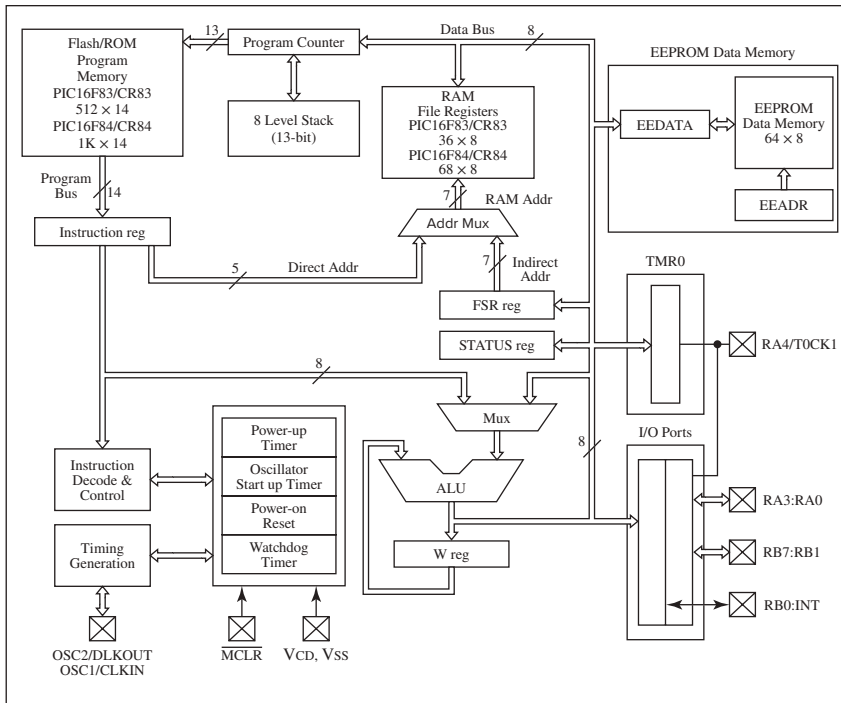
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7.3 Microchip, Inc.

■ CLASS DISCUSSION ITEM 7.1

Car Microcontrollers

List various automobile subsystems that you think are controlled by microcontrollers. In each case, identify all of the inputs to, and outputs from, the microcontroller and describe the function of the software.



Source: Microchip Technology, Inc., Chandler, AZ.

7.3 THE PIC16F84 MICROCONTROLLER



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7.4 Microchip PIC16F84 data sheet

When a program is compiled and downloaded to a PIC, it is stored as a set of binary machine code instructions in the flash program memory. These instructions are sequentially fetched from memory, placed in the instruction register, and executed. Each instruction corresponds to a low-level function implemented with logic circuits on the chip. For example, one instruction might load a number stored in RAM or EEPROM into the **working register**, which is also called the **W register** or **accumulator**; the next instruction might command the ALU to add a different number to the value in this register; and the next instruction might return this summed

value to memory. Because an instruction is executed every four clock cycles, the PIC16F84 can do calculations, read input values, store and retrieve information from memory, and perform other functions very quickly. With a clock speed of 4 MHz, an instruction is executed every microsecond and 1 million instructions can be executed every second. The microcontroller is referred to as 8-bit, because the data bus is 8 bits wide, and all data processing and storage and retrieval occur using bytes.

A useful special purpose timer, called a **watch-dog timer**, is included on PIC microcontrollers. This is a countdown timer that, when activated, needs to be continually reset by the running program. If the program fails to reset the watch-dog timer before it counts down to 0, the PIC will automatically reset itself. In a critical application, you might use this feature to have the microcontroller reset if the software gets caught in an unintentional endless loop.

The RAM, in addition to providing space for storing data, maintains a set of special purpose byte-wide locations called **file registers**. The bits in these registers are used to control the function and indicate the status of the microcontroller. Several of these registers are described below.

The PIC16F84 is packaged on an 18-pin DIP IC that has the pin schematic (pin-out) shown in Figure 7.4. The figure also shows the minimum set of external components recommended for the PIC to function properly. Figure 7.5 shows what the schematic shown in Figure 7.4 looks like when assembled on a breadboard with actual components. Table 7.1 lists the pin identifiers in natural groupings, along with their descriptions. The five pins RA0 through RA4 are digital I/O pins collectively referred to as **PORTA**, and the eight pins RB0 through RB7 are digital I/O pins collectively referred to as **PORTB**. In total, there are 13 I/O lines, called **bidirectional** lines because each can be individually configured in software as an input or output. PORTA and PORTB are special purpose file registers on the PIC that provide the

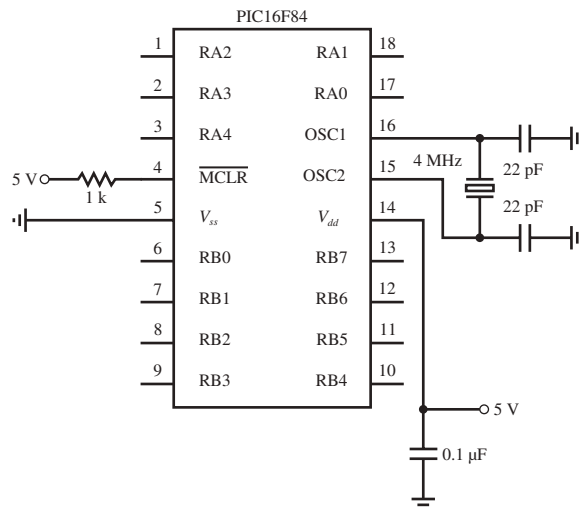


Figure 7.4 PIC16F84 pin-out and required external components.

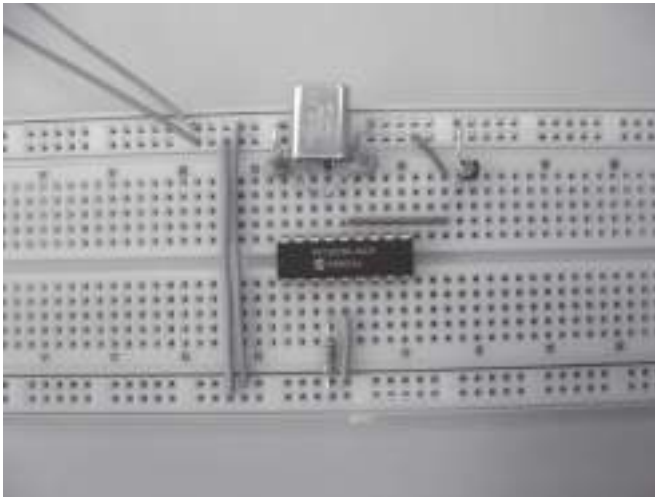


Figure 7.5 Required PIC16F84 components on a breadboard.

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Table 7.1 PIC16F84 pin name descriptions

Pin identifier	Description
RA[0–4]	5 bits of bidirectional I/O (PORTA)
RB[0–7]	8 bits of bidirectional I/O (PORTB)
V_{ss} , V_{dd}	Power supply ground reference (<i>ss</i> : source) and positive supply (<i>dd</i> : drain)
OSC1, OSC2	Oscillator crystal inputs
$\overline{\text{MCLR}}$	Master clear (active low)

interface to the I/O pins. Although all PIC registers contain 8 bits, only the 5 least significant bits (LSBs) of PORTA are used.

An important feature of the PIC, available with most microcontrollers, is its ability to process interrupts. An **interrupt** occurs when a specially designated input changes state. When this happens, normal program execution is suspended while a special interrupt handling portion of the program is executed. This is discussed further in Section 7.6. On the PIC16F84, pins RB0 and RB4 through RB7 can be configured as interrupt inputs.

Power and ground are connected to the PIC through pins V_{dd} and V_{ss} . The *dd* and *ss* subscripts refer to the drain and source notation used for MOS transistors, since a PIC is a CMOS device. The voltage levels (e.g., $V_{dd} = 5\text{ V}$ and $V_{ss} = 0\text{ V}$) can be provided using a DC power supply or batteries (e.g., four AA batteries in series or a 9 V battery connected through a voltage regulator). The master clear pin ($\overline{\text{MCLR}}$) is active low and provides a reset feature. Grounding this pin causes the

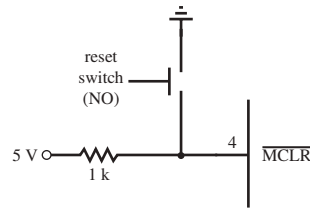


Figure 7.6 Reset switch circuit.

PIC to reset and restart the program stored in EEPROM. This pin must be held high during normal program execution. This is accomplished with the pull-up resistor shown in Figure 7.4. If this pin were left unconnected (floating), the chip might reset itself sporadically. To provide a manual reset feature to a PIC design, you can add a normally open (NO) pushbutton switch as shown in Figure 7.6. Closing the switch grounds the pin and causes the PIC to reset.

The PIC **clock** frequency can be controlled using different methods, including an external RC circuit, an external clock source, or a clock crystal. In Figure 7.4, we show the use of a clock crystal to provide an accurate and stable clock frequency at relatively low cost. The clock frequency is set by connecting a 4-MHz crystal across the OSC1 and OSC2 pins with the 22 pF capacitors grounded as shown in Figure 7.4.

7.4 PROGRAMMING A PIC

To use a microcontroller in mechatronic system design, software must be written, tested, and stored in the ROM of the microcontroller. Usually, the software is written and compiled using a personal computer (PC) and then downloaded to the microcontroller ROM as machine code. If the program is written in assembly language, the PC must have software called a **cross-assembler** that generates machine code for the microcontroller. An assembler is software that generates machine code for the microprocessor in the PC, whereas a cross-assembler generates machine code for a different microprocessor, in this case the microcontroller.

Various software development tools can assist in testing and debugging assembly language programs written for a microcontroller. One such tool is a **simulator**, which is software that runs on a PC and allows the microcontroller code to be simulated (run) on the PC. Most programming errors can be identified and corrected during simulation. Another tool is an **emulator**, which is hardware that connects a PC to the microcontroller in a prototype mechatronic system. It usually consists of a printed circuit board connected to the mechatronic system through cables. The emulator can be used to load and run a program on the actual microcontroller attached to the mechatronic system hardware (containing sensors, actuators, and control circuits). The emulator allows the PC to monitor and control the operation of the microcontroller while it is embedded in the mechatronic system.

The assembly language used to program a PIC16F84 consists of 35 commands that control all functions of the PIC. This set of commands is called the **instruction set** for the microcontroller. Every microcontroller brand and family has its own

specific instruction set that provides access to the resources available on the chip. The complete instruction set and brief command descriptions for the PIC16F84 are listed in Table 7.2. Each command consists of a name called the **mnemonic** and, where appropriate, a list of operands. Values must be provided for each of these operands. The letters f, d, b, and k correspond, respectively, to a file register address (a valid RAM address), result destination (0: W register, 1: file register), bit number (0 through 7), and literal constant (a number between 0 and 255). Note that many of the commands refer to the working register W, also called the accumulator. This is a special CPU register used to temporarily store values (e.g., from memory) for

Table 7.2 PIC16F84 instruction set

Mnemonic and operands	Description
ADDLW k	Add literal and W
ADDWF f, d	Add W and f
ANDLW k	AND literal with W
ANDWF f, d	AND W with f
BCF f, b	Bit clear f
BSF f, b	Bit set f
BTFSC f, b	Bit test f, skip if clear
BTFSS f, b	Bit test f, skip if set
CALL k	Call subroutine
CLRF f	Clear f
CLRW	Clear W
CLRWD	Clear watch-dog timer
COMF f, d	Complement f
DECf f, d	Decrement f
DECFSZ f, d	Decrement f, skip if 0
GOTO k	Go to address
INCF f, d	Increment f
INCFSZ f, d	Increment f, skip if 0
IORLW k	Inclusive OR literal with W
IORWF f, d	Inclusive OR W with f
MOVF f, d	Move f
MOVLW k	Move literal to W
MOVWF f	Move W to f
NOP	No operation
RETFIE	Return from interrupt
RETLW k	Return with literal in W
RETURN	Return from subroutine
RLF f, d	Rotate f left 1 bit
RRF f, d	Rotate f right 1 bit
SLEEP	Go into standby mode
SUBLW k	Subtract W from literal
SUBWF f, d	Subtract W from f
SWAPF f, d	Swap nibbles in f
XORLW k	Exclusive OR literal with W
XORWF f, d	Exclusive OR W with f



Internet Link

7.4 Microchip
PIC16F84
datasheet

calculations or comparisons. At first, the mnemonics and descriptions in the table may seem cryptic, but after you compare functionality with the terminology and naming conventions, it becomes much more understandable. In Example 7.1, we introduce a few of the statements and provide some examples. We illustrate how to write a complete assembly language program in Example 7.2.

For more information (e.g., detailed descriptions and examples of each assembly statement), refer to the PIC16F8X data sheet available on Microchip's website (see Internet Link 7.4).

EXAMPLE 7.1**Assembly Language Instruction Details**

Here, we provide more detailed descriptions and examples of a few of the assembly language instructions to help you better understand the terminology and the naming conventions.

BCF f, b

(read *BCF* as “bit clear f”)

clears bit *b* in file register *f* to 0, where the bits are
numbered from 0 (LSB) to 7 (MSB)

For example, *BCF PORTB, 1* makes bit 1 in PORTB go low (where PORTB is a constant containing the address of the PORTB file register). If PORTB contained the hexadecimal (hex) value FF (binary 11111111) originally, the final value would be hex FC (binary 11111101). If PORTB contained the hex value A8 (binary 10101000) originally, the value would remain unchanged.

MOVLW k

(read *MOVLW* as “move literal to W”)

stores the literal constant *k* in the accumulator (the W register)

For example, *MOVLW 0xA8* would store the hex value A8 in the W register. In assembly language, hexadecimal constants are identified with the *0x* prefix.

RLF f, d

(read *RLF* as “rotate f left”)

shifts the bits in file register *f* to the left 1 bit, and stores the result in *f* if *d* is 1
or in the accumulator (the W register) if *d* is 0. The value of the LSB will become 0,
and the original value of the MSB is lost.

For example, if the current value in PORTB is hex 1F (binary 00011111), then *RLF PORTB, 1* would change the value to hex 3E (binary 00111110).

SWAPF f, d

(read *SWAPF* as “swap nibbles in f”)

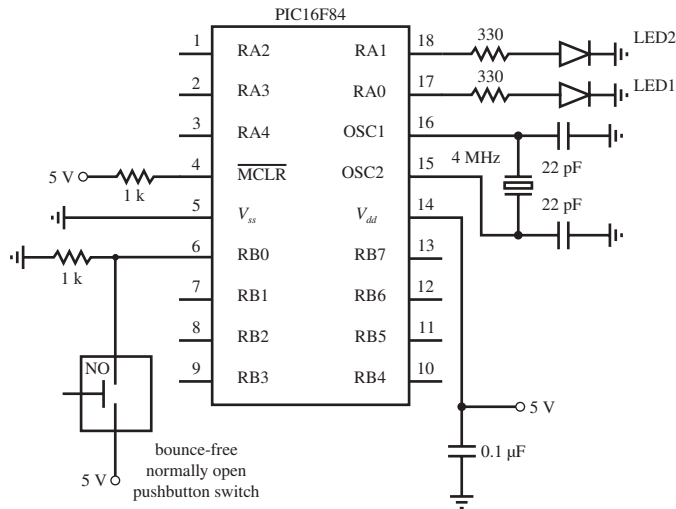
exchanges the upper and lower nibbles (a nibble is 4 bits or half a byte)
of file register *f* and stores the result in *f* if *d* is 1
or in the accumulator (the W register) if *d* is 0

For example, if the memory location at address hex 10 contains the value hex AB, then *SWAPF 0x10, 0* would store the value hex BA in the W register. *SWAPF 0x10, 1* would change the value at address hex 10 from hex AB to hex BA.

Assembly Language Programming Example

EXAMPLE 7.2

The purpose of this example is to write an assembly language program that will turn on an LED when the user presses a pushbutton switch. When the button is released, the LED is to turn off. After the button is pressed and released a specified number of times, a second LED is to turn on and stay lit. The hardware required for this example is shown in the following figure:



The pushbutton switch is assumed to be bounce-free, implying that when it is pressed and then released, a single pulse is produced (the signal goes high when it is pressed and goes low when it is released).

Assembly language code that will accomplish the desired task follows the text below. A remark or comment can be inserted anywhere in a program by preceding it with a semi-colon (;). Comments are used to clarify the associated code. The assembler ignores comments when generating the hex machine code. The first four active lines (*list . . . target*) are assembler directives that designate the processor and define constants that can be used in the remaining code. Defining constants (with the *equ* directive) at the beginning of the program is a good idea because the names, rather than hex numbers, are easier to read and understand in the code and because the numbers can be conveniently located and edited later. Assembly language constants such as addresses and values are written in hexadecimal, denoted with a *0x* prefix.

The next two lines of code, starting with *movlw*, move the literal constant *target* into the W register and then from the W register into the *count* address location in memory. The target value (0x05) will be decremented until it reaches 0x00. The next section of code initializes the special function registers PORTA and TRISA to allow output to pins RA0 and RA1, which drive the LEDs. These registers are located in different banks of memory, hence the need for the *bsf* and *bcf* statements in the program. All capitalized words in the

(continued)

(concluded)

program are constant addresses or values predefined in the processor-dependent include file (p16f84.inc). The function of the TRISA register will be discussed more later; but by clearing the bits in the register, the PORTA pins are configured as outputs.

The main loop uses the *btfss* (bit test in file register; skip the next instruction if the bit is set) and *btfsc* (bit test in file register; skip the next instruction if the bit is clear) statements to test the state of the signal on pin RB0. The tests are done continually within loops created by the *goto* statements. The words *begin* and *wait* are statement labels used as targets for the *goto* loops. When the button is pressed, the state goes high and the statement *btfss* skips the *goto begin* instruction; then LED1 turns on. When the button is released, pin RB0 goes low and the statement *btfsc* skips the *goto wait* instruction; then LED1 turns off.

After the button is released and LED1 turns off, the statement *decfsz* (decrement file register; skip the next instruction if the count is 0) executes. The *decfsz* decrements the *count* value by 1. If the *count* value is not yet 0, *goto begin* executes and control shifts back to the label *begin*. This resumes execution at the beginning of the main loop, waiting for the next button press. However, when the *count* value reaches 0, *decfsz* skips the *goto begin* statement and LED2 is turned on. The last *goto begin* statement causes the program to again jump back to the beginning of the main loop to wait for another button press.

```
; bcount.asm (program file name)
; Program to turn on an LED every time a pushbutton switch is pressed and turn on
; a second LED once it has been pressed a specified number of times
; I/O:
; RB0: bounce-free pushbutton switch (1:pressed, 0:not pressed)
; RA0: count LED (first LED)
; RA1: target LED (second LED)
; Define the processor being used
list p=16f84
include <p16F84.inc>
; Define the count variable location and the initial countdown value
count equ 0x0c                ; address of countdown variable
target equ 0x05               ; number of presses required
; Initialize the counter to the target number of presses
movlw target                  ; move the countdown value into the
                               ; W register
movwf count                   ; move the W register into the count memory
                               ; location
; Initialize PORTA for output and make sure the LEDs are off
bcf    STATUS, RPO            ; select bank 0
clrf   PORTA                  ; initialize all pin values to 0
bsf    STATUS, RPO            ; select bank 1
clrf   TRISA                   ; designate all PORTA pins as outputs
bcf    STATUS, RPO            ; select bank 0
```

```

; Main program loop
begin
    ; Wait for the button to be pressed
    btfss    PORTB, 0
    goto     begin

    ; Turn on the count LED1
    bsf      PORTA, 0

wait
    ; Wait for the button to be released
    btfsc    PORTB, 0
    goto     wait

    ; Turn off the count LED1
    bcf      PORTA, 0

    ; Decrement the press counter and check for 0
    decfsz   count, 1
    goto     begin    ; continue if countdown is still > 0

    ; Turn on the target LED2
    bsf      PORTA, 1

    goto     begin    ; return to the beginning of the main loop

end          ; end of instructions

```

■ CLASS DISCUSSION ITEM 7.2

Decrement Past 0

In Example 7.2, the *decfsz* statement is used to count down from 5 to 0. When 0 (0x00) is decremented, the resulting value at address *count* will be 255 (0xFF), then 254 (0xFE), and so forth. What effect, if any, does this have on the operation of the code and the LED display? To have the program continue its normal operation after the decrement to zero, what code would you need to add?

Learning to program in assembly language can be very difficult at first and may result in errors that are difficult to debug. Fortunately, high-level language compilers are available that allow us to program a PIC at a more user-friendly level. The particular programming language we focus on in the remainder of the chapter is **PicBasic Pro**. The compiler for PicBasic Pro is available from microEngineering Labs, Inc. (see Internet Link 7.5, which points to www.melabs.com). PicBasic Pro is much easier to learn and use than assembly language. It provides easy access to all of the PIC capabilities and provides a rich set of advanced functions and features to support various applications. PicBasic Pro is also closely compatible with the BASIC language used to control Basic Stamp minicontrollers (Parallax, Inc., Rocklin, CA) that utilize the PIC microcontroller. There are also C compilers for



Internet Link

7.5 micro Engineering Labs



Internet Link

7.6 C compilers for the PIC

7.7 Microchip PIC microcontroller resources

the PIC (see Internet Link 7.6). PicBasic Pro is a good choice for introductory-level programming, but C is more appropriate for computation-intensive projects.

For additional information on the PIC and related products, see Internet Link 7.7. This site contains many useful links to manufacturers and other useful web pages that provide resources and information on support literature, useful accessories, and PicBasic Pro.

Section 7.7 introduces Arduino prototyping boards and the Arduino C programming language. The Arduino approach offers a good alternative to PicBasic Pro and PIC microcontroller programming.

7.5 PICBASIC PRO

PIC programs can be written in a form of BASIC called **PicBasic Pro**. The PicBasic Pro compiler can compile these programs, producing their assembly language equivalents, and this assembly code can then be converted to hexadecimal machine code (hex code) that can be downloaded directly to the PIC flash EEPROM through a programming device attached to a PC. Once loaded, the program begins to execute when power is applied to the PIC if the necessary additional components, such as those shown in Figure 7.4, are connected properly.

We do not intend to cover here all aspects of PicBasic Pro programming. Instead, we present an introduction to some of the basic programming principles, provide a brief summary of the statements, and then provide some examples. The PicBasic Pro Compiler manual available online (see Internet Link 7.8) is a necessary supplement to this chapter if you need to solve problems requiring more functionality than the examples we present here. If you have not used a programming language such as BASIC, C, C++, Java, or FORTRAN, then Section 7.5.1 may be challenging for you. Even if this the case, as you read through the examples that follow, the concepts should become clearer.



Internet Link

7.8 PicBasic Pro manual

7.5.1 PicBasic Pro Programming Fundamentals

To illustrate the fundamentals of PicBasic Pro, we start with a very simple example. The goal is to write a program to turn on an LED for a second, then turn it off for a second, repeating for as long as power is applied to the circuit. The code for this program, called *flash.bas*, follows. The hardware required is shown in Figure 7.7. Pin RA2 is used as an output to source current to an LED through a current-limiting resistor. The first two lines in the program are comments that identify the program and its purpose. **Comment lines** must begin with an apostrophe. On any line, information on the right side of an apostrophe is treated as a comment and ignored by the compiler. The label *mainloop* allows the program to return control to this label at a later time using the *Goto* command. The statement *High PORTA.2* causes pin RA2 to go high and the LED turns on. The *Pause* command delays execution of the next line of code a given number of milliseconds (in this case, 1000, which corresponds to 1000 milliseconds or 1 second). The statement *Low PORTA.2* causes pin RA2 to go low, turning the LED off. The next *Pause* causes a 1 sec delay before executing the next line. The *Goto mainloop* statement returns control to the program line

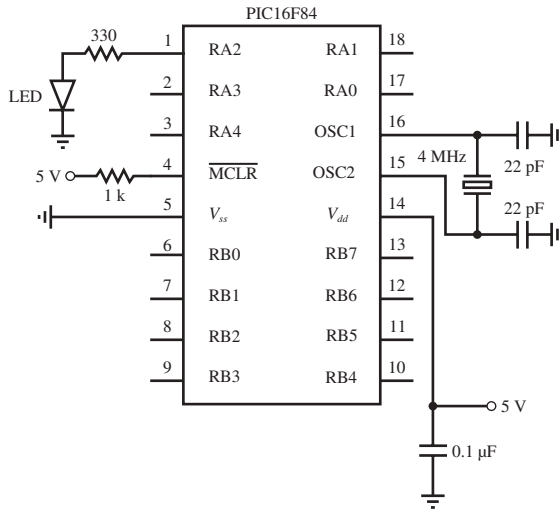


Figure 7.7 Wiring diagram for the flash.bas example.

labeled *mainloop*, and the program continues indefinitely. The *End* statement on the last line of the program terminates execution. In this example, the loop continues until power is removed, and the *End* statement is never reached. However, to be safe you should always terminate a program with an *End* statement.

```
' flash.bas
' Example program to flash an LED once every two seconds

mainloop:
    High PORTA.2          ' turn on LED connected to pin RA2
    Pause 1000            ' delay for one second (1000 ms)

    Low PORTA.2           ' turn off LED connected to pin RA2
    Pause 1000            ' delay for one second (1000 ms)

    Goto mainloop         ' go back to label "mainloop" and repeat
                           ' indefinitely

End
```

Lab Exercise 9 explores how to implement simple programs like *flash.bas* above. The exercise includes steps for wiring circuits to a PIC, entering and compiling PicBasic Pro programs, and downloading executable code from a PC to the flash memory on the PIC.

As illustrated in the simple *flash.bas* example, PicBasic Pro programs consist of a sequence of program statements that are executed one after another. The programmer must be familiar with the syntax of PicBasic Pro, which is easier to learn and debug than assembly language programs. **Comments**, any text preceded by an apostrophe, can be placed anywhere in the program to help explain the purpose of specific lines of the code. Any user-defined labels, variable names, or constant names



Lab Exercise

Lab 9 Programming a PIC microcontroller—part I

are called **identifiers** (e.g., *mainloop* in the preceding example). You can use any combination of characters for these identifiers, provided they do not start with a number. Also, identifiers must be different from all the words reserved by PicBasic Pro (e.g., keywords like *High* and *Low*). Identifiers may be any length, but PicBasic Pro ignores all the characters after the first 32. PicBasic Pro is not case sensitive so it does not matter whether or not letters are capitalized. Therefore, any combination of lower or upper case letters can be used for identifiers, including labels, variables, statements, and register or bit references. For example, to PicBasic Pro, *High* is equivalent to *HIGH* or *high*. However, when writing code, it is best to use a consistent pattern that helps make the program more readable. In the examples presented in this chapter, all variables and labels are written in lower case, all keywords in statements are written with an initial capital, and all registers and constants are written in upper case.

In some applications, you need to store a value for later use in the program (e.g., a counter that is incremented each time a pushbutton switch is pressed). PicBasic Pro lets you create variables for this purpose. The syntax for creating a **variable** is

name Var type (7.1)

where *name* is the identifier to be used to refer to the variable and *type* describes the type and corresponding data storage size of the variable. The type can be **BIT** to store a single bit of information (0 or 1), **BYTE** to store an 8-bit positive integer that can range from 0 to 255 ($2^8 - 1$), or **WORD** to store a 2-byte (16-bit) positive integer that can range from 0 to 65,535 ($2^{16} - 1$). The following lines are examples of variable declarations and assignment statements that store values in variables:

```
my_bit Var BIT
my_byte Var BYTE

my_bit = 0
my_byte = 187
```

The *Var* keyword can also be used to give identifier names to I/O pins or to bits within a byte variable using the following syntax:

name Var byte.bit (7.2)

For example,

```
led Var PORTB.0
lsb Var my_byte.0
```

would designate *led* as the state of pin RB0 and *lsb* as bit 0 of byte variable *my_byte*.

Another type of variable is an **array**, which can be used to store a set or vector of numbers. The syntax for declaring an array is

name Var type[size] (7.3)

where *type* defines the storage type (BIT, BYTE, or WORD) and *size* indicates the number of elements in the array. A particular **element** in an array can be accessed or referenced with the following syntax:

name[i] (7.4)

where i is the index of the element being referenced. The elements are numbered from 0 to size -1 . For example, *values Var byte[5]* would define an array of 5 bytes, and the elements of the array would be *values[0]*, *values[1]*, *values[2]*, *values[3]*, and *values[4]*.

Constants can be given names in a program using the same syntax as that used for variables (Equation 7.1) by replacing the *Var* keyword with *Con* and by replacing the *type* keyword by a constant value. When specifying values in a program, the prefix $\$$ denotes a hexadecimal value and the prefix $\%$ denotes a binary value. If there is no prefix, the number is assumed to be a decimal value. For example, with the following variable and constant definitions, all of the assignment statements that follow are equivalent:

```
number Var BYTE
CONSTANT Con 23

number = 23
number = CONSTANT
number = %10111
number = $17
```

Normally, constants and results of calculations are assumed to be unsigned (i.e., zero or positive), but certain functions, such as sine and cosine, use a different byte format, where the MSB is used to represent the sign of the number. In this case, the byte can take on values between -127 and 127 . Some of the fundamental expressions using **mathematical operators** and functions available in PicBasic Pro are listed in Table 7.3. See other operators and functions, more details, and examples in the PicBasic Pro Compiler manual.

Table 7.3 Selected PicBasic Pro math operators and functions

Math operator or function	Description
A + B	Add A and B
A - B	Subtract B from A
A * B	Multiply A and B
A / B	Divide A by B
A // B	Return the remainder (modulo) of the division of B into A
A << n	Shift A n bits to the left
A >> n	Shift A n bits to the right
COS A	Return the cosine of A
A MAX B	Return the maximum of A and B
A MIN B	Return the minimum of A and B
SIN A	Return the sine of A
SQR A	Return the square root of A
A & B	Return the bitwise AND of A and B
A B	Return the bitwise OR of A and B
A ^ B	Return the bitwise Exclusive OR of A and B
~A	Return the bitwise NOT of A



Lab Exercise

Lab 11 Pulse-width-modulation motor speed control with a PIC

When doing integer arithmetic with fixed-bit-length variables (e.g., BYTE and WORD), one must check for truncation and overflow errors. As pointed out above, each variable type can only store numbers within a certain range (e.g., 0 to 255 for a BYTE variable). If you try to assign an expression to a variable, and the expression's value exceeds the maximum value allowed for the variable, an error will result. This is called **overflow**. **Truncation** occurs with integer division. If an integer division calculation results in a fraction, the remainder of the division (the decimal portion) is discarded. Sometimes the effects of truncation can be minimized or avoided by rearranging terms in an expression so divisions are performed at strategic points. These principles are presented in detail, with examples, in Lab Exercise 11.

There is a collection of PicBasic Pro statements that allow you to read, write, and process inputs from and outputs to the I/O port pins. To refer to an I/O pin, you use the following syntax:

$$\text{port\_name.bit} \quad (7.5)$$

where *port_name* is the name of the port (PORTA or PORTB) and *bit* is the bit location specified as a number between 0 and 7. For example, to refer to pin RB1, you would use the expression PORTB.1. When a bit is configured as an output, the output value (0 or 1) on the pin can be set with a simple assignment statement (e.g., *PORTB.1 = 1*). When a bit is configured as an input, the value on the pin (0 or 1) can be read by referencing the bit directly (e.g., *value = PORTA.2*). All of the bits within a port can be set at one time using an assignment statement of the following form:

$$\text{port\_name} = \text{constant} \quad (7.6)$$

where *constant* is a number between 0 and 255 expressed in binary, hexadecimal, or decimal. For example, *PORTA = %00010001* sets the PORTA.0 and PORTA.4 bits to 1, and sets all other bits to 0. Because the three most significant bits in PORTA are not used, they need not be specified (i.e., *PORTA = %10001* is equivalent and more appropriate).

The I/O status of the PORTA and PORTB bits are configured in two special registers called **TRISA** and **TRISB**. The prefix *TRIS* is used to indicate that tristate gates control whether or not a particular pin provides an input or an output. The input and output circuits for PORTA and PORTB on the PIC16F84 are presented in Section 7.9, where we deal with interfacing. When a TRIS register bit is set high (1), the corresponding PORT bit is considered an input, and when the TRIS bit is low (0), the corresponding PORT bit is considered an output. For example, *TRISB = %01110000* would designate pins RB4, RB5, and RB6 as inputs and the other PORTB pins as outputs. At power-up, all TRIS register bits are set to 1 (i.e., TRISA and TRISB are both set to \$FF or %11111111), so all pins in PORTA and PORTB are treated as inputs by default. You must redefine them if necessary for your application in the initialization statements in your program.

The port bit access syntax described by Equation 7.5 can also be used to access individual bits in byte variables. For example, given the following declarations,

```
my_byte Var byte
my_array Var byte[10]
```

`my_byte.3 = 1` would set bit 3 in `my_byte` to 1 and `my_array[9].7 = 0` would set the MSB of the last element of `my_array` to 0. All bits within a variable can be set by assigning a value or expression to the variable with an **assignment statement**:

`variable = expression` (7.7)

For example,

```
my_byte = 231
my_array[2] = my_byte - 12
```

Two important features in any programming language are statements to perform logical comparisons and statements to branch, loop, and iterate. In PicBasic Pro, logic is executed within an *If . . . Then . . . Else . . .* statement construct, where a logical comparison is made and if the result of the comparison is true, then the statements after *Then* are executed; otherwise, the statements after *Else* are executed. PicBasic Pro supports the **logical comparison operators** listed in Table 7.4. The keywords **And**, **Or**, **Xor** (exclusive Or), and **Not** (or the operator equivalents shown in the table) can also be used in conjunction with parentheses to create compound Boolean expressions for use in logical comparisons. Example 7.3 and other examples to follow illustrate use of logical expressions.

Table 7.4 PicBasic Pro logical comparison operators

Operator	Description
= or ==	equal
<> or !=	not equal
<	less than
>	greater than
<=	less than or equal to
>=	greater than or equal to
&&	“And” compound comparison
	“Or” compound comparison
~	“Not” logical inversion
^^	“Xor” (exclusive “Or”) logical comparison

A PicBasic Pro Boolean Expression

EXAMPLE 7.3

The following PicBasic Pro statement turns on a motor controlled by a transistor connected to pin RA0 when the state of a switch connected to pin RB0 is high or when the state of a switch connected to pin RB1 is low, and when a byte variable *count* has a value less than or equal to 10:

```
If (((PORTB.0 == 1) Or (PORTB.1 == 0)) And (count <= 10)) Then
  High PORTA.0
```


The simplest form of looping is to use a statement label with a *goto* statement as illustrated earlier in the *flash.bas* example. PicBasic Pro also provides *For . . . Next*, *Do . . . Loop* and *While . . . Wend* statement structures to perform looping and iteration. These constructs are demonstrated in examples through the remainder of the chapter.

Table 7.5 lists all of the PicBasic Pro statements (version: 3.0) with corresponding descriptions. Complete descriptions and examples of the statements and their associated parameters and variables can be found in the PicBasic Pro Compiler manual available online at microEngineering, Inc.'s website (see Internet Link 7.8). In Table 7.5, the keywords are capitalized, and the parameters or variables that follow the keywords are shown in lower case. Also, any statement parameters enclosed within curly brackets ({. . .}) are optional. All the features and operators just presented and all the statements listed in the table are built from the limited set of assembly language instructions given in Table 7.2. PicBasic Pro eliminates the cryptic assembly language details for you and provides a high-level, more user-friendly language.



Internet Link

7.8 PicBasic Pro manual (online, PDF file)

Table 7.5 PicBasic Pro (version: 3.0) statement summary

Statement	Description
@ assembly statement	Insert one line of assembly language code.
ADCIN channel, var	Read the on-chip analog to digital converter (if there is one).
ARRAYREAD array_var, {max_length, label,}[item. . .]	Parse array (string) and fill variables.
ARRAYWRITE array_var, {max_length, label,}[item. . .]	Send variables and constants to array (string).
ASM . . . ENDASM	Insert an assembly language code section consisting of one or more statements.
BRANCH index, [label1 {, label2, . . .}]	Computed goto that jumps to a label based on index.
BRANCHL index, [label1 {, label2, . . .}]	Branch to a label that can be outside of the current page of code memory (for PICs with more than 2K of program ROM).
BUTTON pin, down_state, auto_repeat_delay, auto_repeat_rate, countdown_variable, action_state, label	Read the state of a pin and perform debounce (by use of a delay) and autorepeat (if used within a loop).
CALL assembly_label	Call an assembly language subroutine.
CLEAR	Zero all variables.
CLEARWDT	Clear the watch-dog timer.
COUNT pin, period, var	Count the number of pulses occurring on a pin during a period.
DATA { @ location, } constant1 {, constant2, . . . }	Define initial contents of the on-chip EEPROM (same as the EEPROM statement).
DEBUG item1 {, item2, . . . }	Asynchronous serial output to a pin at a fixed baud rate.
DEBUGIN {timeout, label, } [item1 {, item2, . . .}]	Asynchronous serial input from a pin at a fixed baud rate.

Table 7.5 PicBasic Pro (version: 3.0) statement summary

Statement	Description
DISABLE	Disable ON INTERRUPT and ON DEBUG processing.
DISABLE DEBUG	Disable ON DEBUG processing.
DO {UNTIL condition} {WHILE condition} statement. . .	Repeatedly execute a block of statements.
LOOP {UNTIL condition} {WHILE condition}	
DISABLE INTERRUPT	Disable ON INTERRUPT processing.
DTMFOUT pin, {on_ms, off_ms,} [tone1 {, tone2, . . .}]	Produce touch tones on a pin.
EEPROM {@ location,} constant1 {, constant2, . . .}	Define initial contents of on-chip EEPROM (same as the DATA statement).
ENABLE	Enable ON INTERRUPT and ON DEBUG processing.
ENABLE DEBUG	Enable ON DEBUG processing.
ENABLE INTERRUPT	Enable ON INTERRUPT processing.
END	Stop execution and enter low power mode.
ERASECODE block	Erase block of code memory.
EXIT	Exit the current block structure.
FOR count = start TO end {STEP {-} inc} { body statements} NEXT {count}	Repeatedly execute statements as count goes from start to end in fixed increment.
FREQOUT pin, on_ms, freq1{, freq2}	Produce up to two frequencies on a pin.
GOSUB label	Call a PicBasic subroutine at the specified label.
GOTO label	Continue execution at the specified label.
HIGH pin	Make pin output high.
HPWM channel, duty_cycle, frequency	Output hardware pulse width modulated pulse train.
HSERIN {parity_label,} {time_out, label, [item1{, item2, . . .}]}	Hardware asynchronous serial input (if there is a hardware serial port).
HSERIN2 {parity_label,} {time_out, label, [item1{, item2, . . .}]}	Hardware asynchronous serial input, second port.
HSEROUT [item1{, item2, . . .}]	Hardware asynchronous serial output (if there is a hardware serial port).
HSEROUT2 [item1{, item2, . . .}]	Hardware asynchronous serial output, second port.
I2CREAD data_pin, clock_pin, control, { address,} [var1{, var2, . . .}]{, label}	Read bytes from an external I ² C serial EEPROM device.
I2CWRITE data_pin, clock_pin, control, { address,} [var1{, var2, . . .}]{, label}	Write bytes to an external I ² C serial EEPROM device.
IF log_comp THEN label	Conditionally jump to a label.
IF log_comp THEN true_statement	Conditional execution of statement.
IF log_comp {AND/OR log_comp. . .} THEN true_statement. . . {ELSEIF Comp {AND/OR log_comp. . .} THEN true_statement. . .} {ELSE false_statement. . .}	Conditional execution of blocks of statements.
ENDIF	

(continued)

Table 7.5 PicBasic Pro (version: 3.0) statement summary (Continued)

Statement	Description
INPUT pin	Make pin an input.
LCDIN {address,} [var1 {, var2, ...}]	Read RAM on a liquid crystal display (LCD).
LCDOUT item1 {, item2, ...}	Display characters on LCD.
{LET} var = value	Assignment statement (assigns a value to a variable).
LOOKDOWN value, [const1 {, const2, ...}], var	Search constant table for a value.
LOOKDOWN2 value, {test} [value1 {, value2, ...}], var	Search constant/variable table for a value.
LOOKUP index, [const1 {, const2, ...}], var	Fetch constant value from a table.
LOOKUP2 index, [value1 {, value2, ...}], var	Fetch constant/variable value from a table.
LOW pin	Make pin output low.
NAP period	Power down processor for a selected period of time.
ON DEBUG GOTO label	Execute PicBasic debug subroutine at label after every statement if debug is enabled.
ON index GOSUB label {, label. . .}	Computed GOSUB.
ON INTERRUPT GOTO label	Execute PicBasic subroutine at label when an interrupt is detected.
OUTPUT pin	Make pin an output.
OWIN pin, mode, [item. . .] {, label}	1-wire input.
OWOUT pin, mode, [item. . .] {, label}	1-wire output.
PAUSE period	Delay a given number of milliseconds.
PAUSEUS period	Delay a given number of microseconds.
PEEK address, var	Read byte from a register.
PEEKCODE address, var	Read byte from code space.
POKE address, var	Write byte to a register.
POKECODE { @address, } value {, value. . .}	Write byte to code space when programming device.
POT pin, scale, var	Read resistance of a potentiometer, or other variable resistance device, connected to a pin with a series capacitor to ground.
PULSIN pin, state, var	Measure the width of a pulse on a pin.
PULSOUT pin, period	Generate a pulse on a pin.
PWM pin, duty, cycles	Output a pulse width modulated (PWM) pulse train to pin.
RANDOM var	Generate a pseudo-random number.
RCTIME pin, state, var	Measure pulse width on a pin.
READ address, var	Read a byte from on-chip EEPROM.
READCODE address, var	Read a word from code memory.
RESUME {label}	Continue execution after interrupt handling.
RETURN	Continue execution at the statement following last executed GOSUB.
REVERSE pin	Make output pin an input or an input pin an output.
SELECT CASE var	Conditional execution of statements based on values.
CASE expr1 {, expr. . .}	
statement. . .	
CASE expr2 {, expr. . .}	
statement. . .	

Table 7.5 PicBasic Pro (version: 3.0) statement summary

Statement	Description
{ CASE ELSE statement. . . END SELECT	
SERIN pin, mode, { timeout, label, } { [qual1, qual2, . . .], } { item1 {, item2, . . .} }	Asynchronous serial input (Basic Stamp 1 style).
SERIN2 data_pin { \flow_pin }, mode, { parity_ label, } { timeout, label, } [item1 {, item2, . . .}]	Asynchronous serial input (Basic Stamp 2 style).
SEROUT pin, mode, [item1 {, item2, . . .}]	Asynchronous serial output (Basic Stamp 1 style).
SEROUT2 data_pin { \flow_pin }, mode, { pace, } { timeout, label, } [item1 {, item2, . . .}]	Asynchronous serial output (Basic Stamp 2 style).
SHIFTIN data_pin, clock_pin, mode, [var1 { \ bits1 } {, var2 { \bits2 }, . . .}]	Synchronous serial input.
SHIFTOUT data_pin, clock_pin, mode, [var1 { \bits1 } {, var2 { \bits2 }, . . .}]	Synchronous serial output.
SLEEP period	Power down the processor for a given number of seconds.
SOUND pin, [note1, duration1 {, note2, dura- tion2, . . .}]	Generate a tone or white noise on a specified pin.
STOP	Stop program execution.
SWAP var1, var2	Exchange the values of two variables.
TOGGLE pin	Change the state of an output pin.
USBIN end_point, buffer, count_var, label	USB input.
USBINIT	Initialize USB.
USBOUT end_point, buffer, count, label	USB output.
USBSERVICE	USB service loop.
WHILE condition statement. . . WEND	Execute block of statements while condition is true.
WRITE address, value	Write a byte to on-chip EEPROM.
WRITECODE address, value	Write a word to code memory.
XIN data_pin, zero_pin, { timeout, label, } [var1 {, var2, . . .}]	Receive data from an external X-10 type device.
XOUT data_pin, zero_pin, [house_code1 \key_ code1 { \repeat1 } {, house_code2 \key_code2 { \ repeat2, . . .} }]	Send data to an external X-10 type device.

7.5.2 PicBasic Pro Programming Examples

This section presents a series of problems that can be solved with a PIC16F84. The examples illustrate the application of PicBasic Pro. Sections 7.8 and 7.9 present more details on how to interface the PIC to a variety of input and output devices. In Section 7.10, we present a methodical design procedure that will help you create software and associated hardware when challenged to design a new microcontroller-based mechatronic system.

PicBasic Pro Alternative to the Assembly Language Program in Example 7.2

EXAMPLE 7.4

As in Example 7.2, the objective is to turn on an LED when the user presses a pushbutton switch, and turn it off when the button is released. After the button is pressed and released a specified number of times, a second LED is to turn on and stay lit. Example 7.2 presented an assembly language solution to this problem. A corresponding PicBasic Pro solution follows. The comments included throughout the code help explain the function of the various parts of the program.

The *Do . . . Loop* construct allows the program to wait for the first switch to be pressed or released. The loop continually cycles and does nothing while the switch remains at a particular state. In many situations, there would be statements between the *Do* and *Loop* lines that are executed each time through the loop, but none are required here.

The prefix *my_* is included as part of the identifiers *my_count* and *my_button* because the words *count* and *button* are **reserved words**. Reserved words are those used by PicBasic Pro as keywords in statements, predefined constants, and mathematical and logical functions. These words cannot be used as identifiers.

The only fundamental difference in the assembly language and PicBasic Pro solutions is the way the count is handled. Here, we are able to count up and detect when the count reaches the target value. In assembly language, this is not easily done, and we chose to count down instead. Another difference is that PicBasic Pro simplifies how memory is handled. In PicBasic Pro, you do not need to identify addresses for variables, specify memory banks, or move values through the accumulator. PicBasic Pro does all of this for you implicitly.

```
' bcount.bas
' Program to turn on an LED every time a pushbutton switch is pressed, and
' turn on a second LED once it has been pressed a specified number of times

' Define variables and constants
my_count      Var      BYTE      ' number of times switch has been pressed
TARGET        Con      5          ' number of switch presses required

' Define variable names for the I/O pins
my_button     Var      PORTB.0
led_count     Var      PORTA.0
led_target    Var      PORTA.1

' Initialize the counter and guarantee the LEDs are off
my_count = 0
Low led_count
Low led_target

begin:
    ' Wait for the button to be pressed
    Do While (my_button == 0)
        ' Keep looping while the button is up (not pressed)
    Loop

    ' Turn on the count LED now that the switch has been pressed
    High led_count
```

```

    ' Wait for the button to be released
Do While (my_button == 1)
    ' keep looping while the button is down (pressed)
Loop

    ' Turn off the count LED and increment the counter now that the switch
    ' has been released
Low led_count
my_count = my_count + 1

    ' Check if the target has been reached; and if so, turn on the target LED
If (my_count >= TARGET) Then
    High led_target
EndIf

Goto begin
End

```

If you compare the two solutions, you will see that PicBasic Pro code is easier to write and comprehend. This would be even more evident if the problem were more complex. Things that are easy to do using PicBasic Pro but very difficult using assembly language include variable and array management, assignment statements with complex calculations, logical comparison expressions, iteration, interrupts, pauses, and special purpose functions.

One disadvantage to using PicBasic Pro, however, is that it consumes more program EEPROM space. For this example, the assembly language version requires 17 words of program memory and the PicBasic Pro version requires 39 words, even though the function is identical. This is a consequence of using a high-level language such as PicBasic Pro. Fortunately, the inexpensive PIC16F84 allows up to 1024 words, which is adequate for rather complex programs. Also, many other PIC chips have larger memory capacities for longer programs. Furthermore, the cost of microcontrollers continues to fall and memory capacities continue to rise.

■ CLASS DISCUSSION ITEM 7.3

PicBasic Pro and Assembly Language Comparison

Compare the assembly language code in Example 7.2 to the PicBasic Pro code in Example 7.4. Comment on any differences in the way each program functions.

■ CLASS DISCUSSION ITEM 7.4

PicBasic Pro Equivalents of Assembly Language Statements

For each of the assembly language statement examples presented in Example 7.1, write corresponding PicBasic Pro code.

EXAMPLE 7.5**PicBasic Pro Program for the Home Security System Example**

This example presents a PicBasic Pro program used to control the home security system described in Section 6.6. Please refer back to Section 6.6 to review the problem statement. The program comments that follow will help you understand how the code functions. Note how tabs, spaces, blank lines, parentheses, comments, and variable definitions all help make the program more readable. If all these formatting features and definitions were left out, the program would still run, but it would not be as easy for you to understand. The hardware required for PIC implementation is shown in the figure below the code.

The door and window sensors are assumed to be normally open switches that are closed when the door and window are closed. They are wired in series and connected to 5 V through a pull-up resistor; therefore, if either switch is open, then signal A will be high. Both the door and window must be closed for signal A to be low. This is called a **wired-AND** configuration because it is a hardwired solution providing the functionality of an AND gate.

The motion detector produces a high on line B when it detects motion. Single-pole, double-throw switches are used to set the 2-bit code C D. In the figure, the switches are both in the normally closed position; therefore, code C D is 0 0. The alarm buzzer sounds when signal Y goes high, forward biasing the transistor. When Y is high, the 1 k base resistor limits the output current to approximately 5 mA ($5\text{ V} / 1\text{ k}\Omega$), which is well within the output current specification for a PORTA pin (20 mA as listed in Section 7.9.2).

```
' security.bas
' PicBasic Pro program to perform the control functions of the home security
' system presented in Section 6.6
' Define variables for I/O port pins
door_or_window      Var      PORTB.0      ' signal A
motion              Var      PORTB.1      ' signal B
c                   Var      PORTB.2      ' signal C
d                   Var      PORTB.3      ' signal D
alarm               Var      PORTA.0      ' signal Y

' Define constants for use in IF comparisons
OPEN                Con      1            ' to indicate that a door OR window is open
DETECTED            Con      1            ' to indicate that motion is detected

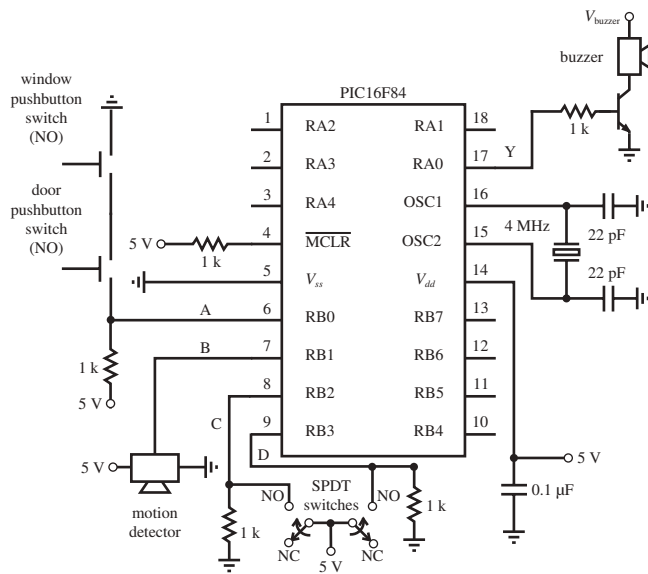
' Make sure the alarm is off to begin with
Low alarm

' Main polling loop
always:
  If ((c == 0) And (d == 1)) Then          ' operating state 1 (occupants sleeping)
    If (door_or_window == OPEN) Then
      High alarm
    Else
      Low alarm
    EndIf
  EndIf
```

```

ElseIf ((c == 1) And (d == 0)) Then           ' operating state 2 (occupants away)
  If ((door_or_window == OPEN) Or (motion == DETECTED)) Then
    High alarm
  Else
    Low alarm
  EndIf
Else                                           ' operating state 3 or NA (alarm
                                             disabled)
  Low alarm
EndIf
Goto always ' continue to poll the inputs
End

```



If all the variable and constant definitions, formatting, and comments were left out, the program would still run properly but the resulting code would be much more difficult to comprehend. This is what the resulting code would look like:

```

LOW PORTA.0
always: If PORTB.2==0 And PORTB.3==1 Then
If PORTB.0==1 Then
High PORTA.0
Else
Low PORTA.0
EndIf
ElseIf PORTB.2==1 And PORTB.3==0 Then

```

(continued)

(concluded)

```
If PORTB.0==1 Or PORTB.1==1 Then
High PORTA.0
Else
Low PORTA.0
EndIf
Else
Low PORTA.0
EndIf
Goto always
End
```

There is no advantage to leaving out the formatting, because it is ignored by the compiler. Also, the variable and constant declarations make no difference in the size of the compiled machine code.

■ CLASS DISCUSSION ITEM 7.5

Multiple Door and Window Home Security System

If you had more than one door and one window, how would modify the hardware design? Would you have to modify the software?

■ CLASS DISCUSSION ITEM 7.6

PIC vs. Logic Gates

In Example 7.5, a PIC solution to the home security system problem was presented as an alternative to the logic gate solution presented in Section 6.6. What are the pros and cons of each approach? Which implementation do you think is the best choice in general and in this problem specifically?

■ CLASS DISCUSSION ITEM 7.7

Home Security System Design Limitation

The home security system design in Example 7.5 has a feature that might be considered a limitation. If a burglar trips the alarm by opening a door or window, he or she can stop the alarm by simply closing the opened door or window. Why might this be considered a design flaw by some users? And what changes could be made to improve the functionality of the system?

Graphically Displaying the Value of a Potentiometer

EXAMPLE 7.6

This example presents code designed to sample the resistance of a potentiometer and display a scaled value in binary form using a set of LEDs. The code uses the PicBasic Pro statement *Pot*, which can indirectly sample the resistance of a potentiometer or other variable resistance. The code for the program, *pot.bas*, and the necessary hardware are included below.

The wiper of a potentiometer is connected to pin RA3, and one end of the potentiometer is in series with a capacitor to ground. Note that the third lead of the potentiometer is unconnected.

Each of pins RB0 through RB7 in PORTB is connected to an LED in series with a current-limiting resistor to ground. When any of these pins goes high, the corresponding LED is on. The eight LEDs display a binary number corresponding to the current position of the potentiometer. The value displayed can range from 0 to 255. This program uses the assignment statement *PORTB = value* to update the display, where *value* is a byte variable (8 bits) that contains the current sample from the potentiometer. The assignment statement drives the outputs of PORTB such that RB0 represents the least significant bit and RB7 represents the most significant bit of the scaled resistance sample.

The test LED attached to pin RA2 is used to indicate that the program is running. When the program is running, the test LED blinks. It is good practice to include some sort of program execution indicator, especially in the debugging stages of a project. The blinking LED signals that the PIC has power and the necessary support components and that the program is loaded, running, and looping properly. This is a simple example, and not much can go wrong with the program logic and sequencing. However, complicated programs containing complex logic, branching, looping, and interrupts may hang up unexpectedly or terminate prematurely, especially before they are fully debugged. A nonblinking LED would indicate a problem with the program.

The syntax for the *Pot* statement is

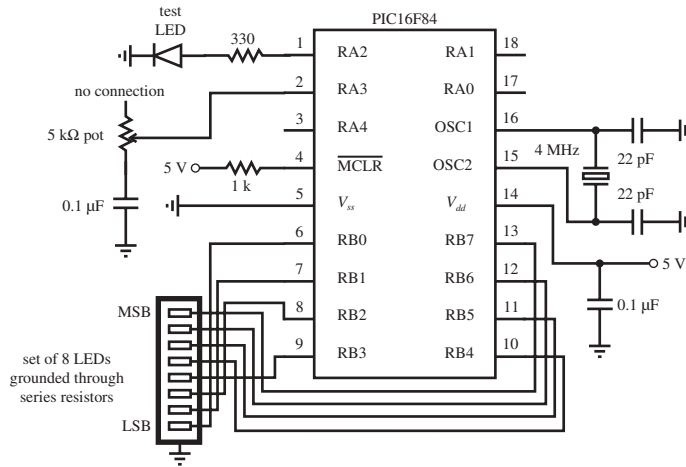
Pot pin, scale, var

where *pin* is the input pin identifier, *scale* is a number between 1 and 255 to adjust for the maximum time constant (RC) of the potentiometer and series capacitor, and *var* is the name of a byte variable used to store the value returned by the *Pot* statement. Refer to the PicBasic Pro manual for details on how to choose an appropriate value for *scale*. When the potentiometer is at minimum resistance, the value of *var* is minimum (0 for 0 Ω), and when the resistance is maximum the value is maximum (255 if *scale* is selected appropriately). For a 5 k Ω potentiometer and a 0.1 μ F series capacitor, an appropriate value for *scale* is 200.

In this example, the *TRISB = %00000000* assignment statement designates all PORTB pins as outputs and is required because the scaled potentiometer value is written directly to PORTB with the *PORTB = value* assignment statement. In previous examples, when statements like *High* and *Low* were used, the TRIS registers did not need to be set explicitly because the statements themselves automatically designate the pins as outputs. *PORTB = value* sets all the PORTB outputs to the corresponding bit values in the byte variable *value*.

(continued)

(concluded)



```
' pot.bas

' Graphically displays the scaled resistance of a potentiometer using a set of
' LEDs corresponding to a binary number ranging from 0 to 255.

' Define variables, pin assignments, and constants
value      Var      BYTE      ' define an 8 bit (byte) variable capable of
                                ' storing numbers between 0 and 255
test_led Var      PORTA.2      ' pin to which a test LED is attached (RA2)
pot_pin Var      PORTA.3      ' pin to which the potentiometer and series
                                ' capacitor are attached (RA3)
SCALE      Con      200      ' value for Pot statement scale factor

' Define the input/output status of the I/O pins
TRISB = %00000000      ' designate all PORTB pins as outputs

mainloop:
    High test_led      ' turn on the test LED
    Pot pot_pin, SCALE, value      ' read the potentiometer value
    PORTB = value      ' display the binary value graphically
                        ' with the 8 PORTB LEDs (RB0 through RB7)

    Pause 100      ' wait one tenth of a second
    Low test_led      ' turn off the test LED as an indication
                        ' that the program and loop are running
    Pause 100      ' wait one tenth of a second

Goto mainloop      ' continue to sample and display the potentiometer value and blink
                    ' the test LED

End
```

This example illustrates how to sample the value of a resistance using the special PicBasic Pro statement *Pot*. PicBasic Pro provides an assortment of other high-level statements (e.g., *Button*, *Freqout*, *Lcdout*, *Lookdown*, *Lookup*, *Pwm*, *Serin*, *Serout*, and *Sound*) that help you create sophisticated functionality with only a few lines of code. Video Demo 7.1 shows a live demonstration of the hardware and software from this example. Eight LEDs provide a visual display of the angular position of a knob (a potentiometer) as it is turned.

**Video Demo**

7.1 Potentiometer input and binary display

■ CLASS DISCUSSION ITEM 7.8

How Does Pot Work?

The PicBasic Pro statement *Pot* applied in Example 7.6 uses a digital I/O pin to measure the resistance of a potentiometer. *Pot* effectively converts the analog resistance value into a digital number, appearing to function as an A/D converter. How do you think PicBasic Pro accomplishes this? Hint: Consider the step response of an RC circuit and the use of a single pin as an output and then an input.

■ CLASS DISCUSSION ITEM 7.9

Software Debounce

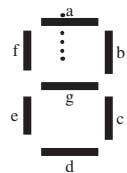
Sections 6.10.1 and 6.12.2 presented how to debounce switches using circuits. These are called a *hardware solutions* because they requires extra components wired together. If a switch is used to input data to a PIC design, debounce can be done in software instead. Assuming that a switch is connected to a PIC by only a single line, write PicBasic Pro code to perform the debounce. Note that the PicBasic Pro statement *Button* can be used for this purpose, but here we want you to think about how you would do it using more fundamental statements.

Option for Driving a Seven-Segment Digital Display with a PIC

There will be PIC applications where you need to display a decimal digit using a seven-segment LED display. The display could represent some calculated or counted value (e.g., the number of times a switch was pressed). One approach is to drive the seven LED segments directly from seven output pins of a PIC. This would involve decoding in software to determine which segments need to be on or off to display the digit properly. If we label the segments as shown in the figure in the margin and if the PORTB pins are wired to the segments of the LED display, where the segments are connected to 5 V through a

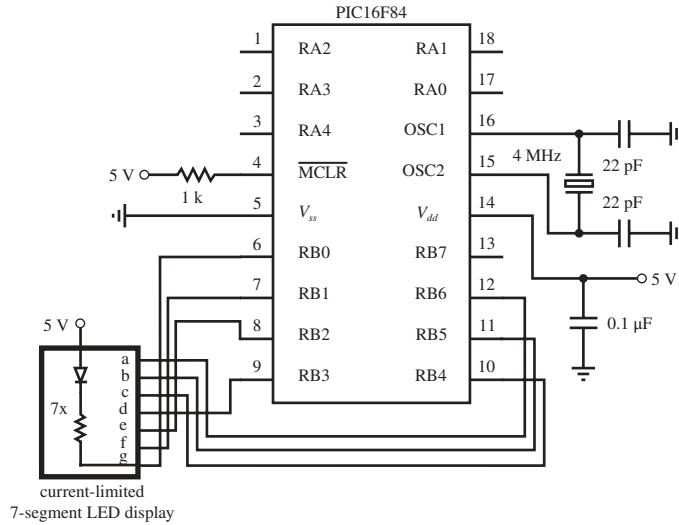
(continued)

DESIGN EXAMPLE 7.1



(concluded)

set of current-limiting resistors, the following initialization code must appear at the top of your program:



```
' Declare variables
number Var BYTE
pins Var BYTE[10]

' Initialize I/O pins
TRISB = %00000000

' Segment codes for each digit where a 0 implies the segment is on and a 1 implies
' it is off, because the PIC sinks current from the LED display
' %gfedcba display
pins[0] = %1000000 ' 0
pins[1] = %1111001 ' 1
pins[2] = %0100100 ' 2
pins[3] = %0110000 ' 3
pins[4] = %0011001 ' 4
pins[5] = %0010010 ' 5
pins[6] = %0000011 ' 6
pins[7] = %1111000 ' 7
pins[8] = %0000000 ' 8
pins[9] = %0011000 ' 9
```

The remainder of your code might consist of a polling loop that needs to update the digital display periodically. A subroutine can be used to accomplish this. **Subroutines** are blocks of code to perform specialized functions that may need to be executed repeatedly or in

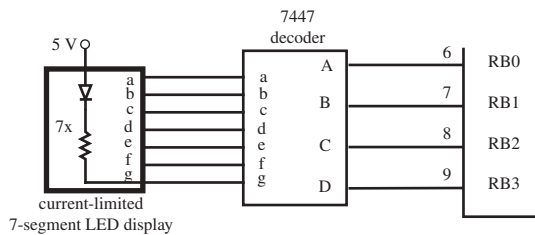
numerous places within your program. Using the byte variable *number* declared in the code, the following subroutine could be used to display the value stored in the variable:

```
' Subroutine to display a digit on a 7-segment LED display. The value of the
' digit must be stored in a byte variable called "number." The value is assumed
' to be less than 10; otherwise, all segments are turned off to indicate an error.
display_digit:
    If (number < 10) Then
        PORTB = pins[number]      ' display the digit
    Else
        PORTB = %1111111         ' turn off all 7 segments
    EndIf
Return
```

A number can be displayed at any point in your program by assigning the value to the variable *number* and calling the subroutine. For example, the following statements would display the digit 8:

```
number = 8
Gosub display_digit
```

The solution just presented above requires seven output pins. Because the PIC16F84 has a total of only 13 I/O pins, this could limit the addition of other I/O functions in your design. An alternative design that requires fewer output pins uses a seven-segment decoder IC (e.g., 7447). Here, only four I/O pins are required as shown next:



For this case, the *pins* array is not required, and only pins RB0 through RB3 require initialization as outputs. The subroutine would change to

```
display_digit:
    If (number < 10) Then
        PORTB = (PORTB & $F0) | number      ' display the digit
    Else
        PORTB = (PORTB & $F0) | $F         ' turn off all segments
    EndIf
Return
```

The assignment statement for PORTB uses a **logic mask** to retain the four MSBs of PORTB, which may have been independently set by other program statements for other functions, and to assign the binary equivalent of *number* to the four LSBs that are output to

(continued)

(concluded)

the seven-segment display driver. A logic mask is a bit string used to protect selected bits in a binary number from change while allowing others to change. The bitwise AND (&) and OR (|) operators are used to help accomplish the mask operation. The term *PORTB & \$F0* retains the four MSBs while clearing the four LSBs with zeros. For example, if *PORTB*'s current value is %11011001, then *PORTB & \$F0* yields the following result:

$$\begin{array}{rcl}
 \%11011001 & & (\text{PORTB}) \\
 \& & \\
 \%11110000 & & (\$F0) \\
 = & & \\
 \%11010000 & & (\text{PORTB} \& \$F0)
 \end{array}$$

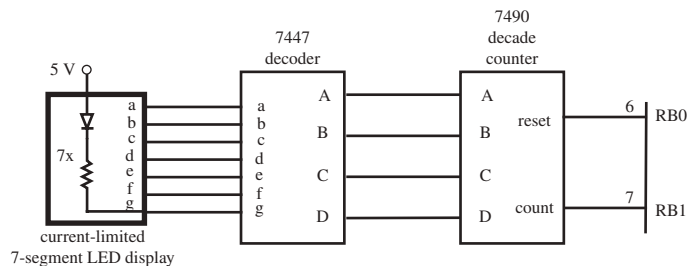
By OR-ing this result with *number*, the four LSBs are replaced by the corresponding binary value of *number*. For example, if the current value of *number* is 7 (%0111), then *(PORTB & \$F0) | number* would yield the following result:

$$\begin{array}{rcl}
 \%11010000 & & (\text{PORTB} \& \$F0) \\
 | & & \\
 \%00000111 & & (\text{number}) \\
 = & & \\
 \%11010111 & & ((\text{PORTB} \& \$F0) | \text{number})
 \end{array}$$

As you can see, the four MSBs of *PORTB* remain unchanged, and the four LSBs have changed to the binary value of *number*.

The *\$F* (15) in the *Else* clause is the input value required by the decoder IC to blank all seven segments.

If you lack the luxury of even four I/O pins in your design but still wish to display a digit, another alternative is to use a 7490 decade counter IC with reset and count inputs. The reset input is assumed to have positive logic, so when the line goes high, the counter is reset to 0. The count input is edge triggered, and in this example it does not matter if it is positive-edge or negative-edge triggered. Only two PIC I/O pins are required to drive this alternative as shown next:



In this case, only pins RB0 and RB1 need be initialized as outputs, and a new counter variable (*i*) has to be declared for use in the subroutine. Also, two pin assignments can be made as follows:

```

i          Var      BYTE      ' counter variable used in For loop
reset      Var      PORTB.0    ' signal to reset the counter to 0
count      Var      PORTB.1    ' signal to increment the counter by 1
  
```

The subroutine would change to

```
display_digit:
    Pulsout reset, 1          ' send a full pulse to reset the counter
                              ' to zero
    If (number < 10) Then
        ' Increment the counter "number" times to display the appropriate
        ' digit
        For i = 1 To number
            Pulsout count, 1    ' send a full pulse to increment the
                              ' counter
        Next i
    Else
        ' Increment the counter 15 times to clear the display (all segments
        ' off)
        For i = 1 To 15
            Pulsout count, 1    ' send a full pulse to increment the
                              ' counter
        Next i
    EndIf
Return
```

Here, the PicBasic Pro statement *Pulsout* is used to send a pulse to each of the control pins. The syntax of this command is

Pulsout pin, period

where *pin* is the pin identifier (e.g., PORTB.0) and *period* is the length of the pulse in tens of microseconds. The pulses generated by the code above are 10 microseconds wide.

In this example, the last two alternatives require additional components (the decoder and counter ICs). If the physical size of the design is no constraint and an objective is to minimize cost by not having to use an additional PIC16F84 or an alternative PIC with more I/O pins, then one of the latter alternatives might be attractive.

■ CLASS DISCUSSION ITEM 7.10

Fast Counting

In the third option presented in Design Example 7.1, the counter was incremented the appropriate number of times to display the desired decimal value on the display. Do you think that this counting will be detectable on the display? Why or why not?

Lab Exercise 10 shows how to wire components and write software to create some of the functionality presented in Design Example 7.1. The exercise expands upon the design example functionality by providing a display of all hexadecimal



Lab Exercise

Lab 10

Programming a PIC microcontroller—part II



Video Demo

- 7.2** Hexadecimal counter using a 555 timer and data flip-flops for switch debounce
- 7.3** Hexadecimal counter with software debounce

digits from 0 to F. Video Demos 7.2 and 7.3 show two different designs explored in Lab Exercise 10. The first solution uses a 555 timer circuit with data latches to debounce pushbutton switch input signals, and the second solution deals with switch bounce in software using delays.

7.6 USING INTERRUPTS

The program to solve the home security system problem presented in Example 7.5 uses a method called **polling**, where the program continually checks (or “polls”) sensor values within a loop, updating the output accordingly in each cycle through the loop. Program flow is easy to understand, because all processing takes place within the main program loop. The loop continues to cycle as long as the microcontroller is powered. For more complex applications, polling may not be suitable, because the loop may take too long to execute. In a long loop, the inputs may not be checked often enough.

An alternative approach is to use an interrupt. In an interrupt-driven program, some inputs are connected to special input lines, designated as interrupts. When one or more of these lines changes level, the microcontroller temporarily suspends normal program execution while the change is acted on by a subprogram or function called an **interrupt service routine**. At the end of the service routine, control is returned to the main program at the point where the interrupt occurred. Because polling is easier to implement (and debug when there are problems), it is generally preferred over interrupts, as long as the polling loop can run fast enough. However, in situations where many functions are being performed during a long program loop and you don’t want to add frequent manual checks for input changes, interrupts can be very useful.

To detect interrupts, two specific registers on the PIC must be initialized correctly. These are the option register (**OPTION_REG**) and the interrupt control register (**INTCON**). The definition for each bit in the first register (**OPTION_REG**) follows. Recall that the least significant bit is on the right and designated as bit 0 (b_0), while the most significant bit is on the left and designated as bit 7 (b_7):

$$\text{OPTION\_REG} = \%b_7b_6b_5b_4b_3b_2b_1b_0$$

- bit 7:** RBPU: PORTB pull-up enable bit
 1 = PORTB pull-ups are disabled
 0 = PORTB pull-ups are enabled
- bit 6:** Interrupt edge select bit
 1 = Interrupt on rising edge of signal on pin RBO
 0 = Interrupt on falling edge of signal on pin RBO
- bit 5:** TOCS: TMRO clock source select bit
 1 = External signal on pin RA4
 0 = Internal instruction cycle clock (CLKOUT)
- bit 4:** TOSE: TMRO source edge select bit
 1 = Increment on high-to-low transition of signal on pin RA4
 0 = Increment on low-to-high transition of signal on pin RA4

bit 3: PSA: prescaler assignment bit
 1 = Prescaler assigned to the Watchdog timer (WDT)
 0 = Prescaler assigned to TMRO

bits 2, 1, and 0:

3-bit value used to define the prescaler rate for the timer features

Value	TMRO Rate	WDT Rate
000	1 : 2	1 : 1
001	1 : 4	1 : 2
010	1 : 8	1 : 4
011	1 : 16	1 : 8
100	1 : 32	1 : 16
101	1 : 64	1 : 32
110	1 : 128	1 : 64
111	1 : 256	1 : 128

In the *onint.bas* example presented below, OPTION_REG is set to \$FF, which is %11111111. Setting bit 7 high disables PORTB pull-ups and setting bit 6 high causes interrupts to occur on the positive edge of a signal on pin RB0. When pull-ups are enabled, the PORTB inputs are held high until they are pulled low by the external input circuit (e.g., a switch to ground wired to pin RB0). Bits 0 through 5 are important only when using special purpose timers.

The definition for each bit in the second register (INTCON) follows:

bit 7: GIE: global interrupt enable bit
 1 = Enables all unmasked interrupts
 0 = Disables all interrupts

bit 6: EEIE: EE write complete interrupt enable bit
 1 = Enables the EE write complete interrupt
 0 = Disables the EE write complete interrupt

bit 5: TOIE: TMRO overflow interrupt enable bit
 1 = Enables the TMRO interrupt
 0 = Disables the TMRO interrupt

bit 4: INTE: RBO interrupt enable bit
 1 = Enables the RBO/INT interrupt
 0 = Disables the RBO/INT interrupt

bit 3: RBIE: RB port change interrupt enable bit (for pins RB4 through RB7)
 1 = Enables the RB port change interrupt
 0 = Disables the RB port change interrupt

bit 2: TOIF: TMRO overflow interrupt flag bit
 1 = TMRO has overflowed (must be cleared in software)
 0 = TMRO did not overflow

bit 1: INTF: RBO interrupt flag bit
 1 = The RBO interrupt occurred
 0 = The RBO interrupt did not occur

bit 0: RBIF: RB port change interrupt flag bit
 1 = At least one of the signals on pins RB4 through RB7 has changed state (must be cleared in software)
 0 = None of the signals on pins RB4 through RB7 has changed state

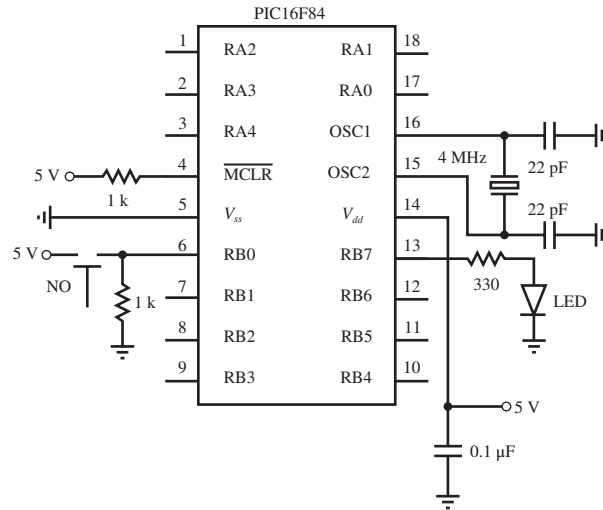


Figure 7.8 Interrupt example wiring diagram.

In the *onint.bas* example that follows, `INTCON` is set to `$90`, which is `%10010000`. For interrupts to be enabled, bit 7 must be set to 1. Bit 4 is set to 1 to check for interrupts on pin `RB0`. Bits 0 and 1 are used to indicate interrupt status during program execution. If more than one interrupt signal were required, bit 3 would be set to 1, which would enable interrupts on pins `RB4` through `RB7`. In that case, `INTCON` would be set to `$88` (`%10001000`). To check for interrupts on `RB0` and `RB4–7`, `INTCON` would be set to `$98` (`%10011000`). `PORTA` has no interrupt capability, and `PORTB` has interrupt capability only on pin `RB0` and pins `RB4` through `RB7`. Bits 6, 5, and 2 are for advanced features not used in this example.

A simple example, called *onint.bas*, that illustrates the use of interrupts follows. The corresponding wiring diagram is shown in Figure 7.8. The program's function is described in detail in the following paragraphs.

```
' onint.bas

' This program turns on an LED and waits for an interrupt on PORTB.0. When RB0
' changes state, the program turns the LED off for 0.5 seconds and then resumes
' normal execution.

led    var    PORTB.7                ' designate pin RB7 as "led"
OPTION_REG = $FF                    ' disable PORTB pull-ups and detect positive
                                      ' edges on interrupt
On Interrupt Goto myint ' define interrupt service routine location
INTCON = $90                        ' enable interrupts on pin RB0

' Turn LED on and loop until there is an interrupt
mainloop:
    High led
    Goto mainloop
```

```

' Interrupt handling routine
Disable                                ' disable interrupts until the Enable
                                      ' statement appears

myint:
    Low led                            ' turn LED off
    Pause 500                          ' wait 0.5 seconds
    INTCON.1 = 0                       ' clear interrupt flag
    Resume                             ' return to main program
Enable                                ' allow interrupts again

End                                    ' end of program

```

The *onint.bas* program turns on an LED connected to pin RB7 until an external interrupt occurs. A normally open pushbutton switch connected to pin RB0 provides the source for the interrupt signal. When the signal transitions from low to high, the interrupt routine executes, causing the LED to turn off for half a second. Control then returns to the main loop, causing the LED to turn back on again.

The first active line creates the variable name *led* to denote the pin identifier PORTB.7. In the next line, the `OPTION_REG` is set to `$FF` (or `%11111111`) to disable PORTB pull-ups and configure the interrupt to be triggered when the positive edge of a signal occurs on pin RB0. The PicBasic Pro statement *On Interrupt Goto* designates the label *myint* as the location to which program control jumps when an interrupt occurs. The value of the `INTCON` register is set to `$90` (or `%10010000`) to properly enable RB0 interrupts.

The three lines starting with the label *mainloop* cause the program to loop continually, maintaining program execution while waiting for an interrupt. The LED connected to pin RB7 remains on during this loop. The loop is called an **infinite loop**, because it cycles as long as no interrupt occurs. Note that an active statement (such as *High led*) must exist between the label and the *Goto* of the loop for the interrupt to function, because PicBasic Pro checks for interrupts only after a statement is completed.

The final section of the program contains the interrupt service routine. *Disable* must precede the label, and *Enable* must follow the *Resume* to prevent checking for interrupts until control is returned to the main program. The interrupt service routine executes when control of the program is directed to the beginning of this routine, labeled by *myint*, when an interrupt occurs on pin RB0. At the identifier label *myint*, the statement *Low led* clears pin RB7, turning off the LED. The *Pause* statement causes a 500 millisecond delay, during which time the LED remains off. The next line sets the `INTCON.1` bit to 0 to clear the interrupt flag. The interrupt flag was set internally to 1 when the interrupt signal was received on pin RB0, and this bit must be reset to 0 before exiting the interrupt routine, so that subsequent interrupts can be serviced. At the end of the *myint* routine, control returns to the main program loop where the interrupt occurred. Lab Exercise 9 explores the concepts and example presented in this section.

It should be pointed out that PicBasic Pro does not handle interrupts very efficiently, and the code required can be confusing. As mentioned earlier, PicBasic Pro checks for interrupt input changes only after each statement is done executing, so interrupts will not be detected and acted upon during statement that might take a



Lab Exercise

Lab 9

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ming a PIC
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part I

while to execute (e.g., *Pause* and *Sound* commands with long durations). Hardware interrupts can be very effective when using other programming languages and microcontrollers that deal with interrupts more naturally, but PicBasic Pro software interrupts should generally be avoided. It is often easier and better to use simple polling loops instead. The exception is when you have a long program loop performing many sequential functions and you want to be able to interrupt the action at any point during loop execution (e.g., when the user presses a button). In those situations, the PicBasic Pro interrupt feature can be very useful.

7.7 THE ARDUINO PROTOTYPING PLATFORM

This book has emphasized the PIC microcontroller and the PicBasic Pro programming language since the original edition. We made these choices for several reasons. First of all, Microchip PIC microcontrollers are very widespread and are in many commercial products. Also, PicBasic Pro is the easiest language to learn and understand compared to other alternatives, especially for students new to programming. However, in recent years, the Arduino prototyping boards and supporting C-based programming language have become quite popular, and there are many supporting online resources and products available making the Arduino environment very easy to learn and use. Therefore, we decided to add this brief overview and introduction to the Arduino alternative along with useful examples and resources to support those who want to pursue this route.

Arduino is an open-source prototyping platform consisting of Atmel-microcontroller-based prototyping boards and a free Java-based integrated development environment (IDE) which makes it very easy to interface to the boards and program them using a C-based programming language. There are also many free and useful software libraries that add functionality for programming all sorts of add-on devices. The Arduino community is very large and provides significant online support in the form of tutorials and example code that are presented in easy-to-follow and accessible ways. There are also many inexpensive products available (sensors, add-on plug-and-play modules, actuators, etc.) that come with example Arduino code and examples, making it very easy to add functionality to a design and get up and running quickly. The Arduino experience has revolutionized what is possible for do-it-yourself (DIY) hobbyists who want to create smart projects with embedded control and intelligence. And you don't need much background in electronics, programming, or engineering to get simple projects up and running very quickly.

The Arduino IDE software can be downloaded for free from the main Arduino website at Internet Link 7.9. The IDE is used to create, compile, and upload programs to Arduino boards via a USB cable which can also provide power to the board. The IDE can also monitor, display messages from, and communicate input to the Arduino board while the uploaded program runs. The maximum current that can be provided through a USB cable is limited to about 500 mA for USB 2.0 and 900mA for USB 3.0, but the boards can also be powered with an AC adaptor if more current is needed or if you want your project to run untethered from a computer.

There are many Arduino board options available that vary in size, speed, memory capacity, and functionality. The most common is the Arduino UNO shown in



Internet Link

7.9 Arduino website

Figure 7.9. The UNO is a printed circuit board (PCB) containing all of the components you need to power, interface to, and program the onboard microcontroller to get an easy start with any project. The board includes a 20MHz Atmel ATmega328P 8-bit microcontroller with 14 digital I/O pins, 6 analog inputs, 32 KB of flash memory, and 2 KB of RAM. Also included on the board are a USB interface, a voltage regulator, a clock crystal oscillator, several indicator LEDs, an LED for project use, and header strips for easy connections to the board or for plugging in Arduino Shield boards that can extend the capabilities of the main board. Inexpensive Shields are commercially available for expanded I/O, sensor and motor interfaces and drivers, wireless communication, cellular communication, etc. Another common Arduino board is the Arduino MEGA which has a bigger processor (the ATmega2560) with many more I/O pins (54 total), and more functionality (e.g., more PWM pins, more analog inputs, and four channels of serial communication). A list and detailed comparison of all of the Arduino boards available, which come in a wide range of sizes and capabilities, can be found at Internet Link 7.10.

Arduino programs are written in a C-based language, and the programs you write are usually referred to as “Sketches.” A Sketch includes two functions: `setup()` and `loop()`. The `setup()` function runs only once when the Arduino is powered up or reset. The `setup()` function is useful to declare and initialize variables and constants, define I/O pins as inputs and outputs, and other initialization tasks you want to perform only once. After the `setup()` function completes, the `loop()` function is called or run over and over again in an infinite loop until the Arduino is powered



Internet Link

7.10 Arduino board specs



Figure 7.9 Arduino UNO.

©2017 Arduino

**Internet Link**

7.11 Arduino language reference guide

7.12 Arduino libraries

**Internet Link**

7.13 Vilros Arduino Uno Ultimate Starter Kit + LCD

7.14 Jeremy Blum Arduino tutorial videos

7.15 Arduino website tutorials

7.16 Arduino online forum for technical support and questions

**Internet Link**

7.8 PicBasic Pro compiler manual

7.11 Arduino language reference guide

down or reset. The complete language reference guide is available online at Internet Link 7.11. It summarizes every programming structure, function, and variable type available, and it provides complete documentation and examples for each feature. There are also numerous add-on software libraries that are available to extend the basic capabilities of the language. A summary and complete documentation, including examples, are available at Internet Link 7.12. Some of the libraries make it easy to control devices like LCD and LED displays, and servo and stepper motors. Others are available to facilitate communication with other components via wireless connections, the Internet, and various standard serial interfaces. There are also libraries useful for managing data and performing advanced calculations and control.

The best way to learn the Arduino language and environment is to run through a set of tutorials. It also helps to have a starter kit like the Vilros Ultimate Starter Kit + LCD (see Internet Link 7.13). It includes an Arduino Uno Rev3 Board with USB cable, a breadboard, a holder for the UNO and breadboard, jumper wires, resistors, diodes, transistors, LEDs, pushbutton switches, a temperature sensor, a photocell, a buzzer, a DC motor, a small RC servomotor, a relay, an LCD with a pre-soldered pin header, and a tutorial booklet. This is everything you need to start a wide range of small mechatronics and hobby projects. The included tutorial booklet is excellent. If you work through all of the exercises and study all of the code included, you will know most of what you need to know concerning the Arduino language and environment . . . and the tutorials are fun! There are also countless books and online resources available to help you learn the Arduino language. A set of tutorials by Jeremy Blume on YouTube are excellent. They can be found at Internet Link 7.14. Jeremy also has a supporting book called “Exploring Arduino” (see the Bibliography) that is very well written. The Arduino website also contains many useful examples in the Tutorials section at Internet Link 7.15. There are also many categorized code examples under the File menu of the Arduino IDE (under the Examples submenu) that are very useful as starting points for various tasks common in typical projects. Examples of how to use all Arduino C features can be found in the online language reference guide (Internet Link 7.11). And if all of the examples and online help are not enough, you can always visit the Arduino online technical forum to search for answers to your questions or to post a new question for help (see Internet Link 7.16).

Table 7.6 provides a collection of examples of many common microcontroller software tasks, written in both PicBasic Pro and Arduino C. These example code blocks can be useful starting points in your programming projects. The table can also serve as a code translation guide if you are attempting to convert a PicBasic Pro program (e.g., the examples in this chapter) to Arduino C, or vice versa. The online PicBasic Pro compiler manual (Internet Link 7.8) and Arduino C language reference guide (Internet Link 7.11) can also be very useful in this regard. Although the focus in this chapter is the Microchip PIC microcontroller and PicBasic Pro, as you will see as you gain experience with other programming languages and different microcontroller platforms, programming is very similar in all languages and with all microcontrollers. Also, many of the concepts involved with interfacing and principles of operation are also very similar from one hardware platform to another. As an example of how similar code can be between PicBasic Pro and Arduino C, see Example 7.7.

Table 7.6 Arduino-to-PicBasicPro Code Translation Examples

Arduino code	PicBasic Pro equivalent
<i>Comments/Remarks:</i>	<i>Code Structure, Comments/Remarks:</i>
<code>/* A multiple-line comment is bracketed like this */</code>	<code>' A multiple-line comment is ' bracketed like this</code>
<code>// Here' s a single-line comment</code>	<code>' Here' s a single-line comment</code>
<code>... code ... // end-of-line remark</code>	<code>... code ... ' end-of-line remark</code>
<i>Code Structure:</i>	<i>Code Structure:</i>
<code>// Declare global variables ...</code>	<code>' Declare global variables ...</code>
<code>// Define and initialize pins and special // features void setup() { ... }</code>	<code>' Define and initialize pins and special ' features ... ' Infinite loop run continuously Do While (1) ' Call subroutine/function Gosub my_function ... Loop</code>
<code>// Infinite loop run continuously void loop() { // Call subroutine/function my_function(); ... }</code>	<code>End</code>
<code>// Define function void my_function(void) { ... }</code>	<code>' Define function my_function: ... Return</code>
<i>Digital Input/Output and Logic:</i>	<i>Digital Input/Output and Logic:</i>
<code>const int buttonPin = 2; const int ledPin = 13;</code>	<code>buttonPin Var PORTA.3 ledPin Var PORTB.7</code>
<code>void setup() { pinMode(ledPin, OUTPUT); pinMode(buttonPin, INPUT); }</code>	<code>' These commands are not required ' (done by High/Low commands or default) ' Output ledPin ' Input buttonPin</code>
<code>// Turn on the LED if the button is down if (digitalRead(buttonPin) == HIGH) digitalWrite(ledPin, HIGH); else digitalWrite(ledPin, LOW);</code>	<code>' Turn on the LED if the button is down If (buttonPin == 1) Then High ledPin Else Low ledPin EndIf</code>

(continued)

Table 7.6 Arduino-to-PicBasicPro Code Translation Examples (Concluded)

Arduino code	PicBasic Pro equivalent
<i>Using a Function or Subroutine:</i>	<i>Using a Function or Subroutine:</i>
const int ledPin = 13; short i;	ledPin Var PORTB.7 I Var BYTE
void setup() { pinMode(ledPin, OUTPUT); }	Gosub blink_led ' blink the LED once ' Blink the LED 5 times For I = 1 to 5 Gosub blink_led Next I
blink_led(); // blink the LED once // Blink the LED 5 times for (i=1; i<=5; i++) blink_led();	' Subroutine to blink an LED blink_led: High ledPin Pause 500 Low ledPin Pause 500 Return
// Function to blink an LED void blink_led() { digitalWrite(ledPin, HIGH); delay(500); digitalWrite(ledPin, LOW); delay(500); }	
<i>Analog Input and Scaling:</i>	<i>Analog Input and Scaling:</i>
int x_raw; int x_scaled;	x_raw Var WORD x_scaled Var BYTE
x_raw = analogRead(A0);	Adcin 0, x_raw
// Scale raw value from 0-1023 to 0-255 // range x_scaled = map(x_raw, 0, 1023, 0, 255);	' Scale raw value from 0-1023 to 0-255 range x_scaled = x_raw / 4 ' scale from 10 bits to 8
// Limit the scaled value to within a range x_scaled = constrain(x_scaled, 0, 255);	
<i>LCD Output (countdown timer):</i>	<i>LCD Output (countdown timer):</i>
#include <LiquidCrystal.h>	i Var BYTE
short i;	' Wait for LCD to power up Pause 500
LiquidCrystal lcd(2, 3, 4, 5, 6, 7);	
void setup() { lcd.begin (16, 2); }	' Display countdown from 10 to 0 on the LCD For i = 10 To 0 ' Clear the LCD and display the countdown

Table 7.6 Arduino-to-PicBasicPro Code Translation Examples

Arduino code	PicBasic Pro equivalent
<pre>// Display countdown from 10 to 0 on the LCD for (i=10; i>0; i--) { /* Clear the lcd and display the countdown text and value */ lcd.clear(); lcd.print("count down:"); // move cursor to 2nd row, 2nd col lcd.setCursor(1, 1); lcd.print(i); delay(1000); // pause for 1 second }</pre>	<pre>' text and value Lcdout \$FE, 1, "count down: " Lcdout \$FE, \$C0, " ", Dec i Pause 1000; ' pause for 1 second Next i ' Clear the LCD Lcdout \$FE, 1</pre>
<pre>// Clear LCD lcd.clear();</pre> <i>Keypad Serial Interface and Compound Logic:</i> <pre>// Define variables byte key_val; // button value byte number; // value changed by buttons // Define keypad button codes const byte key1=0x30; const byte key2=0x31; const byte key3=0x32; void setup() { /* Initialize serial communication (receiving on pin 0) */ Serial.begin(2400); } // Keypad processing loop while (true) { // do always (infinite loop) // Wait for a keypad button to be pressed while (Serial.available() == 0); // Read the keypad value from the buffer key_val = Serial.read(); // Perform the appropriate function if ((key_val == key1) && (number > 0)) { // decrement number--; } }</pre>	<pre>' Define variables key_pin Var PORTB.0 ' input pin key_val Var BYTE ' button value key_mode Con 0 ' selects 2400 baud number Var BYTE ' value changed by buttons ' Define keypad button codes key1 Con \$30 key2 Con \$31 key3 Con \$32 ' Keypad processing loop Do While (1) ' do always (infinite loop) ' Wait for a keypad button to be pressed ' and read the value Serin key_pin, key_mode, key_val ' Perform the appropriate function If ((key_val = key1) And (number > 0)) Then ' decrement number = number - 1 ElseIf (key_val = key2) Then ' reset number = 0</pre>

(continued)

Table 7.6 Arduino-to-PicBasicPro Code Translation Examples (Concluded)

Arduino code	PicBasic Pro equivalent
<pre> else if (key_val == key2) { // reset number = 0; } else if ((key_val == key3) && (number < 255)){ // increment number++; } // Call a function to process the number process_display(); } // Define function void process_display (void) { ... } </pre>	<pre> ElseIf ((key_val = key3) And (number < 255)) Then ' increment number = number + 1 EndIf ' Call a subroutine to process the number Gosub process_display Loop End ' Define function process_display: ... Return </pre>
Servomotor Control: <pre> #include <Servo.h> // Define variables const int servoPin=9; const int sensorPin=2; Servo myServo; int ang; // servo angle // Initialize I/O pins void setup() { pinMode(sensorPin, INPUT); myServo.attach(servoPin); } /* Continually sweep over the full servo range checking a digital sensor every 15 degrees */ void loop() { // Start in the 0 degree servo position myServo.write(0); // Wait for the servo to go to // (or return to) the 0 position delay(1000) </pre>	Servomotor Control: <pre> ' Servo duty cycle info: ' position (degrees) = pulse width (ms) = ' duty cycle (%) = Hpwm 0-255 value ' 0 degrees = 1 ms = 5% = 13 ' 90 degrees = 1.5 ms = 7.5% = 19 ' 180 degrees = 2 ms = 10% = 25 servoFreq Con 50 ' 1/(20ms) = 50Hz ' Define variables dutyCycle Var BYTE servoPin Var PORTB.0 ' RBO (pin 9 set to CCP1) sensorPin Var PORTA.3 duty_cycle Var BYTE ' servo angle ' Initialize pins Input sensorPin; ' Output servoPin ' not required (done by Hpwm) ' Continually sweep over the full servo range ' checking a digital sensor every 15 degrees Do While (1) ' do always (infinite loop) </pre>

Table 7.6 Arduino-to-PicBasicPro Code Translation Examples

Arduino code	PicBasic Pro equivalent
<pre> for (ang=15; ang<=180; ang+=15) { myServo.write(ang); delay(500); // wait 0.5s for servo to move // Read the sensor and react accordingly if (digitalRead(sensorPin) == HIGH) sensor_react(); } } // Process the sensor detect event void sensor_react() { // Do something here } </pre>	<pre> ' Start in the 0 degree servo position Hpwm 1, 13, servoFreq ' Wait 1s for the servo to go ' to (or return to) 0 position Pause 1000 For dutyCycle = 13 To 25 ' step = 1 = 15 deg. Hpwm 1, dutyCycle, servoFreq ' Can use PULSOUT instead to get finer control Pause 500 ' wait 0.5s for servo to move ' Read the sensor and react accordingly If (sensorPin) Then Gosub sensorReact Next dutyCycle Loop End ' Process the sensor detect event sensorReact: ' Do something here Return </pre>
<i>Sending a Song to a Speaker:</i> <pre> // Define note pitches (in Hz) // (can put in "pitches.h" instead // with #include "pitches.h"): #define NOTE_C 262 #define NOTE_D 294 #define NOTE_E 330 #define NOTE_G 392 // Define variables const int speakerPin=9; const int buttonPin=2; const int n=30; // number of notes int i; // Song notes int notes[] = { NOTE_E, NOTE_D, NOTE_C, NOTE_D, NOTE_E, NOTE_E, NOTE_E, 0, NOTE_D, NOTE_D, NOTE_D, 0, NOTE_E, NOTE_G, NOTE_G, 0, NOTE_E, NOTE_D, NOTE_C, NOTE_D, </pre>	<i>Sending a Song to a Speaker:</i> <pre> ' Define note pitches (in Hz) NOTE_C Con 262 NOTE_D Con 294 NOTE_E Con 330 NOTE_G Con 392 ' Define variables speakerPin Var PORTB.0 buttonPin Var PORTA.3 n Var BYTE i Var BYTE ' Song notes n = 30 ' number of notes notes Var WORD[30] ' Note - the compact Arraywrite function works ' only for BYTE variables notes[0]=NOTE_E : notes[1]=NOTE_D notes[2]=NOTE_C : notes[3]=NOTE_D </pre>

(continued)

Table 7.6 Arduino-to-PicBasicPro Code Translation Examples (Concluded)

Arduino code	PicBasic Pro equivalent
<pre> NOTE_E, NOTE_E, NOTE_E, NOTE_E, NOTE_D, NOTE_D, NOTE_E, NOTE_D, NOTE_C, 0 }; // Song note durations (in ms) int durations[] = { 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 1500, 500 }; // Initialize I/O pins void setup() { pinMode(speakerPin, OUTPUT); pinMode(buttonPin, INPUT); } // Play "Mary Had a Little Lamb" while // button down void loop() { if (digitalRead(buttonPin) == HIGH) { for (i=0; i<n; i++) { tone (speakerPin, notes[i], durations[i]); // Add slight pause (50 ms) between notes delay (50); } } } </pre>	<pre> notes[4]=NOTE_E : notes[5]=NOTE_E notes[6]=NOTE_E : notes[7]=0 notes[8]=NOTE_D : notes[9]=NOTE_D notes[10]=NOTE_D : notes[11]=0 notes[12]=NOTE_E : notes[13]=NOTE_G notes[14]=NOTE_G : notes[15]=0 notes[16]=NOTE_E : notes[17]=NOTE_D notes[18]=NOTE_C : notes[19]=NOTE_D notes[20]=NOTE_E : notes[21]=NOTE_E notes[22]=NOTE_E : notes[23]=NOTE_E notes[24]=NOTE_D : notes[25]=NOTE_D notes[26]=NOTE_E : notes[27]=NOTE_D notes[28]=NOTE_C : notes[29]=0 ' Song note durations (in ms) durations Var WORD[30] durations[0]=500 : durations[1]=500 durations[2]=500 : durations[3]=500 durations[4]=500 : durations[5]=500 durations[6]=500 : durations[7]=500 durations[8]=500 : durations[9]=500 durations[10]=500 : durations[11]=500 durations[12]=500 : durations[13]=500 durations[14]=500 : durations[15]=500 durations[16]=500 : durations[17]=500 durations[18]=500 : durations[19]=500 durations[20]=500 : durations[21]=500 durations[22]=500 : durations[23]=500 durations[24]=500 : durations[25]=500 durations[26]=500 : durations[27]=500 durations[28]=1500 : durations[29]=500 ' Initialize I/O pins ' Output speakerPin ' not necessary Input buttonPin ' Play "Mary Had a Little Lamb" while button down Do While (buttonPin) For i = 0 To n-1 Freqout speakerPin, durations[i], notes[i] ' could use the Sound command instead ' Add slight pause (50 ms) between notes Pause 50; Next i Loop </pre>

Arduino C Version of the Home Security System Example

EXAMPLE 7.7

Example 7.5 presented a PicBasic Pro solution to the home security system example from Section 6.6. Here, we will look at an Arduino C equivalent, converting the PicBasic Pro code with the help of the code translation guide in Table 7.6. Here is the equivalent Arduino C code with enough documentation comments for you to follow along:

```
// security.c
// Arduino C program to perform the control functions of the home security
// system presented in Section 6.6

// Define global variables for I/O pin numbers
const byte c_pin=1;           // signal C
const byte d_pin=2;           // signal D
const byte door_or_window_pin=3; // signal A
const byte motion_pin=4;       // signal B
const byte alarm=5;            // signal Y
// Define global variables to store input pin values
bool c;
bool d;
bool door_or_window;
bool motion;

// Define global constants for use in IF comparisons
const bool OPEN=HIGH;         // to indicate that a door OR window is open
const bool DETECTED=HIGH;      // to indicate that motion is detected

// Initialize I/O pins status and values
void setup() {
    // Define status for each I/O pin
    pinMode(c_pin, INPUT);
    pinMode(d_pin, INPUT);
    pinMode(door_or_window_pin, INPUT);
    pinMode(motion_pin, INPUT);
    pinMode(alarm, OUTPUT);

    // Make sure the alarm is off to begin with
    digitalWrite(alarm, LOW);
}

// Main polling loop
void loop() {
    c = digitalRead(c_pin);
    d = digitalRead(d_pin);
    door_or_window = digitalRead(door_or_window_pin);
    motion = digitalRead(motion_pin);
```

(continued)

(concluded)

```

if ((c == 0) && (d == 1)) {           // operating state 1 (occupants sleeping)
    if (door_or_window == OPEN)
        digitalWrite(alarm, HIGH);
    else
        digitalWrite(alarm, LOW);
}
else if ((c == 1) && (d == 0)) {      // operating state 2 (occupants away)
    if ((door_or_window == OPEN) || (motion == DETECTED))
        digitalWrite(alarm, HIGH);
    else
        digitalWrite(alarm, LOW);
}
else                                 // operating state 3 or NA (alarm disabled)
    digitalWrite(alarm, LOW);
}

```

Compare the Arduino C code above to the PicBasic Pro code in Example 7.5 to see how similar they are. The only real differences are with subtle syntax. Note that the Arduino variable type *bool* is a Boolean variable similar to PicBasic Pro's *BIT* variable type. A *bool* variable can have only the value 1 (*HIGH*) or 0 (*LOW*). Another difference is the `loop()` function which is called repeatedly to create the polling loop automatically, without needing *Goto* label jumps or a *Do-While* loop.



Internet Link

7.17 PIC microcontroller student design projects

7.18 Project components used by past students

7.20 PIC I/O interface devices and useful accessories

At Colorado State University, we have required a microcontroller-based project in our junior-level Mechatronics course for many years now. Quite a few students have used Arduino boards over the years, even though our focus in the course has been the PIC. Video demonstrations of hundreds of the best projects to date can be found at Internet Link 7.17. In recent years, we have posted final project reports and microcontroller code (PIC and Arduino C) along with the videos for some of the most impressive projects. These examples can be useful to students and hobbyists wanting to create projects of similar scale and complexity. Also, Internet Link 7.18 provides a categorized list of all components used successfully by past students. This is an excellent resource for knowing what types of components are commercially available for projects like these, along with where to find them at affordable prices.

7.8 INTERFACING COMMON PIC PERIPHERALS

This section introduces interfacing a PIC to two common peripheral devices. The first is a 12-button keypad that can be used to input numeric data. The second is a liquid crystal display that can be used to output messages and numeric information to the user. More information on these and other useful peripheral devices can be found online (see Internet Link 7.20).

7.8.1 Numeric Keypad

Figure 7.10 illustrates a common four-row, three-column 12-button **keypad**. Figure 7.11 shows a photograph of two common keypads. One has 12 keys with a ribbon cable interface, and the other has 16 keys with solder holes to which individual wires can be attached. Each key in a keypad is attached to a normally open (NO) pushbutton switch. When a key is pressed, the switch closes. Figure 7.12 illustrates the electrical schematic of the keypad with a recommended interface to the PIC16F84. A standard keypad has a seven-pin header for connection to a ribbon cable socket. There is one pin for each row and one pin for each column as numbered in Figure 7.12.

The four rows (row 1, row 2, row 3, row 4) are connected to pins RB7 through RB4, which are configured as inputs. Internal pull-up resistance is available as a software option on these pins, so external pull-up resistors are not required (see details in Section 7.9.1). The three columns (col 1, col 2, col 3) are connected to pins RB0 through RB2, which are configured as outputs. The following PicBasic Pro code contains initializations and a framework for a polling loop that can be used to process input from the keypad. The column outputs are cleared low one at a time, and each row input is polled to determine if the key switch in that column is closed.

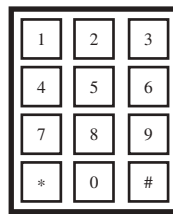


Figure 7.10 Numeric keypad.



Figure 7.11 Photograph of 12-key and 16-key numeric keypads.

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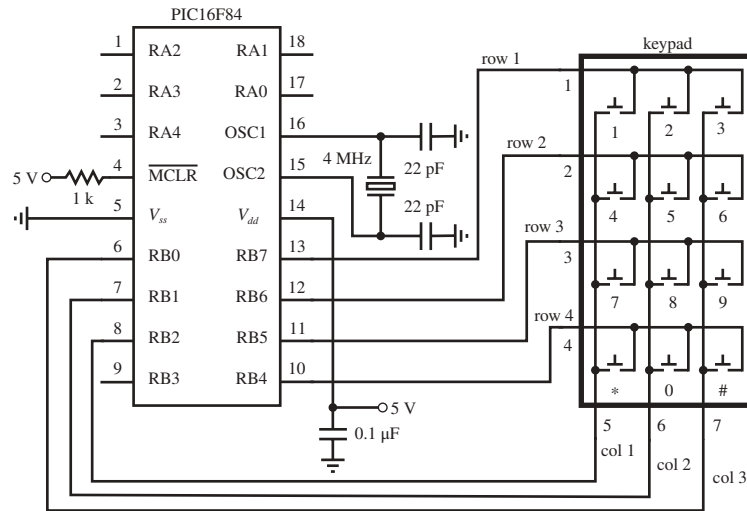


Figure 7.12 Numeric keypad schematic and PIC interface.

For example, if col 1 is low while col 2 and col 3 are high, and only the 1 key is being held down, then row 1 will be low while the remaining row lines will be high, indicating that only the 1 key is down. Statements could be added to the *If* statement blocks, in place of the comments, to process the input.

```
' Pin assignments
row1 Var PORTB.7
row2 Var PORTB.6
row3 Var PORTB.5
row4 Var PORTB.4
col1 Var PORTB.2
col2 Var PORTB.1
col3 Var PORTB.0

' Disable PORTB pull-ups
OPTION_REG = $FF

' Initialize the I/O pins (RB7:RB4 and RB3 as inputs and RB2:RB0 as outputs)
TRISB = %11111000

' Keypad polling loop
mainloop:
    ' Check column 1
    Low col1 : High col2 : High col3
    If (row1 == 0) Then
        ' key 1 is down
    EndIf
    If (row2 == 0) Then
        ' key 4 is down
    EndIf
```

```

If (row3 == 0) Then
    ' key 7 is down
EndIf
If (row4 == 0) Then
    ' key * is down
EndIf

' Check column 2
High col1 : Low col2 : High col3
If (row1 == 0) Then
    ' key 2 is down
EndIf
If (row2 == 0) Then
    ' key 5 is down
EndIf
If (row3 == 0) Then
    ' key 8 is down
EndIf
If (row4 == 0) Then
    ' key 0 is down
EndIf

' Check column 3
High col1 : High col2 : Low col3
If (row1 == 0) Then
    ' key 3 is down
EndIf
If (row2 == 0) Then
    ' key 6 is down
EndIf
If (row3 == 0) Then
    ' key 9 is down
EndIf
If (row4 == 0) Then
    ' key # is down
EndIf
' Continue polling
Goto mainloop
End

```

Lab Exercise 11 explores how to wire and accept input from a numeric keypad. In this case, three keys of a keypad are used to control the motion of a DC motor. Video Demo 7.5 shows a demonstration of the example in action.

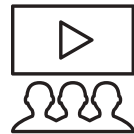
7.8.2 LCD Display

The other common peripheral device we want to highlight is a standard Hitachi 44780-based **liquid crystal display (LCD)**. LCDs come in different shapes and sizes that can support different numbers of rows of text and different numbers of



Lab Exercise

Lab 11 Pulse-width-modulation motor speed control with a PIC



Video Demo

7.5 Pulse-width-modulation speed control of a DC motor, with keypad input

characters per row. The standard choices for the number of characters and rows are 8×2 , 16×1 , 16×2 , 16×4 , 20×2 , 24×2 , 40×2 , and 40×4 . An example of a common 20×2 LCD is shown in Figure 7.13. It is illustrated schematically in the top of Figure 7.14. Applications of LCDs include displaying messages or information to the user (e.g., a home thermostat display, a microwave oven display, or a

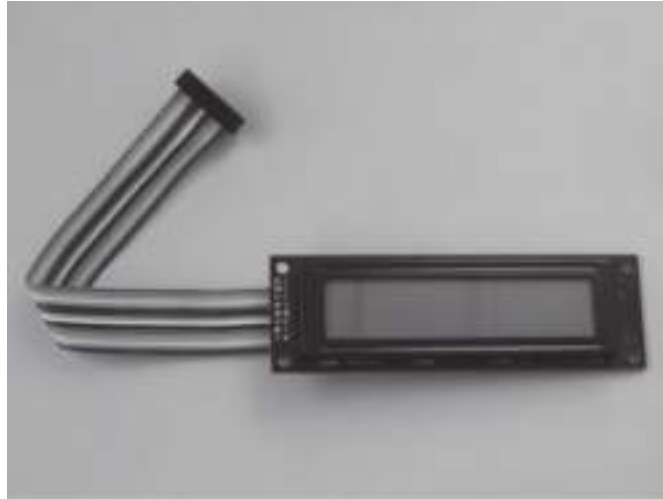


Figure 7.13 Photograph of an LCD.

©David Alciatore

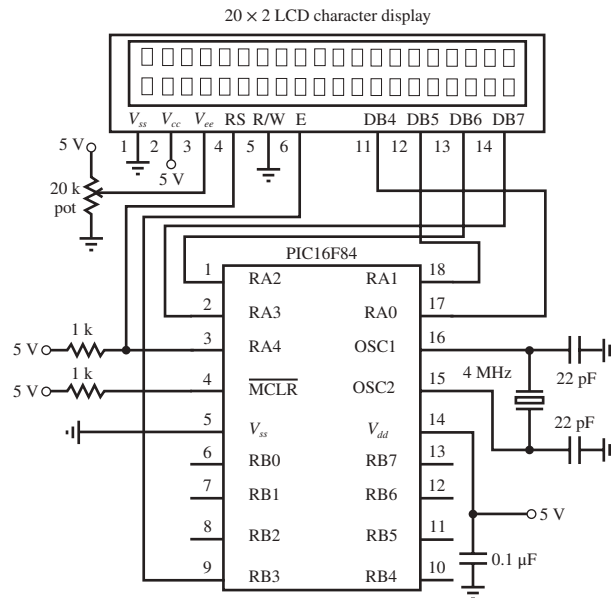


Figure 7.14 LCD PIC interface.

Table 7.7 Liquid crystal display pin descriptions

Pin	Symbol	Description
1	V_{ss}	Ground reference
2	V_{cc}	Power supply (5 V)
3	V_{ee}	Contrast adjustment voltage
4	RS	Register select (0: instruction input; 1: data input)
5	R/W	Read/write status (0: write to LCD; 1: read from LCD RAM)
6	E	Enable signal
7–14	DB0–DB7	Data bus lines

digital clock) and displaying a hierarchical input menu for changing settings and making selections (e.g., a copy machine or printer display).

For an LCD display with 80 characters or less (all but the 40×4 just listed), the display is controlled via 14 pins. The names and descriptions of these pins are listed in Table 7.7. PicBasic Pro offers a simple statement called *Lcdout* to control an LCD display. LCD displays with more than 80 characters (40×4) use a 16-pin header with different pin assignments not compatible with *Lcdout*. A 14-pin LCD can be controlled via four or eight data lines. PicBasic Pro supports both, but it is recommended that you use four lines to minimize the number of I/O pins required. Figure 7.14 shows the recommended interface to the PIC using a four-line data bus. Commands and data are sent to the display via lines DB4 through DB7, and lines DB0 through DB3 (pins 7 through 10) are not used. Pin RA4 is connected to 5 V through a pull-up resistor because it is an open drain output (see details in Section 7.9). The potentiometer connected to V_{ee} is used to adjust the contrast between the foreground and background shades of the display. The RS, R/W, and E lines are controlled automatically by PicBasic Pro when communicating with the display. Detailed information about LCD displays and how to write your own interface can be found online (see Internet Link 7.20).

With the hardware interface shown in Figure 7.14, the display can be controlled with the PicBasic Pro statement *Lcdout*. The simplest form of this statement is *Lcdout text*, where *text* is a string constant (e.g., *Lcdout "Hello world."*). The statement also supports various commands for controlling the display and cursor and for outputting numbers and data in different formats. Refer to the description of the *Lcdout* statement in the PicBasic Pro compiler manual for more information on these options. Here is a simple example to illustrate the use of the commands and format controls. If *x* is defined as a byte variable and currently contains the value 123, the following statement,

```
Lcdout $FE, 1, "Current value for x:", $FE, $C0, " ", DEC x
```

would clear the display and output the following two-line message:

```
Current value for x:
123
```

The code word *\$FE* indicates to the display that the next item is a command. In the example above, command *1* clears the display and command *\$C0* moves the cursor



Internet Link

7.20 PIC I/O interface devices and useful accessories



Video Demo

7.6 LCD display**THREADED DESIGN EXAMPLE****C.2 DC motor position and speed controller—Keypad and LCD interfaces**

Video Demo

1.8 DC motor position and speed controller**Internet Link****7.21** Paladin Semiconductor**7.22** PDN1144 keypad decoder

to the beginning of the next line. The prefix *DEC* is used to instruct the display to output the following number in its decimal digit form rather than its corresponding ASCII character. Video Demo 7.6 shows a demonstration of the example *Lcdout* statement above, where the displayed number is incremented by a *For* loop.

The following figure shows the functional diagram for Threaded Design Example C (see Section 1.3 and Video Demo 1.8), with the portion described here highlighted.

The wiring diagram that follows shows the components and connections for this part of the design. A special integrated circuit available from Paladin Semiconductor (see Internet Link 7.21) called the PDN1144 keypad decoder is used to monitor keypresses on the keypad and transmit them to the PIC via a serial interface. Detailed information about this device can be found in the data sheet (see Internet Link 7.22). The PDN1144, in addition to monitoring and transmitting keypress information, provides audio feedback to the user when a buzzer is connected as shown. The *Beep* signal switches the transistor on and off, causing the buzzer to oscillate. The LED in parallel with the buzzer provides a visual cue that a keypad button is being pressed. The LCD is wired in the standard way shown in Figure 7.14, allowing convenient use of the PicBasic Pro statement: *Lcdout*. However, notice that there are two differences in the wiring since a PIC16F88 is being used. The pull-up resistor on pin 3 is not required because RA4 is not an open-drain output on the PIC16F88 (unlike with the PIC16F84). Also, no pull-up resistor is required on pin 4 because this pin can be configured as an additional I/O pin (RA5) on the PIC16F88, so there is no problem leaving it floating since it is not being used (unlike with the MCLR feature of the PIC16F84 that must be held high to prevent a microcontroller reset).

Presented below is a portion of the PicBasic Pro code designed to accept input from the keypad and display a menu-driven user interface on the LCD. The remainder of the code will be presented in Threaded Design Example C.3. The *Serin* command in the first line of the “main” loop waits for keypress data to be transmitted from the PDN1144. The set of *If* statements then dispatches the appropriate subroutine based on the user selection. Again, more details will be shown in Threaded Design Example C.3. Two program lines important to LCD operation in this design are the *ANSEL = 0* and *Pause 500* lines before the main loop. The *ANSEL = 0* line is required because the PORTA and PORTB digital I/O pins can serve other purposes, including use as analog-to-digital (A/D) converters, with the PIC being used in this design (the PIC16F88). Setting ANSEL to 0 disables the alternative A/D features allowing the pins to be used properly as digital I/O by the *Lcdout* command. The *Pause 500* line is required because when power is first applied to an LCD, a small amount of time is required for the LCD to power up and be ready to function properly. If commands are sent to the LCD before it is ready to receive them, unexpected results can result.

```
' Turn off A/D converters (thereby allowing use of pins for I/O)
ANSEL = 0
' Define I/O pin name
key_serial Var PORTB.0                ' keypad serial interface input
```

```

' Declare Variables
key_value Var BYTE                                ' code byte from the keypad

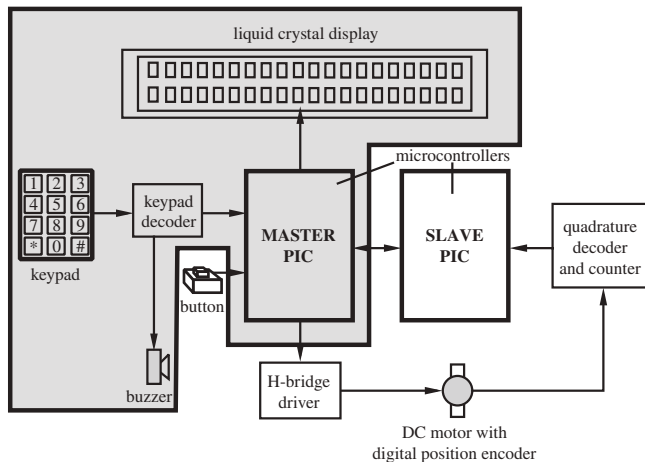
' Define constants
key_mode Con 0                                    ' 2400 baud mode for serial connection to keypad.
key_1 Con $30                                     ' hex code for the 1-key on the keypad
key_2 Con $31                                     ' hex code for the 2-key on the keypad
key_3 Con $32                                     ' hex code for the 3-key on the keypad

' Wait 1/2 second for the LCD to power up
Pause 500
' Wait for a keypad button to be pressed (i.e., polling loop)
Gosub main_menu                                  ' display the main menu on the LCD

main:
  Serin key_serial, key_mode, key_value
  If (key_value = key_1) Then
    Gosub position
  ElseIf (key_value = key_2) Then
    Gosub speed
  ElseIf (key_value = key_3) Then
    Gosub adjust_gains
  EndIf
  Goto main      ' continue polling keypad buttons
End ' end of main program

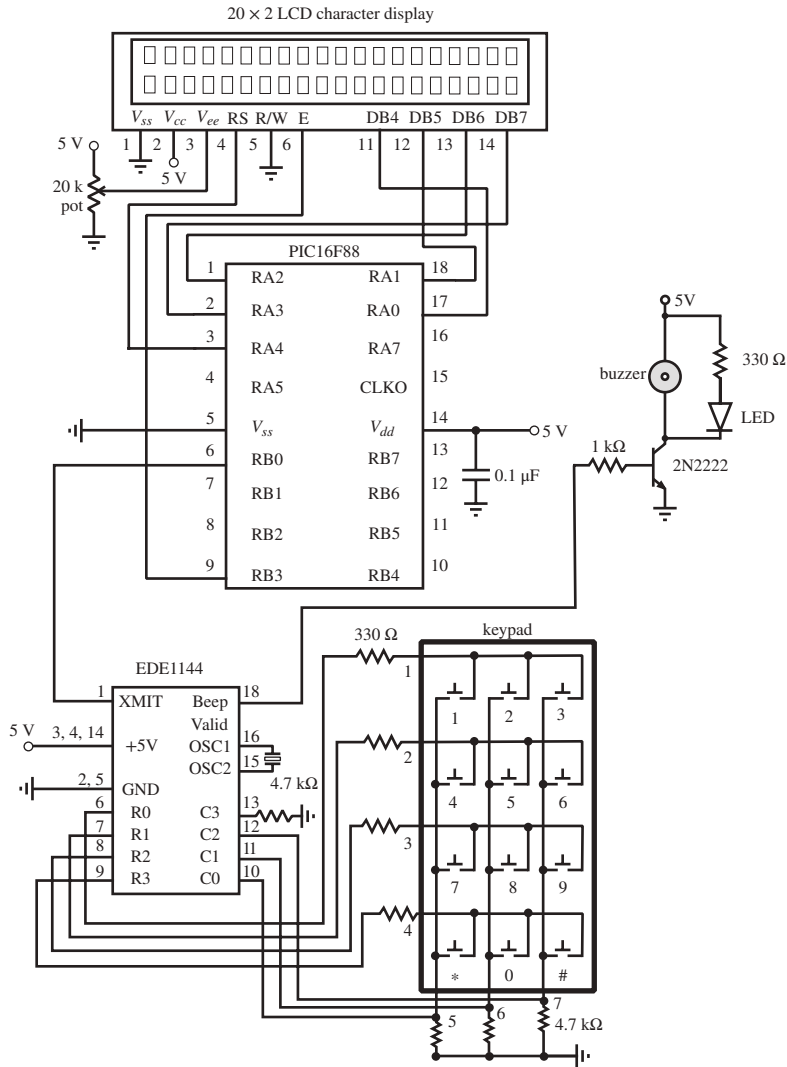
' Subroutine to display the main menu on the LCD
main_menu:
  Lcdout $FE, 1, "Main Menu:"
  Lcdout $FE, $C0, "1:pos. 2:speed 3:gain"
Return

```



(continued)

(concluded)



7.9 INTERFACING TO THE PIC

In this section, we discuss interfacing the PIC to a variety of input and output devices. As we saw in Section 7.5.1, each pin in the I/O ports may be configured in software as an input or an output. In addition, the port pins may be multiplexed with other functions to use additional features of the PIC. In this section, we examine the electronic schematics of the different input and output ports of the PIC16F84. The ports are different combinations of TTL and CMOS devices and have voltage and current limitations that must be considered when interfacing other devices to

the PIC. You should first refer to Section 6.11 to review details of TTL and CMOS equivalent output circuits and open drain outputs.

We begin by looking at the architecture and function of each of the ports individually. PORTA is a 5-bit-wide latch with the pins denoted by RA0 through RA4. The block diagram for pins RA0 through RA3 is shown in Figure 7.15, and the block diagram for pin RA4 is shown in Figure 7.16. The five LSBs of the TRISA register configure the 5-bit-wide latch for input or output. Setting a TRISA bit high causes the corresponding PORTA pin to function as an input, and the CMOS output driver in high impedance mode, essentially removing it from the circuit. Reading the PORTA register accesses the pin values. Clearing a TRISA bit low causes the corresponding PORTA pin to serve as an output, and the data on the data latch appears on the pin. RA4 is slightly different in that it has a Schmitt trigger input buffer that triggers with a distinct transition even for a slowly changing and/or noisy input (see Section 6.12.2). Also, the output configuration of RA4 is open drain, and external components (e.g., a pull-up resistor to power) are required to complete the output circuit.

PORTB is also bidirectional but is 8 bits wide. Its data direction register is denoted by TRISB. Figure 7.17 shows the schematic for pins RB4 through RB7, and Figure 7.18 shows pins RB0 through RB3. A high on any bit of the TRISB register sets the tristate gate to the high impedance mode, which disables the output driver. A low on any bit of the TRISB register places the contents of the data latch on the selected output pin. Furthermore, all of the PORTB pins have **weak pull-up** FETs.

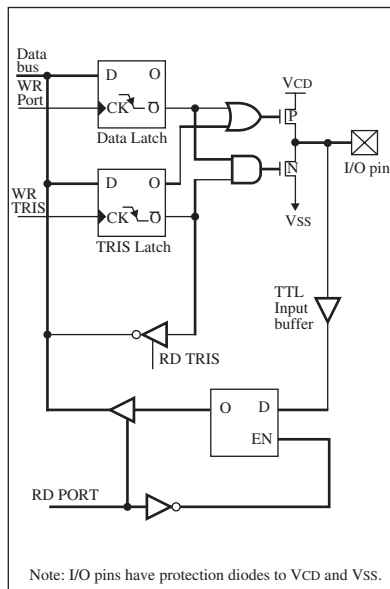


Figure 7.15 Block diagram for pins RA0 through RA3.

Source: Microchip Technology, Inc., Chandler, AZ.

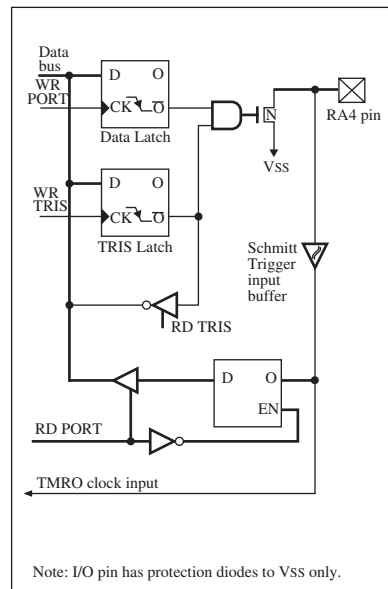


Figure 7.16 Block diagram for pin RA4.

Source: Microchip Technology, Inc., Chandler, AZ.

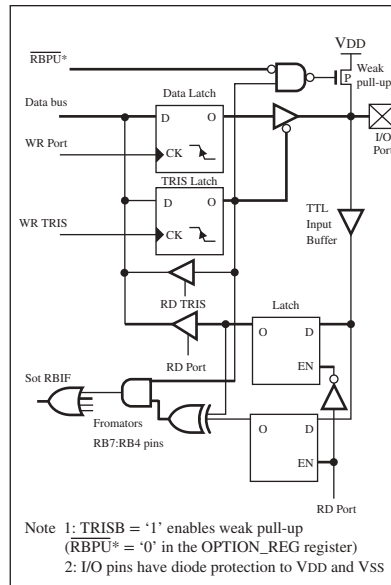


Figure 7.17 Block diagram for pins RB4 through RB7.

Source: Microchip Technology, Inc., Chandler, AZ.

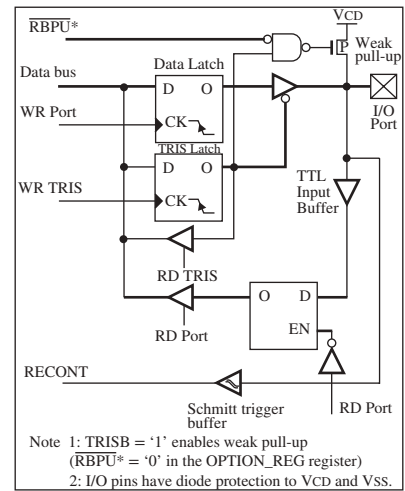


Figure 7.18 Block diagram for pins RB0 through RB3.

Source: Microchip Technology, Inc., Chandler, AZ.

These FETs are controlled by a single control bit called $\overline{\text{RBPU}}$ (active low register B pull-up). When this bit is low the FET acts like a weak pull-up resistor. This pull-up is automatically disabled when the port pin is configured as an output. $\overline{\text{RBPU}}$ can be set in software through the OPTION_REG special purpose register (see Section 7.6).

7.9.1 Digital Input to the PIC

Figure 7.19 illustrates how to properly interface different types of components and digital families of devices as inputs to the PIC. All I/O pins of the PIC that are configured as inputs interface through a TTL input buffer (pins RA0 through RA3 and pins RB0 through RB7) or Schmitt trigger input buffer (RA4). The Schmitt trigger enhances noise immunity for a slowly changing input signal. Because an input pin is TTL buffered in the PIC, interfacing a TTL gate or device to the PIC can be done directly unless it has an open-collector output. In this case, an external pull-up resistor is required. Because the output of a 5 V powered CMOS device swings nearly from 0 to 5 V, the device will drive a PIC input directly. The weak pull-up option on pins RB0 through RB7 is useful when using mechanical switches or keypads for input (see Section 7.8). The pull-up FET maintains a 5 V input until the switch is closed, bringing the input low. Although a TTL input usually floats high if it is open, the FET pull-up option is useful, because it simplifies the interface to external devices (e.g., keypad input). Finally, one must be aware of the current specifications of the PIC

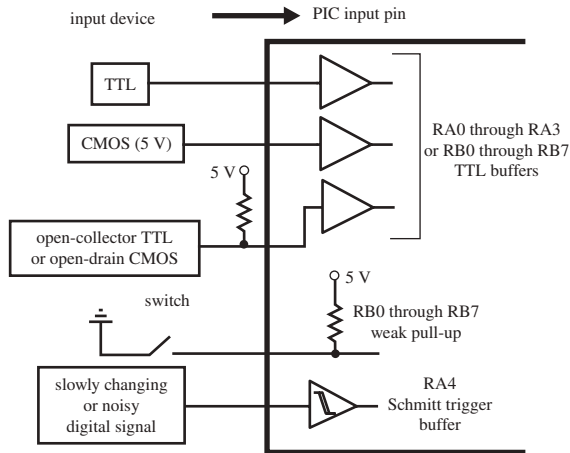


Figure 7.19 Interface circuits for input devices

input and output pins. For the PIC16F84, there is a 25 mA sink maximum per pin with a 80 mA maximum for the entire PORTA and a 150 mA maximum for PORTB.

7.9.2 Digital Output from the PIC

Figure 7.20 illustrates how to properly interface different types of components and digital families of devices to outputs from the PIC. Pins RA0 through RA3 have full CMOS output drivers, and RA4 has an open-drain output. RB0 through RB7 are TTL buffered output drivers. A 20 mA maximum current is sourced per pin with a 50 mA maximum current sourced by the entire PORTA and a 100 mA maximum for PORTB. You should always include appropriate current-limiting resistors in microcontroller output circuits (e.g., with LEDs, transistor bases, relay coils, and speakers) to prevent output pin or PORT currents from being pushed to their limits. Sourcing too much current from one or more output pins can limit how much current is available for other output pins in the PORT. Attempting to exceed a PORT's current limit can result in unexpected loss in functionality of currently-working components when additional output circuits are interfaced to the PIC.

CMOS outputs can drive single CMOS or TTL devices directly. TTL outputs can drive single TTL devices directly but require a pull-up resistor to provide an adequate high-level voltage to a CMOS device. To drive multiple TTL or CMOS devices, a buffer can be used to provide adequate current for the fan-out. Because pin RA4 is an open-drain output, external power is required. Note that when RA4 is high, the output pin is grounded to V_{ss} , switching the small current load on, and when RA4 is low, the output is an open circuit, switching the load off. When interfacing transistors, power transistors, and relays, current requirements must be considered for a proper interface. If the PIC contains a D/A converter, it can be used with an amplifier to drive an analog load directly. Otherwise, as shown in the figure, an external D/A IC can be used with the digital I/O ports.

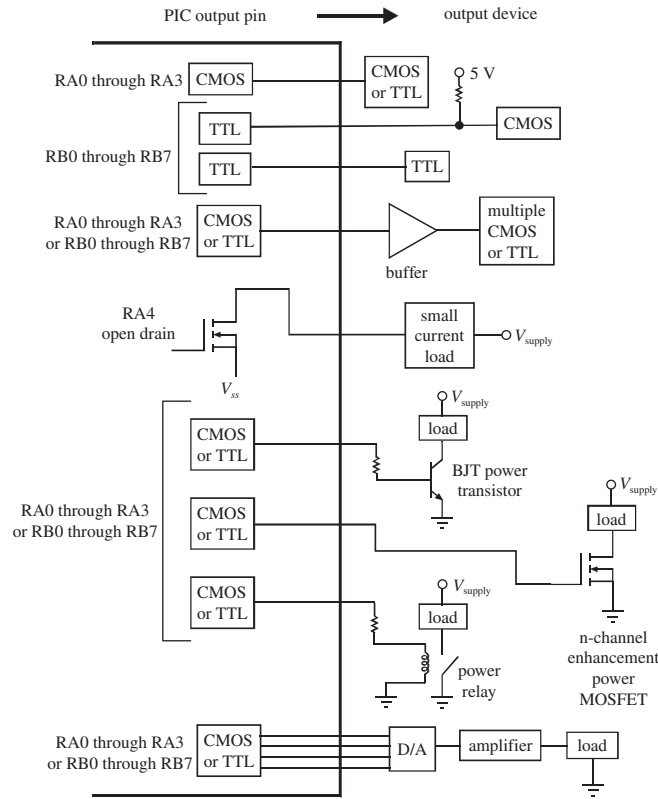


Figure 7.20 Interface circuits for output devices.



Lab Exercise

Lab 11 Pulse-width-modulation motor speed control with a PIC

As an example of using a PIC digital output to control a high-current load, a power MOSFET is used to switch power to a DC motor in Lab Exercise 11. The voltage is actually switched on and off very quickly. To vary the speed of the motor, the percentage of on and off times (i.e., the **duty cycle**) is changed. This is called **pulse-width modulation** (see Section 10.5.3 for more information).

7.10 SERIAL COMMUNICATION

There are numerous standard protocols that allow microcontrollers to communicate data with each other and with other compatible digital devices. These protocols are categorized as either **asynchronous** or **synchronous** based on whether or not the data communication is synchronized by a separate clock signal or not. Asynchronous communication is not synchronized by a separate shared clock signal. Instead, data is sent or received at a constant **baud rate** (bits/sec). Common standard protocols for this type of serial communication are **RS-232** (used in older PCs), **USB** (Universal Serial Bus, standard with all modern computers and peripherals), and **UART** (Universal, Asynchronous Receiver/Transmitter). Most microcontrollers

provide hardware and/or software support for many forms of serial communication including the UART protocol. For devices to communicate, they just need to be sending or receiving at the same baud rate, where the data is sent from one device to the other one bit at a time (i.e., serially). Two-way communication can occur with separate transmit (TX) and receive (RX) lines, or the communication can occur in either direction via a single line. The PicBasic Pro commands *Serin* and *Serout* use this type of serial communication (see Example 7.8).

With synchronous serial communication, a shared clock signal is used to synchronize data transmission between devices. Two common protocols for synchronous communication are **SPI** (Serial Peripheral Interface) and **I²C** (Inter-Integrated Circuit, pronounced “eye squared see” or “eye two see”). With the SPI protocol, devices can communicate in both directions simultaneously in what is called full-duplex mode. There is a separate serial clock line (SCLK) that synchronizes transmission of data between the devices. A master device can communicate with any number of slave devices. A particular slave is identified for communication via a separate slave-select line (SS) going to each slave. Bidirectional communication occurs on separate master-out/slave-in (MOSI) and master-in/slave-out (MISO) lines that are shared by the master and all slave devices. Data can be sent at any rate, and the rate does not need to be consistent since everything is synchronized by the clock signal (hence the name synchronous). The PicBasic Pro commands *Shiftin* and *Shiftout* use SPI serial communication.

The I²C protocol is a more-complicated but more-flexible standard that allows two-way communication among multiple devices using bus-based communication via two wires shared by all connected devices. Both the serial data line (SDA) and serial clock line (SCL) of I²C communication are bidirectional. At the start of any communication, a master device decides which slave device to communicate with by sending out that slave’s unique address. Then the slave sends or listens for data to/from the master. A slave device cannot initiate communication; it can only respond to requests from the master. Both the SDA and SCL lines are open-drain outputs that must be pulled up by external resistors to the source voltage. The PicBasic Pro commands *I2cread* and *I2cwrite* enable I²C communication with other I²C-compatible devices.

Another common form of synchronous serial communication is called a **one-wire** link, where both the communication rate and data are transmitted via a single line. When sending data, an initial pulse is sent, whose pulse width indicates the rate at which incoming bits will be sent, and then the data is sent one bit at a time. The PicBasic Pro commands *Owin* and *Owout* allow the PIC to communicate with one-wire-compatible devices.

Programming examples using different forms of serial communication can be found under “serial communication” at Internet Link 7.17. Example 7.8 provides an excellent example of how to use serial communication to send data between micro-controllers. A video demonstration of the example can be found at Video Demo 7.6. You might want to view the video before you read through the example so you can better relate to it. Additional examples relating to various categories of programming tasks, including serial communication, can be found at Internet Link 7.17.



Internet Link

7.17 Student project resources page

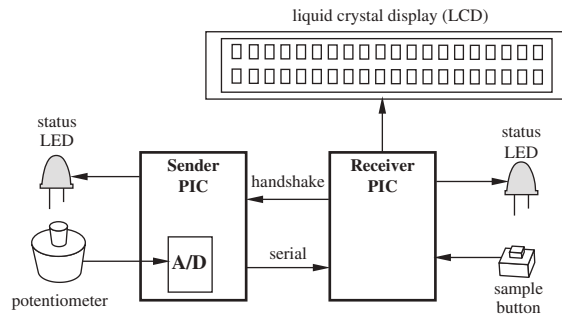


Video Demo

7.6 PIC A/D conversion, serial communication, and LCD output

EXAMPLE 7.8**PIC A/D conversion, Serial Communication, and LCD Messaging**

This example demonstrates how to use PicBasic Pro for analog-to-digital (A/D) conversion, serial communication, and liquid crystal display (LCD) messaging. It also covers how to communicate between two PICs and between a PIC and an Arduino board. The functional diagram below illustrates the components of the system, along with the flow of information. The “Receiver PIC” waits for a pushbutton switch to be pressed. When that occurs, the handshake line instructs the “Sender PIC” to read a potentiometer’s position with an A/D converter and send the digital value back serially to the Receiver PIC that displays the value on an LCD. Both PICs have status LEDs used to indicate to the user that things are working properly. Obviously, all tasks in this examples could be handled by a single microcontroller, but the example is still useful to show how these things can be done (e.g., in case the microcontrollers are also busy doing other things or are also attached to multiple other devices, creating a need for more than one microcontroller and an ample number of I/O pins).

**Internet Link**

7.11 How to program a PIC

7.17 PIC16F88 code template

Below is a detailed wiring diagram for the entire system along with PicBasic Pro code for both the Receiver PIC and the Sender PIC, both of which are PIC16F88s. The code is well-commented so it should be easy to follow the logic, especially if you first view the demonstration in Video Demo 7.6. Both programs were built from the same PIC16F88 code template available at Internet Link 7.17, which includes automatic definition of configuration parameters and specification of the internal clock speed, as described at Internet Link 7.11.

Receiver PIC Code:

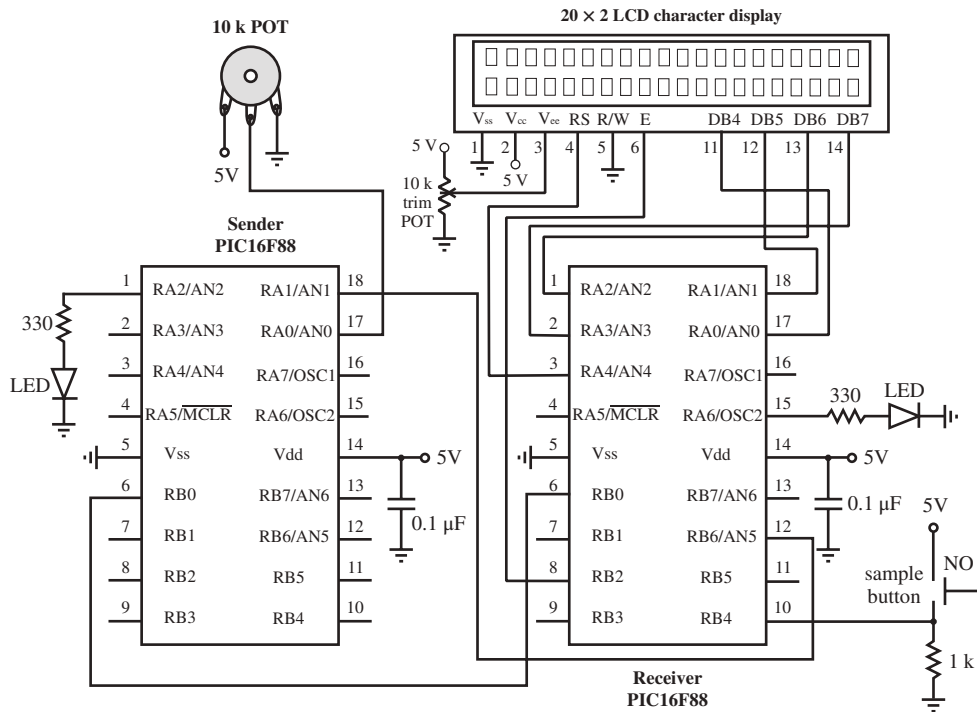
```

' receiver.bas

' Code for the receiver PIC in an example illustrating A/D conversion,
' hand shaking, serial communication, and LCD output

' Define nondefault configuration settings (from the PIC16F88 code template)

```



```
#CONFIG
    _CONFIG _CONFIG1, _INTRC_IO & _PWRTE_ON & _MCLR_OFF & _LVP_OFF
#ENDCONFIG
```

```
' Set the internal oscillator frequency to 8 MHz
DEFINE OSC 8
OSCCON.4 = 1
OSCCON.5 = 1
OSCCON.6 = 1
```

```
' Turn off the A/D converters
ANSEL = 0
```

```
' Define variables and constants
led          Var      PORTA.6
sample_button Var      PORTB.4
hand_shake   Var      PORTB.6
serial        Var      PORTB.0
pot_value     Var      BYTE
baud_rate     Con      2
```

```
' LED attached to pin RA6
' button attached to pin RB4
' handshake line on pin RB6
' serial communication through pin RB0
' POT value received from sender PIC
' 9600 baud-rate mode for serial communication
```

(continued)

(concluded)

```
' Blink the LED three times to indicate the PIC is running
Gosub Blink : Gosub Blink : Gosub Blink

' Wait 1/2 sec for the LCD to power up, and clear the LCD
Pause 500
Lcdout $FE, 1

' Make sure the handshake line is off initially
Low hand_shake

' Main program loop
start:
    ' Wait for the button to be pressed
    Do While (sample_button == 0) : Loop

    ' Handshake with the sender PIC and receive the POT value serially
    High hand_shake          ' signals the sender PIC to send
    Serin serial, baud_rate, pot_value ' wait for and receive POT value
    Low hand_shake

    ' Display the received POT value on the LCD and blink the LED
    Lcdout $FE, 1, "POT value = ", DEC pot_value
    Gosub Blink
Goto start

End      ' end of main program (not required since never reached)

' Subroutine to blink the LED on and off once
Blink:
    High led      ' turn on the LED
    Pause 250     ' wait 1/4 second
    Low led       ' turn off the LED
    Pause 250     ' wait 1/4 second
Return
```

Sender PIC Code:

```
' sender.bas

' Code for the sender PIC in an example illustrating A/D conversion,
' hand shaking, serial communication, and LCD output

' Define nondefault configuration settings (from the PIC16F88 code template)
```

```

#CONFIG
    __CONFIG __CONFIG1, _INTRC_IO & _PWRTE_ON & _MCLR_OFF & _LVP_OFF
#endconfig

' Set the internal oscillator frequency to 8 MHz
Define OSC 8
OSCCON.4 = 1
OSCCON.5 = 1
OSCCON.6 = 1

' Setup the A/D converter
ANSEL = 0      ' turn off all A/D converters
ANSEL.0 = 1    ' turn on the ANO (pin 17) A/D converter

' Define variables and constants
led          Var      PORTA.2      ' LED attached to pin RA2
hand_shake   Var      PORTA.1      ' Sender
serial       Var      PORTB.0      ' serial communication through pin RB0
pot_value    Var      Byte         ' POT value sent to receiver PIC
baud_rate     Con      2           ' 9600 baud-rate mode for serial communication

' Blink the LED three times to indicate the PIC is running
Gosub Blink : Gosub Blink : Gosub Blink

' Main program loop
start:
    ' Wait for the sender to set the handshake line high
    Do While (hand_shake == 0) : Loop

    ' Read the POT value and send it serially to the receiver PIC
    Adcin 0, pot_value
    Serout serial, baud_rate, [pot_value]

    ' Blink the LED to indicate the value was sent
    Gosub Blink
Goto start

End ' end of main program (not required since never reached)

' Subroutine to blink the LED on and off once
Blink:
    High led      ' turn on the LED
    Pause 250     ' wait 1/4 second
    Low led       ' turn off the LED
    Pause 250     ' wait 1/4 second
Return

```

(continued)

(concluded)

Below is an Arduino C version of the Receiver code, showing how similar and easy it is to communicate serially between an Arduino board and a PIC. Compare the code below to the PIC Receiver code above to see the similarities and differences.

Arduino Receiver Code:

```
// Arduino_receiver.c

// Code for an Arduino version of the receiver PIC in an example illustrating
// A/D conversion, hand shaking, serial communication, and LCD output

// NOTE: Be sure to disconnect the pin 0 (RX) line before re-programming the Arduino
// NOTE: Select "Serial Monitor" under the "Tools" menu to see the printed messages

// Define global variables and constants
const byte led=13;
const byte sample_button=12;
const byte hand_shake=11;
byte pot_value=0;

// The setup function runs once when you press reset or power the board
void setup() {
  // Initialize pin I/O status
  pinMode(led, OUTPUT);
  pinMode(sample_button, INPUT);
  pinMode(hand_shake, OUTPUT);

  // Open serial communication for write read on pin 0 (RX)
  Serial.begin(9600);
  Serial.println("Serial communication initiated.");

  // Blink the LED three times to indicate the Arduino is running
  blink(); blink(); blink();

  // Make sure the handshake line is off initially
  digitalWrite(hand_shake, LOW);
}

// Main program loop
void loop() {
  // Wait for the button to be pressed
  while (digitalRead(sample_button) == LOW);
  Serial.println(" button pressed");

  // Handshake with the sender PIC and receive the POT value serially
  digitalWrite(hand_shake, HIGH); // signals the sender PIC to send
  // Wait for serial data to arrive
```

```

while (Serial.available() == 0);
// Read serial data
pot_value = Serial.read();
digitalWrite(hand_shake, LOW);

// Display the received POT value on the serial monitor and blink the LED
Serial.print("POT value = ");
Serial.println(pot_value, DEC);
blink();
}

// Subroutine to blink the LED on and off once
void blink() {
  digitalWrite(led, HIGH); // turn the LED on (HIGH is the voltage level)
  delay(250);              // wait for a second
  digitalWrite(led, LOW);  // turn the LED off by making the voltage LOW
  delay(250);              // wait for a second
}

```

7.11 METHOD TO DESIGN A MICROCONTROLLER-BASED SYSTEM

In all the examples presented in this chapter, the problems were simple, yielding short solutions to illustrate fundamental coding structures. Also, many design decisions were included as part of the problem statements. In solving a larger or more open-ended problem, it is advisable to follow a methodical design process that will take you from the initial problem statement to a programmed microcontroller that can be embedded in application hardware. A design procedure we recommend follows. To illustrate the application of the procedure, we apply it to the problem presented in Design Example 7.2. Lab Exercise 11 also shows the procedure applied to an example.

1. *Define the problem.* State the problem in words to explain the desired functionality of the device (i.e., what is the device supposed to do?).
2. *Draw a functional diagram.* Draw a block diagram that illustrates all of the major components of the design and shows how they are interconnected. Each component can be shown as a square with a descriptive label inside or, preferably, as a pictorial representation (e.g., a clipart image or photograph). Use single lines to connect the components (regardless of the number of wires involved), and include arrowheads to indicate the direction of signal flow.
3. *Identify I/O requirements.* List the types of inputs and outputs required and what functions need to be performed by the microcontroller. You need to identify the number of each type of I/O line you require, including digital inputs, digital outputs, A/D converters, D/A converters, and serial ports.



Internet Link

7.23 Microchip
PIC flash product
line

4. *Select appropriate microcontroller models.* Based on the types and number of inputs and outputs identified in the previous step, choose one or more microcontrollers that have sufficient on-chip resources. Another factor that influences this choice is the anticipated amount of program and data memory required. If the program is very complex and the application requires significant data storage, then choose a microcontroller with ample memory capacity. If multiple PICs are required (due to I/O and/or memory constraints), the PICs can communicate with each other through I/O lines by using simple handshaking (e.g., wait for a signal from another PIC to go high before doing something and then send another signal back when done) or PicBasic Pro's *Serout* and *Serin* statements for serial communication (e.g., to share data between the PICs). Refer to manufacturer literature for a list of available models and capacities. Information for Microchip's entire line of PIC microcontroller products can be found online (see Internet link 7.23, which points to the line of reprogrammable flash-memory microcontrollers listed at www.microchip.com).

5. *Identify necessary interface circuits.* Refer to the microcontroller input and output circuit specifications and use the information in Section 7.9 to design appropriate interface circuitry utilizing pull-up resistors, buffers, transistors, relays, and amplifiers where required. Also, in cases that require many digital I/O lines, where the PIC(s) selected do not provide enough I/O pins, there are ways to interface to a large number of lines with a smaller set of pins. One approach is to use shift registers (e.g., the 74164, 74594, or 74595 for output, and the 74165 or 74597 for input), where a small set of PIC I/O pins (two for the nonlatched type and three for the latched type) can be used to transmit bits serially to or from an 8-bit register, providing eight lines of I/O. Another alternative when expanding your I/O capability is to use a device providing multiplexed programmable I/O ports (e.g., the Intel 82C55A programmable peripheral interface, or PPI). This type of device allows one I/O port to switch access among several I/O ports. With Intel's 82C55A, 5 control lines and 8 data lines provide access to 24 lines of general purpose, user-configurable I/O.

6. *Decide on a programming language.* You can write the code in assembly language or in a high-level language such as C or PicBasic Pro. We recommend PicBasic Pro, especially if you are new to programming. C might be a better choice if your project requires complicated calculations, algorithms, or data structures. PicBasic Pro does not support signed or floating point variables. C is also more suitable for very large projects, where functionality can be more efficiently compartmentalized into formal functions that can receive passed arguments and use local variables. PicBasic Pro does not support C-type functions, only branching subroutines with global-variable access. C compilers available for the PIC are described at Internet Link 7.6. Arduino prototyping boards are also programmed in C. For more information, see Section 7.7. Assembly language is necessary only when extremely fast execution speed is required or if memory capacity is a limiting factor.

7. *Draw the detailed wiring diagram.* Draw a detailed wiring diagram (AKA "circuit schematic") showing required components, input and output interface



Internet Link

7.6 C compilers for
the PIC

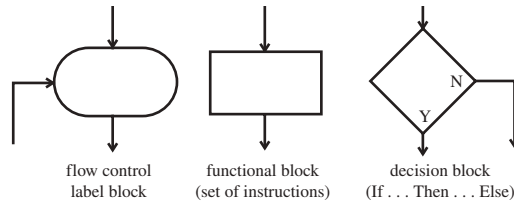


Figure 7.21 Software flowchart building blocks.

circuitry, and wire connections. If using the PIC16F84, Figure 7.4 serves as a good starting point.

8. *Draw a program flowchart.* A **flowchart** is a graphical representation of the required functionality of your software. Figure 7.21 illustrates a set of building blocks that can be used to construct a flowchart. The flow control block is used as a destination label for a *goto* branch or a loop (e.g., *For . . . Next*, *Do . . . Loop* or *While . . . Wend*). The functional block represents one or more instructions that perform some task. The decision block is used to represent logic decisions. Design Example 7.2 illustrates how a typical flowchart is constructed.
9. *Write the code.* Implement the flowchart in software by writing code to create the desired functionality. Develop and test the code incrementally, writing and testing only a small section of code at a time. This approach allows you to “divide and conquer” large projects into small manageable tasks so you won’t be overwhelmed and confused by the entirety of the project.
10. *Build and test the system.* Compile your code into machine code and download the resulting hex file to the microcontroller. This can be done using a programming device available from the manufacturer (e.g., the U2 programmer from microEngineering Labs, or the PicStart Plus serial programmer from Microchip). Internet link 7.24 points to the detailed list of steps required to create, compile, and download code using PicBasic Pro with Microcode Studio and microEngineering Labs’ U2 programmer or with MPLAB and Microchip’s PicStart Plus programmer. The procedure is also presented and used in Lab Exercise 9. If using a prototyping board like an Arduino (see Section 7.7), the process of compiling and downloading code to the microcontroller is an easy one-step process. After downloading the code, assemble the system hardware, including the microcontroller and interface circuitry. Then, fully test the system for the desired functionality.

It is recommended to do steps 9 and 10 incrementally as you build functionality, carefully testing and debugging each addition before continuing. For example, make sure you can read and process an input first. Then add and test additional inputs and incrementally add and test output functionality. In other words, do not try to code, build, and test the entire system on the first attempt!

For more advice on designing, building, and testing microcontroller-based systems, including advice on how to select a power supply, see Section 7.12.



Internet Link

7.24 How to program a PIC



Lab Exercise

Lab 9 Programming a PIC microcontroller—part I

DESIGN EXAMPLE 7.2



Internet Link

7.25 PIC-based class design project description

7.26 Combination security device project description



Lab Exercise

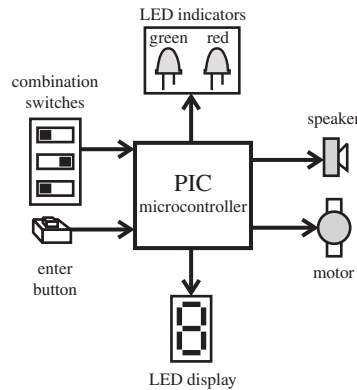
Lab 15 A microcontroller-based design project

PIC Solution to an Actuated Security Device

For many years, we assigned interesting, challenging, and fun class projects in our Introduction to Mechatronics and Measurement Systems course at Colorado State University. Internet Link 7.25 points to a generic project description that we currently use in the course. Internet Link 7.26 points to the specific guidelines for a combination security device project described here. Lab Exercise 15 also introduces the course project and provides useful reference information for powering a PIC project, using batteries, using relays vs. transistors, soldering, and dealing with other practical considerations.

We now illustrate the procedure just presented to generate a basic design. Then we describe some of the student solutions, because an interesting part of the project was the creativity that the class groups exhibited in solving this problem.

- 1. Define the problem.** The goal of the project is to use the PIC16F84 microcontroller in the design of a combination security lock device. The device requirements include switches to enter a combination, a pushbutton switch to process the combination, LEDs and a buzzer to indicate the success of a combination attempt, a digital display to indicate the number of failed combination attempts, and an actuator to perform a useful output function. In the simple design presented here, we use three toggle switches to enter the combination allowing for eight possible combinations.
- 2. Draw a functional diagram.** The figure below illustrates the major components in our basic design example.



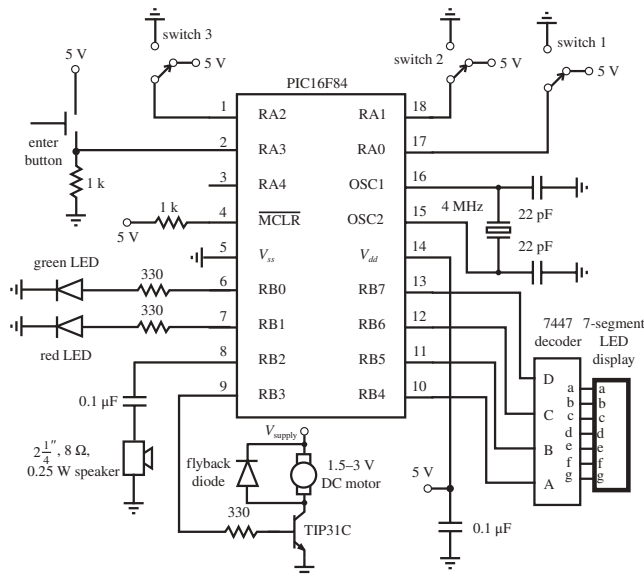
- 3. Identify I/O requirements.** The inputs and outputs are all digital for this problem.
Inputs:

- three switches for the combination
- one pushbutton switch to serve as an enter key

Outputs:

- two LEDs to indicate the combination status
- one seven-segment LED digit display
- one small speaker
- one small DC motor

4. *Select appropriate microcontroller models.* If we drive the seven-segment display with four digital outputs (see Design Example 7.1), the required number of digital I/O lines is 12. This is the only I/O we require (i.e., we do not need A/D, D/A, or serial ports). The PIC16F84 is adequate for this problem because it provides 13 digital I/O pins.
5. *Identify necessary interface circuits.* A 7447 interface is required to decode the four digital outputs to control the seven-segment display (see Design Example 7.1). A small audio speaker can be driven directly through a series capacitor, as recommended in the description of the *Sound* statement in the PicBasic Pro compiler manual. Internet Link 7.27 shows how to use a transistor and high-pass filter to get louder audio from a microcontroller when necessary. And Video Demo 7.8 shows how you can use an audio amplifier circuit to boost any audio signal. The PIC cannot source enough current to drive the motor directly, so a digital output is used to bias a power transistor connected to the motor. The only I/O pin we will not use is RA4, the special purpose Schmitt trigger input and open drain output pin.
6. *Decide on a programming language.* We chose to use PicBasic Pro. This or some other high-level language should always be your first choice, unless you have extreme memory or speed constraints.
7. *Draw the detailed wiring diagram.* The following figure shows the necessary components. It does not matter which I/O pins are used for the different functions, but we kept them organized according to function.

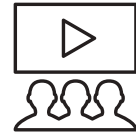


8. *Draw a program flowchart.* The next figure illustrates the logic and flow necessary to perform the desired functions. The program checks the state of the combination switches when the pushbutton switch is pressed and compares the switch states to a prestored combination. If the combination is valid, a green LED and a DC motor turn on and stay on while the enter button is held down. If the



Internet Link

7.27 Easy way to get louder audio from a microcontroller



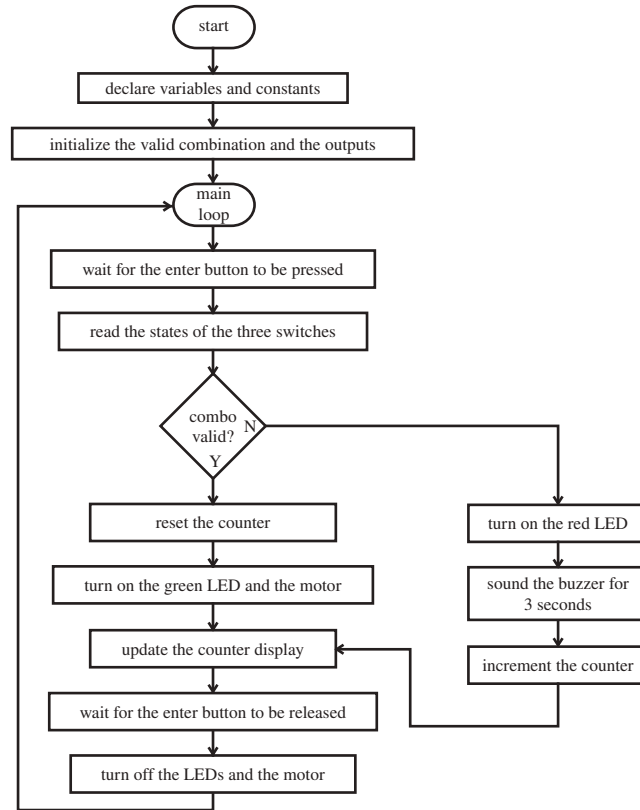
Video Demo

7.8 How to make an LM386 audio amplifier circuit

(continued)

(concluded)

combination is invalid, a red LED turns on, a buzzer sounds for 3 sec, and the digital display of failures is incremented by 1. When a valid combination is entered, the counter display resets to 0.



9. *Write the code.* The PicBasic Pro code to implement the logic and flow illustrated by the flowchart follows. Note that multiple PicBasic Pro statements can be included on a single line if they are separated by colons (e.g., the multiple *Low* statements). Also, a long statement can be continued on a second line by ending the first line with an underscore (e.g., the long *If* statement). Because the byte variable *number_invalid* is constrained to vary between 0 and 9, its four least significant bits represent the number in the binary-coded decimal form required by the display decoder.

```

' project.bas
' This program checks the state of three switches when a pushbutton switch is
' pressed and compares the switch states to a prestored combination. If the
' combination is valid, a green LED and a DC motor turn on and stay on while the
' pushbutton switch is held down. If the combination is invalid, a red LED turns
' on, a buzzer sounds for 3 seconds, and the displayed digit (representing the
' number of failed attempts) increments by one. When a valid combination is
' entered, the counter display resets to zero.

```

```

' Declare all variables
switch_1 Var PORTA.0 ' first combination switch
switch_2 Var PORTA.1 ' second combination switch
switch_3 Var PORTA.2 ' third combination switch
enter_button Var PORTA.3 ' combination enter key
green_led Var PORTB.0 ' green LED indicating a valid combination
red_led Var PORTB.1 ' red LED indicating an invalid combination
speaker Var PORTB.2 ' speaker signal for sounding an alarm
motor Var PORTB.3 ' signal to bias the motor power transistor
a Var PORTB.4 ' bit 0 for the 7447 BCD input
b Var PORTB.5 ' bit 1 for the 7447 BCD input
c Var PORTB.6 ' bit 2 for the 7447 BCD input
d Var PORTB.7 ' bit 3 for the 7447 BCD input
combination Var BYTE ' stores the valid combination in the 3 LSBs
number_invalid Var BYTE ' counter used to keep track of the number of bad
                        ' combinations

' Initialize the valid combination and turn off all output functions
combination = %101 ' valid combination (switch 3:on, switch
                  ' 2:off, switch 1:on)
Low green_led : Low red_led ' make sure the LEDs are off
Low motor ' make sure the motor is off
Low a : Low b : Low c : Low d ' display zero on the digit display
number_invalid = 0 ' reset the number of invalid combinations
                  ' to zero

' Beginning of the main polling loop
mainloop:
    ' Wait for the enter button to be pressed
    If (enter_button == 0) Then mainloop

    ' Read switches and compare their states to the valid combination
    If ((switch_1 == combination.0) AND (switch_2 == combination.1)_
        AND (switch_3 == combination.2)) Then
        ' Turn on the green LED
        High green_led

        ' Turn on the motor
        High motor

        ' Reset the combination attempt counter
        number_invalid = 0
    Else
        ' Turn on the red LED
        High red_led

        ' Sound the alarm
        Sound speaker, [80,100]

        ' Increment the combination attempt counter and check for overflow
        number_invalid = number_invalid + 1

```

(continued)

(concluded)

```

        If (number_invalid > 9) Then
            number_invalid = 0
        EndIf
    EndIf

    ' Update the invalid combination attempt counter digit display
    a = number_invalid.0 : b = number_invalid.1 : c = number_invalid.2
    d = number_invalid.3

    ' Wait for the enter button to be released
loop2: If (enter_button == 1) Then loop2

    ' Turn off the LEDs and the motor
    Low green_led : Low red_led
    Low motor

    ' Loop back to the beginning of the polling loop to continue the process
Goto mainloop
End      ' end of program

```

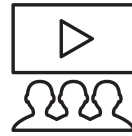
10. *Build and test the system.* Now that we have a detailed wiring diagram and a complete program, all that remains is to build and test the system. When first testing the system, comment out secondary parts of the code (by placing comment apostrophes in front of selected lines to temporarily disable them), in order to test the remaining parts. In the example, we could test the combination input and green LED but comment out the motor driver, the alarm, and the count and digital display. This way, we could ensure that the basic I/O and logic of the program function properly when the programmed PIC is inserted in the circuit. Then, additional functionality can be added a piece at a time to achieve the complete solution. We recommend you create a first prototype on a solderless breadboard until all of the bugs have been worked out. Then, a more permanent version can be created on a protoboard or printed circuit board.

When we assigned this design problem, as a class project, we had 30 groups of three or four students creating unique designs. Some of the more interesting designs included a wall safe, where the students fabricated a section of drywall with a face plate containing three light switches. Externally it appeared to be a set of switches to control lights in a room, but when the switches were set in the correct combination and a small pushbutton switch on the side was pressed, a solenoid released a spring-loaded door exposing a hidden wall safe. Another design was a rocket launcher. When the correct switch combination was entered, interesting sound effects were created (by using various *For . . . Next* loops and the PicBasic Pro *Sound* statement), and then the digital display performed a countdown. When the count reached 0, the device used a relay to fire a model rocket, which rose several hundred feet and landed softly with parachute assist. This was demonstrated to the whole class and a curious crowd on the campus grounds outside our building. The most popular design was affectionately called the *Beer-Bot* shown in the following image. This device dispensed a glass of liquid to the user if he or she knew the correct combination.

When the correct combination was entered, the platform (lower right) translated out of the device with the aid of a DC motor driving a rack and pinion mechanism. The end of travel was detected by a limit switch. The platter was spring loaded so a simple switch could detect when a glass of adequate weight had been placed on it. Then the platter retracted and a pump was turned on to draw fluid from a concealed reservoir. When the liquid reached a certain level, a circuit was completed between two metal leads (top right) that pivot into the glass when the platter is retracted. At this point, the pump was turned off and the platter extended to present the full glass to the user, accompanied by delightful sound effects. Video Demo 7.9 shows a demonstration of the Beer-Bot in action, and Internet Link 7.17 points to numerous video demonstrations of other student design project solutions. These clips represent some of the best student projects at Colorado State University since 2001.



©David Alciatore



Video Demo

7.9 Beer-Bot—secure liquid dispensing system



Internet Link

7.17 Student microcontroller design project demonstrations

Below, we present the complete hardware and software solutions to the three threaded design examples (A, B, and C). Details for various parts of the solution are presented throughout the book. Refer to the list of Threaded Design Examples in the front matter of the book for page number references to the various solution portions presented. All electrical components and devices used to build all of the Threaded Design Example projects are listed with ordering information at Internet Link 1.4.



Internet Link

1.4 Threaded Design Example components

THREADED DESIGN EXAMPLE

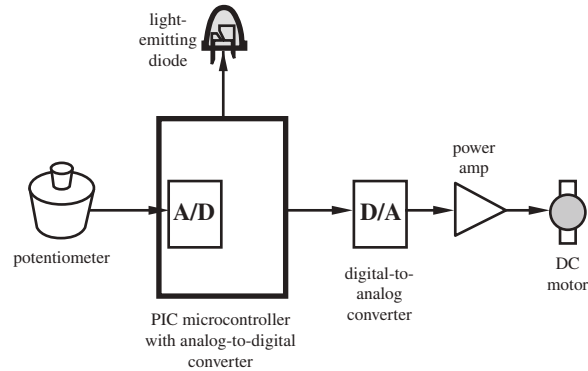
DC motor power-op-amp speed controller—Full solution

A.4

The figure below shows the functional diagram for Threaded Design Example A (see Section 1.3 and Video Demo 1.6). Here, we include the entire solution to this problem. Some of the details can be found in Threaded Design Example A.2 (the potentiometer interface), A.3 (the power amp motor driver), and A.5 (the D/A converter).

(continued)

(concluded)



Video Demo

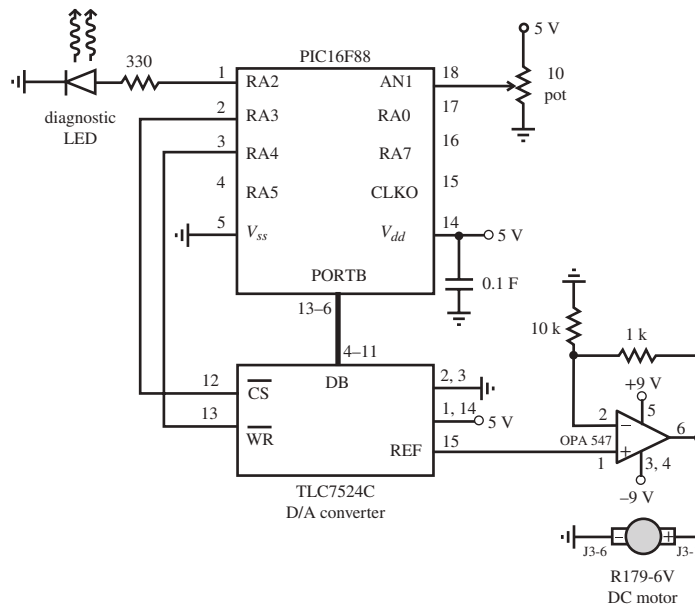
1.6 DC motor power-op-amp speed controller



Internet Link

7.28 TLC7524C D/A converter

The entire wiring diagram and software listing for a PIC16F88 are shown below. The code is commented, so you should be able to follow the logic as it relates to the functional diagram and wiring diagram. Specific information for the TLC7524C D/A converter can be found at Internet Link 7.28.



```
' poweramp.bas (PIC16F88 microcontroller)
' Design Example
' Power amp motor driver controlled by a potentiometer
' A potentiometer is attached to an A/D input in the PIC. The PIC
' outputs the corresponding voltage as a digital word to a TI TLC7524
' external D/A converter, which is attached to a TI OPA547 power-op-amp
' circuit. The amplifier circuit can provide up to 500 mA of current
' to a DC motor (e.g., R179-6V-ENC-MOTOR)
```

```

' Configure the internal 8MHz internal oscillator
DEFINE OSC 8
OSCCON.4 = 1 : OSCCON.5 = 1 : OSCCON.6 = 1

' Turn on and configure AN1 (the A/D converter on pin 18)
ANSEL.1 = 1 : TRISA.1 = 1
ADCON1.7 = 1          ' have the 10 bits be right-justified
DEFINE ADC_BITS 10    ' AN1 is a 10-bit A/D

' Define I/O pin names
led Var PORTA.2        ' diagnostic LED
da_cs Var PORTA.3      ' external D/A converter chip select (low: activate)
da_wr Var PORTA.4      ' external D/A converter write (low: write)

' Declare Variables
ad_word Var WORD       ' word from the D/A converter (10 bits padded with 6 0's)
ad_byte Var BYTE      ' byte representing the pot position

' Define constants
blink_pause Con 200    ' 1/5 second (200 ms) pause between LED blinks

' Initialize I/O
TRISB = 0              ' initialize PORTB pins as outputs
High da_wr             ' initialize the A/D converter write line
Low da_cs              ' activate the external D/A converter

' Main program (loop)
main:
    ' Read the potentiometer voltage with the A/D converter
    Adcin 1, ad_word
    ' Scale the A/D word value down to a byte
    ad_byte = ad_word/4

    ' Send the potentiometer byte to the external D/A
    PORTB = ad_byte
    Low da_wr
    Pauseus 1          ' wait 1 microsec for D/A to settle
    High da_wr

    ' Blink the LED to indicate voltage output
    Gosub blink

Goto main  ' continue polling the potentiometer

End  ' end of main program

' Subroutine to blink the speed control indicator LED
blink:
    Low led
    Pause blink_pause
    High led
    Pause blink_pause

Return

```

THREADED DESIGN EXAMPLE

B.2 Stepper motor position and speed controller—Full solution



Video Demo

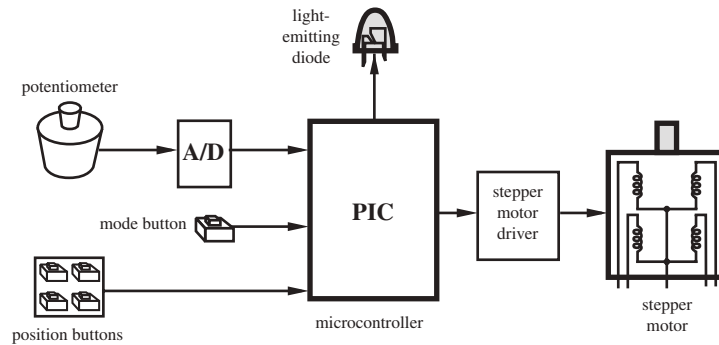
1.7 Stepper motor position and speed controller



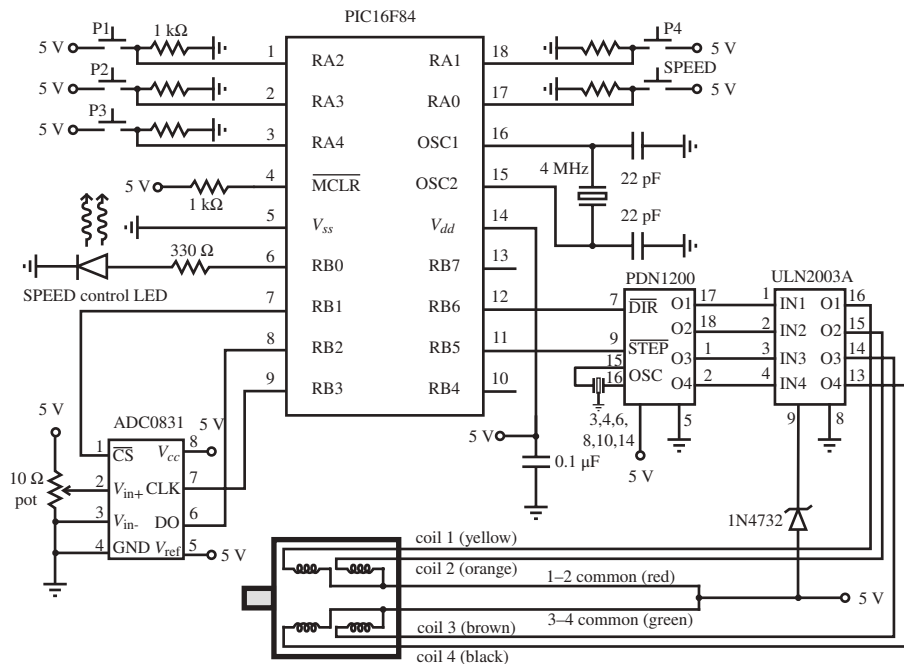
Internet Link

7.29 PDN1200 unipolar stepper motor driver

The figure below shows the functional diagram for Threaded Design Example B (see Section 1.3 and Video Demo 1.7). Here, we show the complete solution to this problem.



The wiring diagram and software listing are shown below. The code is commented, so you should be able to follow the logic as it relates to the functional diagram and wiring diagram. A special integrated circuit available from Paladin Semiconductor (see Internet Link 7.29) called the PDN1200 is used to generate the proper coil sequences for the stepper motor (see Threaded Design Example B.3).



```

' stepper.bas (PIC16F84 microcontroller)

' Design Example
' Position and Speed Control of a Stepper Motor

' Four pushbutton switches are used to index to four different
' positions (0, 45, ' 90, and 180 degrees). Another pushbutton switch
' is used to toggle in and out of speed control mode (indicated by
' an LED). When in speed control mode, a potentiometer is used to
' control the speed. When to the right of the center position,
' the motor is turned CW at a speed proportional to the pot position.
' The motor turns CCW for pot positions to the left of center. The pot
' position is read from an external A/D converter (National
' Semiconductor ADC0831). The PIC retrieves the bits from the A/D
' converter via a clock signal generated by the PIC. The stepper
' motor is controlled via an Paladin Semiconductor PDM1200 unipolar
' driver IC and a ULN2003A Darlington driver.

' Define I/O pin names
led Var PORTB.0           ' speed control indicator LED
AD_start Var PORTB.1      ' A/D converter conversion start bit
                           ' (must be held low during A/D conversion)
AD_data Var PORTB.2       ' A/D converter data line
                           ' (for serial transmission of data bits)
AD_clock Var PORTB.3      ' A/D converter clock signal (400 kHz maximum)
P1 Var PORTA.2            ' position 1 NO button (0 degrees)
P2 Var PORTA.3            ' position 2 NO button (45 degrees)
P3 Var PORTA.4            ' position 3 NO button (90 degrees)
P4 Var PORTA.1            ' position 4 NO button (180 degrees)
SPD Var PORTA.0           ' speed control NO button to toggle speed control mode
motor_dir Var PORTB.6     ' stepper motor direction bit (0:CCW 1:CCW)
motor_step Var PORTB.5    ' stepper motor step driver (1 pulse = 1 step)

' Declare Variables
motor_pos Var BYTE        ' current angle position of the motor (0, 45, 90, or 180)
new_motor_pos Var Byte    ' desired angle position of the motor
delta Var BYTE            ' required magnitude of angular motion required
num_steps Var BYTE        ' number of steps required for the given angular motion
step_period Var BYTE      ' millisecond width of step pulse (1/2 of period)
i Var Byte                ' counter used for For loops
AD_value Var BYTE         ' byte used to store the 8-bit value from the A/D converter
AD_pause Var BYTE         ' clock pulse width for the A/D converter
blink_pause Var BYTE      ' millisecond pause between LED blinks
bit_value Var BYTE        ' power of 2 value for each bit used in the A/D conversion

' Define Constants
CW Con 0                  ' clockwise motor direction
CCW Con 1                 ' counterclockwise motor direction

```

(continued)

(concluded)

```
' Initialize I/O and variables
TRISA = $FF          ' configure all PORTA pins as inputs
TRISB = %00000100    ' configure all PORTB pins as outputs except RB2
High AD_start         ' disable A/D converter
Low motor_step        ' start motor step signal in low state
motor_pos = 0         ' assume the current position is the 0 degree position
step_period = 10      ' initial step speed (1/100 second between steps)
AD_pause = 10         ' 10 microsecond pulsewidth for the A/D clock
blink_pause = 200     ' 1/5 second pause between LED blinks

' Blink the speed control LED to indicate start-up
Gosub blink : Gosub blink

' Wait for a button to be pressed (i.e., polling loop)
main:
    If (P1 == 1) Then
        ' Move motor to the 0 degree position
        new_motor_pos = 0
        Gosub move
    ElseIf (P2 == 1) Then
        ' Move motor to the 45 degree position
        new_motor_pos = 45
        Gosub move
    ElseIf (P3 == 1) Then
        ' Move motor to the 90 degree position
        new_motor_pos = 90
        Gosub move
    ElseIf (P4 == 1) Then
        ' Move motor to the 180 degree position
        new_motor_pos = 180
        Gosub move
    ElseIf (SPD == 1) Then
        ' Enter speed control mode
        Gosub speed
    EndIf
    Goto main      ' continue polling buttons
End ' end of main program

' Subroutine to blink the speed control indicator LED
blink:
    High led
    Pause blink_pause
    Low led
    Pause blink_pause
Return

' Subroutine to move the stepper motor to the position indicated by motor_pos
' (the motor step size is 7.5 degrees)
```

```

move:
    ' Set the correct motor direction and determine the required displacement
    If (new_motor_pos > motor_pos) Then
        motor_dir = CW
        delta = new_motor_pos - motor_pos
    Else
        motor_dir = CCW
        delta = motor_pos - new_motor_pos
    EndIf

    ' Determine the required number of steps (given 7.5 degrees per step)
    num_steps = 10*delta / 75

    ' Step the motor the appropriate number of steps
    Gosub move_steps

    ' Update the current motor position
    motor_pos = new_motor_pos
Return

' Subroutine to move the motor a given number of steps (indicated by num_steps)
move_steps:
    For i = 1 to num_steps
        Gosub step_motor
    Next
Return

' Subroutine to step the motor a single step (7.5 degrees) in the motor_dir
' direction
step_motor:
    Pulsout motor_step, 100*step_period          ' (100 * 10microsec = 1 millisec)
    Pause step_period
    ' Equivalent code:
    ' High motor_step
    ' Pause step_period
    ' Low motor_step
    ' Pause step_period
Return

' Subrouting to poll the POT for speed control of the stepper motor
speed:
    ' Turn on the speed control LED indicator
    High LED

    ' Wait for the SPEED button to be released
    Gosub button_release

    ' Polling loop for POT speed control
    pot_speed:
        ' Check if the SPEED button is down

```

(continued)

(concluded)

```

    If (SPD == 1) Then
        ' Wait for the SPEED button to be released
        Gosub button_release

        ' Turn off the speed control LED indicator
        Low led

        ' Assume the new position is the new 0 position
        motor_pos = 0

        ' Exit the subroutine
        Return
    EndIf

    ' Sample the POT voltage via the A/D converter
    Gosub get_AD_value

    ' Adjust the motor speed and direction based on the POT value and
    ' step the motor a single step.
    ' Enforce a deadband at the center of the range
    ' Have the step period range from 100 (slow) to 1 (fast)
    If (AD_value > 150) Then
        motor_dir = CW
        step_period = 100 - (AD_value - 150)*99/(255 - 150)
        Gosub step_motor
    ElseIf (AD_value < 100) Then
        motor_dir = CCW
        step_period = 100 - (100 - AD_value)*99/100
        Gosub step_motor
    EndIf
EndIf

```

```

' Continue polling
goto pot_speed

```

Return ' end of subroutine, but not reached (see the SPD If statement above)

' Subroutine to wait for the speed control button to be released
button_release:

```

    Pause 50      ' wait for switch bounce to settle
    Do While (SPD == 1) : Loop
    Pause 50      ' wait for switch bounce to settle

```

Return

' Subroutine to sample the POT voltage from the A/D converter
' The value (0 to 255) is returned in the variable AD_value and corresponds
' to the original 0 to 5V analog voltage range.

get_AD_value:

```

    ' Initialize the A/D converter
    Low AD_clock      ' initialize the clock state
    Low AD_start      ' enable the A/D converter
    Gosub pulse_clock ' send initialization pulse to A/D clock

```

```

' Get each converted bit from the A/D converter (at 50 kHz)
bit_value = 128      ' value of the MSB
AD_value = 0
For i = 7 To 0 Step -1  ' for each bit from the MSB to the LSB
    ' Output clock pulse
    Gosub pulse_clock
    AD_value = AD_value + AD_data*bit_value
    bit_value = bit_value / 2
Next i

' Disable the A/D converter
High AD_start
Return

' Subroutine to send a pulse to the A/D clock line
pulse_clock:
    Pulsout AD_clock, 1 : PauseUS 10  ' 20 microsecond pulse
Return

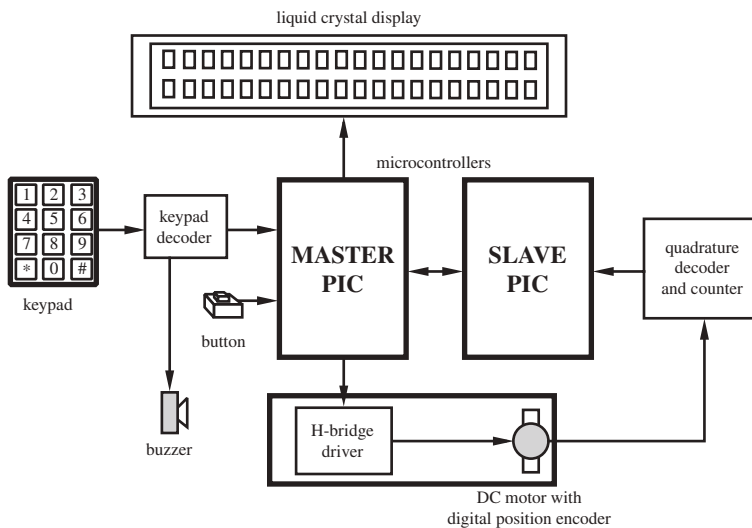
```

THREADED DESIGN EXAMPLE

DC motor position and speed controller—Full solution with serial interface

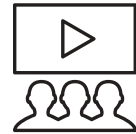
C.3

The figure below shows the functional diagram for Threaded Design Example C (see Section 1.3 and Video Demo 1.8). Presented here is the entire solution to this problem. This solution utilizes two PIC microcontrollers. The main PIC is referred to as the “master” PIC, because it controls most of the system functions; the secondary PIC is referred to as the “slave” PIC, because it simply provides information to the master PIC upon command.



The wiring diagram and software listings are shown below. The code is commented, so you should be able to follow the logic as it relates to the functional diagram and wiring

(continued)



Video Demo

1.8 DC motor position and speed controller

(concluded)

diagram. There are two software listings. One is for the master PIC (a PIC16F88) that monitors the keypad (see Threaded Design Example C.2), provides a menu-driven user interface on the LCD (see Threaded Design Example C.2), and drives the motor (see Threaded Design Examples C.4 and C.5). The other listing is for the slave PIC (a PIC16F84) that monitors the digital encoder sensor on the motor shaft and transmits the position information to the master PIC.

As with the other threaded design examples, details covering the different components of the design can be found throughout the book. This solution is a good example of how to communicate among multiple PICs using a serial interface. The specific code designed to implement the communication can be found in the *get_encoder* subroutine in the master PIC code and the main loop in the slave PIC code. One I/O line is simply set high or low by the master PIC to command the slave PIC when to send data. A second I/O line then receives the data through a standard serial communication protocol.

master PIC code:

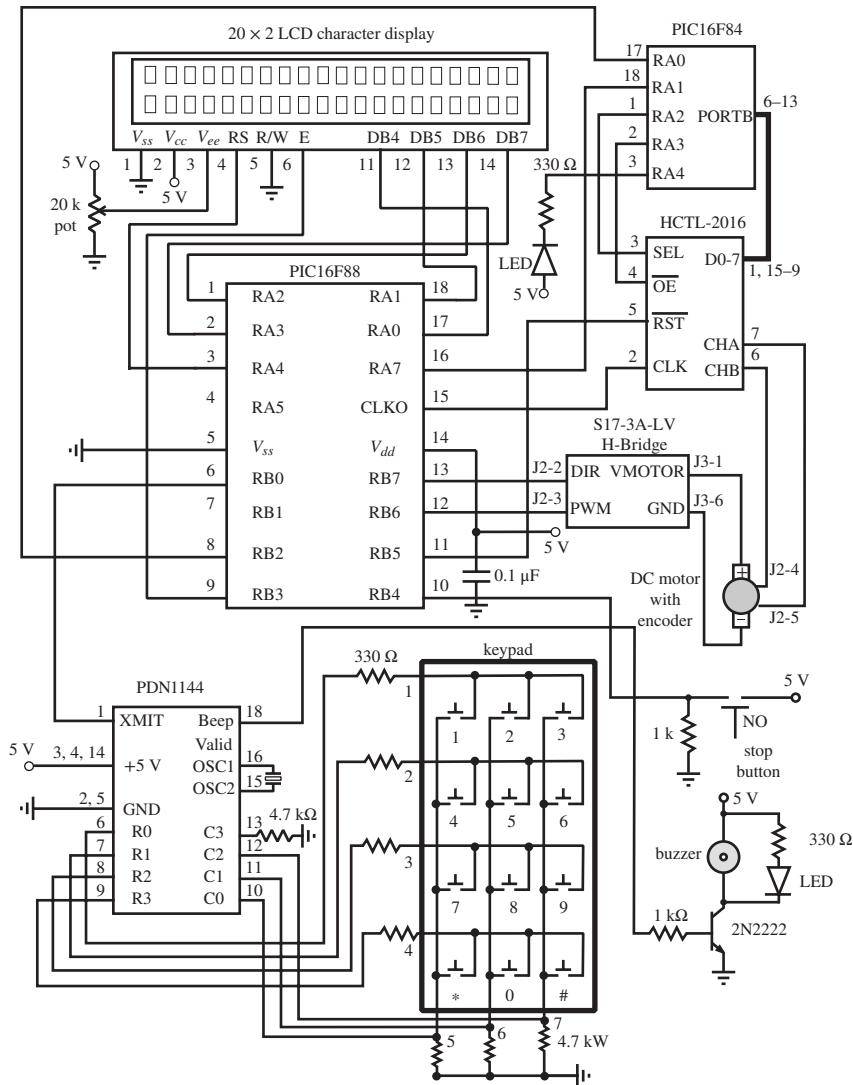
```
' dc_motor.bas (PIC16F88 microcontroller)

' Design Example
' Position and Speed Control of a DC Servomotor.

' The user interface includes a keypad for data entry and an LCD for text
' messages. The main menu offers three options: 1 - position control,
' 2 - speed control, and 3 - position control gain and motor PWM control.
' When in position control mode, pressing a button moves to indexed positions
' (1 - 0 degrees, 2 - 45 degrees, 3 - 90 degrees, and 4 - 180 degrees). When
' in speed control mode, pressing 1 decreases the speed, pressing 2 reverses
' the motor direction, pressing 3 increases the speed, and pressing 0 starts
' the motor at the indicated speed and direction. The motor is stopped with
' a separate pushbutton switch. When in gain and PWM control mode,
' pressing 1/4 increases/decreases the proportional gain factor (kP)
' and pressing 3/6 increases/decreases the number of PWM cycles sent
' to the motor during each control loop update.

' Pressing the "#" key from the position, speed, or gain menus returns control
' back to the main menu. Paladin Semiconductor's PDN1144 keypad encoder is used to
' detect when a key is pressed on the keypad and transmit data (a single byte per
' keypress) to the PIC16F88. Acroname's R179-6V-ENC-MOTOR servomotor is
' used with their S17-3A-LV H-bridge for PWM control. A second PIC (16F84),
' running dc_enc.bas, is used to communicate to an Agilent HCTL-2016
' quadrature decoder/counter to track the position of the motor encoder.
' The 16F88 communicates to the 16F84 via handshake (start) and serial
' communication lines.

' Configure the internal 8MHz internal oscillator
DEFINE OSC 8
OSCCON.4 = 1 : OSCCON.5 = 1 : OSCCON.6 = 1
```



```
' Turn off A/D converters (thereby allowing use of pins for I/O)
```

ANSEL = 0

```
' Define I/O pin names
```

```
key_serial Var PORTB.0
```

```
motor_dir Var PORTB.7
```

```
motor_pwm Var PORTB.6
```

```
stop_button Var PORTB.4
```

```
enc_start Var PORTB.2
```

```
enc_serial Var PORTA.7
```

```
enc_rst Var PORTB.5
```

```
' keypad serial interface input
```

' motor H-bridge direction line

```
' motor H-bridge pulse-width-modulation line
```

```
' motor stop button
```

```
' signal line used to start encoder data transmission
```

```
' serial line used to get encoder data from the 16F84
```

```
' encoder counter reset signal (active low)
```

(continued)

(concluded)

```
' Declare Variables
key_value Var BYTE
motor_pos Var Word
new_motor_pos Var Word
error Var Word
motor_speed Var BYTE
motion_dir Var BIT
on_time Var WORD
off_time Var WORD
enc_pos Var WORD
i Var Byte
kp Var BYTE
pwm_cycles Var BYTE

' Define constants
key_mode Con 0
key_1 Con $30
key_2 Con $31
key_3 Con $32
key_4 Con $34
key_5 Con $35
key_6 Con $36
key_7 Con $38
key_8 Con $39
key_9 Con $41
key_star Con $43
key_0 Con $44
key_pound Con $45
CW Con 1
CCW Con 0
pwm_period Con 50
enc_mode Con 2

' Initialize I/O and variables
TRISB.6 = 0
TRISB.7 = 0
motion_dir = CW
motor_pos = 0
motor_speed = 50
kp = 50
pwm_cycles = 20

Low motor_pwm
Low enc_start
Gosub reset_encoder

' code byte from the keypad
' current motor position in degrees
' desired motor position (set point) in degrees
' error magnitude between current and desired positions
' motor speed as percentage of maximum (0 to 100)
' motor direction (1: CW/Forward 0: CCW/Reverse)
' PWM ON pulse width
' PWM OFF pulse width
' motor encoder position (high byte and low byte)
' counter variable for For loops
' proportional gain factor position control
' # of PWM pulses sent during the position control loop

' 2400 baud mode for serial connection to keypad
' hex code for the 1-key on the keypad
' hex code for the 2-key on the keypad
' hex code for the 3-key on the keypad
' hex code for the 4-key on the keypad
' hex code for the 5-key on the keypad
' hex code for the 6-key on the keypad
' hex code for the 7-key on the keypad
' hex code for the 8-key on the keypad
' hex code for the 9-key on the keypad
' hex code for the *-key on the keypad
' hex code for the 0-key on the keypad
' hex code for the #-key on the keypad
' motor clockwise (forward) direction
' motor counterclockwise (reverse) direction
' period of each motor PWM signal cycle (in microsec)
' (50 microsec corresponds to 20kHz)
' 9600 baud mode for serial connection to the encoder IC

' configure H-bridge DIR pin as an output
' configure H-bridge PWM pin as an output
' starting motor direction: CW (forward)
' define the starting motor position as 0 degrees
' starting motor speed = 50% duty cycle
' starting proportional gain for position control
' starting # of PWM pulses sent during the
' position control loop
' make sure the motor is off to begin with
' disable encoder reading to begin with
' reset the encoder counter
```

```

' Wait 1/2 second for the LCD to power up
Pause 500

' Wait for a keypad button to be pressed (i.e., polling loop)
Gosub main_menu      ' display the main menu on the LCD
main:
    Serin key_serial, key_mode, key_value
    If (key_value = key_1) Then
        Gosub reset_encoder
        Gosub position
    ElseIf (key_value = key_2) Then
        motor_speed = 50      ' initialize to 50% duty cycle
        Gosub speed
    ElseIf (key_value = key_3) Then
        Gosub adjust_gains
    EndIf
Goto main      ' continue polling keypad buttons

End ' end of main program

' Subroutine to display the main menu on the LCD
main_menu:
    Lcdout $FE, 1, "Main Menu:"
    Lcdout $FE, $C0, "1:pos. 2:speed 3:gain"
Return

' Subroutine to reset the motor encoder counter to 0
reset_encoder:
    Low enc_rst      ' reset the encoder counter
    High enc_rst     ' activate the encoder counter
Return

' Subroutine for position control of the motor
position:
' Display the position control menu on the LCD
    Lcdout $FE, 1, "Position Menu:"
    Lcdout $FE, $C0, "1:0 2:45 3:90 4:180 #:<"

    ' Wait for a keypad button to be pressed
    Serin key_serial, key_mode, key_value

    ' Take the appropriate action based on the key pressed
    If (key_value == key_1) Then
        new_motor_pos = 0
    ElseIf (key_value == key_2) Then
        new_motor_pos = 45
    ElseIf (key_value == key_3) Then
        new_motor_pos = 90

```

(continued)

(concluded)

```

ElseIf (key_value == key_4) Then
    new_motor_pos = 180
ElseIf (key_value == key_pound) Then
    Gosub main_menu
    Return
Else
    Goto position
EndIf

' Position control loop
Do While (stop_button == 0)      ' until the stop button is pressed
    ' Get the encoder position (enc_pos)
    Gosub get_encoder

    ' Calculate the error signal magnitude and sign and set the motor direction
    ' Convert encoder pulses to degrees. The encoder outputs 1230 pulses
    ' per 360 degrees of rotation
    motor_pos = enc_pos * 36 / 123
    If (new_motor_pos >= motor_pos) Then
        error = new_motor_pos - motor_pos
        motor_dir = CW
    Else
        error = motor_pos - new_motor_pos
        motor_dir = CCW
    EndIf

    ' Set the PWM duty cycle based on the current error
    If (error > 20) Then          ' use maximum speed for large errors
        motor_speed = kp
    Else
        ' Perform proportional position control for smaller errors
        motor_speed = kp * error / 20
    EndIf

    ' Output a series of PWM pulses with the speed-determined duty cycle
    Gosub pwm_periods            ' calculate the on and off pulse widths
    For i = 1 to pwm_cycles
        Gosub pwm_pulse          ' output a full PWM pulse
    Next i

    ' Display current position and error on the LCD
    Lcdout $FE, 1, "pos:", DEC motor_pos, " error:", DEC error
    Lcdout $FE, $C0, "exit: stop button"
Loop

Goto position                  ' continue the polling loop
Return                          ' end of subroutine, not reached (see the #-key If above)

```

```

' Subroutine to get the encoder position (enc_pos) from the counter
get_encoder:

    ' Command the PIC16F84 to transmit the low byte
    High enc_start

    ' Receive the high byte
    SERIN enc_serial, enc_mode, enc_pos.HighBYTE

    ' Command the PIC16F84 to transmit the high byte
    Low enc_start

    ' Receive the low byte
    SERIN enc_serial, enc_mode, enc_pos.LowBYTE
Return

' Subroutine to calculate the PWM on and off pulse widths based on the desired
' motor speed (motor_speed)
pwm_periods:
    ' Be careful to avoid integer arithmetic and
    ' WORD overflow [max=65535] problems
    If (pwm_period >= 655) Then
        on_time = pwm_period/100 * motor_speed
        off_time = pwm_period/100 * (100-motor_speed)
    Else
        on_time = pwm_period*motor_speed / 100
        off_time = pwm_period*(100-motor_speed) / 100
    EndIf
Return

' Subroutine to output a full PWM pulse based on the data from pwm_periods
pwm_pulse:
    ' Send the ON pulse
    High motor_pwm
    Pauseus on_time

    ' Send the OFF pulse
    Low motor_pwm
    Pauseus off_time
Return

' Subroutine for speed control of the motor
speed:
    ' Display the speed control menu on the LCD
    Gosub speed_menu

    ' Wait for a keypad button to be pressed
    Serin key_serial, key_mode, key_value

```

(continued)

(concluded)

```

' Take the appropriate action based on the key pressed
If (key_value == key_1) Then
    ' Slow the speed by 10%
    If (motor_speed > 0) Then          ' don't let speed go negative
        motor_speed = motor_speed - 10
    EndIf
ElseIf (key_value == key_2) Then
    ' Reverse the motor direction
    motion_dir = ~motion_dir
ElseIf (key_value == key_3) Then
    ' Increase the speed by 10%
    If (motor_speed < 100) Then        ' don't let speed exceed 100
        motor_speed = motor_speed + 10
    EndIf
ElseIf (key_value == key_pound) Then
    Gosub main_menu
    Return
ElseIf (key_value == key_0) Then
    ' Run the motor until the stop button is pressed
    Gosub run_motor
Else
    ' Wrong key pressed
    Goto speed
EndIf

Goto speed      ' continue the polling loop
Return          ' end of subroutine, not reached (see the #-key If above)

' Subroutine to display the speed control menu on the LCD
speed_menu:
    Lcdout $FE, 1, "speed:", DEC motor_speed, " dir:", DEC motion_dir
    Lcdout $FE, $C0, "1:- 2:dir 3:+ 0:start #:<"
Return

' Subroutine to run the motor at the desired speed and direction until the
' stop button is pressed. The duty cycle of the PWM signal is the
' motor_speed percentage
run_motor:
    ' Display the current speed and direction
    Lcdout $FE, 1, "speed:", DEC motor_speed, " dir:", DEC motion_dir
    Lcdout $FE, $C0, "exit: stop button"

    ' Set the motor direction
    motor_dir = motion_dir

    ' Output the PWM signal
    Gosub pwm_periods          ' calculate the on and off pulse widths

```

```

Do While (stop_button == 0)      ' until the stop button is pressed
    Gosub pwm_pulse              ' send out a full PWM pulse
Loop

    ' Return to the speed menu
    Gosub speed_menu
Return

' Subroutine to wait for the stop button to be pressed and released
' (used during program debugging)
button_press:
    Do While (stop_button == 0) : Loop      ' wait for button press
    Pause 50                               ' wait for switch bounce to settle
    Do While (stop_button == 1) : Loop      ' wait for button release
    Pause 50                               ' wait for switch bounce to settle
Return

' Subroutine to allow the user to adjust the proportional and derivative
' gains used in position control mode
adjust_gains:
    ' Display the gain values and menu on the LCD
    Gosub gains_menu

    ' Wait for a keypad button to be pressed
    Serin key_serial, key_mode, key_value

    ' Take the appropriate action based on the key pressed
    If (key_value == key_1) Then
        ' Increase the proportional gain by 10%
        If (kp < 100) Then
            kp = kp + 10
        EndIf
    ElseIf (key_value == key_4) Then
        ' Decrease the proportional gain by 10%
        If (kp > 0) Then      ' don't allow negative gain
            kp = kp - 10
        EndIf
    ElseIf (key_value == key_3) Then
        ' Increase the number of PWM cycles sent each position control loop
        pwm_cycles = pwm_cycles + 5
    ElseIf (key_value == key_6) Then
        ' Decrease the number of PWM cycles sent each position control loop
        If (kp > 5) Then      ' maintain positive number of pulses
            pwm_cycles = pwm_cycles - 5
        EndIf
    ElseIf (key_value == key_pound) Then
        Gosub main_menu
    Return

```

(continued)

(concluded)

```

Else
    Goto adjust_gains
EndIf

Goto adjust_gains      ' continue the polling loop
Return                 ' end of subroutine, not reached (see the #-key If above)

' Subroutine to display the position control gain, the number of PWM
' cycles/loop, and the adjustment menu on the LCD
gains_menu:
    Lcdout $FE, 1, "kp:", DEC kp, " PWM:", DEC pwm_cycles
    Lcdout $FE, $C0, "1:+P 4:-P 3:+C 6:-C #:<"
Return

```

slave PIC code:

```

' dc_enc.bas (PIC16F84 microcontroller)

' Design Example
' Position and Speed Control of a dc Servomotor.

' Slave program to send encoder data, upon request, to the a PIC16F88
' microcontroller running dc_motor.bas

' Define I/O pin names and constants
enc_start Var PORTA.0 ' signal line used to start encoder data transmission
enc_serial Var PORTA.1 ' serial line used to send encoder data to the 16F88
enc_sel Var PORTA.2     ' encoder data byte select (0:high 1:low)
enc_oe Var PORTA.3      ' encoder output enable latch signal (active low)
led Var PORTA.4         ' diagnostic LED (open drain output: 1:OC, 0:ground)
enc_mode Con 2          ' 9600 baud mode for serial connection to encoder IC
blink_pause Con 200     ' 1/5 second (200 ms) pause between LED blinks

' Turn off the diagnostic LED
High led

' Wait to ensure the PIC16F88 is initialized
PAUSE 500

' Initialize I/O signals
High enc_oe          ' disable encoder output
Low enc_sel          ' select the encoder counter high byte initially
                    ' (to prevent transparent latch on low byte)

' Blink the LED to indicate proper operation
Gosub blink : Gosub blink : Gosub blink

' Main loop
start:
    ' Wait for the start signal from the PIC16F88 to go high
    Do While (enc_start == 0) : Loop

```

```

' Enable the encoder output (latch the counter values)
Low enc_oe

' Send out the high byte of the counter
SEROUT enc_serial, enc_mode, [PORTB]

' Wait for the start signal from the PIC16F88 to go low
Do While (enc_start == 1) : Loop

' Send out the low byte of the counter
High enc_sel
SEROUT enc_serial, enc_mode, [PORTB]

' Disable the encoder output
High enc_oe
Low enc_sel
goto start ' wait for next request

End ' end of main program (not reached)

' Subroutine to blink the diagnostic LED on and back off again
blink:
    Low led
    Pause blink_pause
    High led
    Pause blink_pause
Return

```



Lab Exercise

Lab 9 Programming a PIC microcontroller—Part I

Lab 10 Programming a PIC microcontroller—Part II

Lab 11 Pulse-width-modulation motor speed control with a PIC

■ CLASS DISCUSSION ITEM 7.11

Negative logic LED

Why does the *blink* subroutine in the slave PIC code in Threaded Design Example C.3 use negative logic (i.e., *Low* turns the LED on, and *High* turns it off)?

7.12 PRACTICAL CONSIDERATIONS

Throughout this chapter we’ve seen how to design and program microcontroller-based systems. As with most things in the “real world,” when you actually construct circuits and implement software, things don’t always work perfectly. Lab Exercises 9 through 11 provide experiences that will help you develop some of the skills necessary to be successful. The best advice anyone could give concerning designing a complicated microcontroller-based system is to follow a methodical design procedure as documented and demonstrated in Section 7.11. It also helps to have and follow a detailed procedure for the specific development system you are using. Internet Link 7.24 provides the detailed procedure necessary for working with Microchip PIC microcontrollers programmed in PicBasic Pro, using Microcode Studio and microEngineering Labs’ U2 programmer or MPLAB and Microchip’s



Internet Link

7.24 How to program a PIC

PicStart Plus programmer. Section 7.7 introduced Arduino prototyping boards and how to program them.

7.12.1 PIC Project Debugging Procedure

The following check list and items of advice can be helpful when **debugging** software and trying to get a PIC circuit to function properly:

1. Before writing and testing the entire code for your project, always start with a very simple program (e.g., the *flash.bas* program in Section 7.5.1) on your PIC(s) to first make sure all necessary components and wiring are in place to allow the PIC(s) to run.
2. Once the PIC is known to be running properly, incrementally add and test portions of your code, one functional component at a time. In other words, modularize your software and independently develop and test each module (i.e., don't write the entire program at once, expecting it to work).
3. Use LEDs to indicate status and location within your program when it is running and to indicate input and output states.
4. Be aware of the different characteristics of the I/O pins on the PIC. Refer to Section 7.9 to see how to properly interface to the different pins for different purposes.
5. Be aware that PicBasic Pro commands totally occupy the processor while they are running (e.g., the line after a SOUND command is not reached or processed until the SOUND command has completely finished its action).
6. If you are using a PIC with no internal oscillator (e.g., the PIC16F84), make sure your circuit includes the proper clock crystal and capacitor components. If you are using a PIC with an internal oscillator (e.g., the PIC16F88), make sure you have included the necessary initialization code (e.g., see the code template for the PIC16F88 available in Internet Link 7.30).
7. Make sure you carefully select all of the configuration bit settings when downloading code to a PIC, so the oscillator, timers, and selected pin functions are defined properly. This can be done manually each time a PIC is reprogrammed (as documented in Internet Link 7.24), or you can define all of the settings in your code as described in Internet Link 7.31.
8. Follow all of the recommendations in Section 2.10.2 for prototyping circuits.
9. If using a PIC, always follow the programming procedure in Internet Link 7.24 to ensure that you don't miss any important steps or details.



Internet Link

7.30 PIC16F88
code template

7.31 Setting
configuration bits
in code

7.32 Lessons
learned by past
students

Much more advice for developing and debugging microcontroller-based systems can be found at Internet Link 7.32, which provides a summary of “lessons learned” by many past students in our mechatronics course at Colorado State University. Also, additional debugging and troubleshooting advice can be found in Section 2.10.2 dealing with general breadboard, circuit and prototyping advice, Section 2.10.6 dealing with how to limit and address electromagnetic interference, and Section 7.12.4 dealing with microcontroller-project design and prototyping.

7.12.2 Power Supply Options for Microcontroller Projects

There are a number of ways to provide the DC power required by a PIC and any ancillary digital integrated circuits. Actuators may also be powered by the same DC supply if their drive voltages match that of the digital circuitry, and if the current demands don't exceed the supply's capacity. We begin by assuming that TTL digital ICs are being used, which require a regulated 5 V DC source. If CMOS is used exclusively, there are fewer restrictions on the regulation of the DC voltage.

Figure 7.22 shows several low-cost options for powering systems requiring a 5 V supply. These and other options include:

1. A 6 V, 9 V, or 12 V wall transformer with a 5 V regulator
2. A potted power supply with AC input and 5 V regulated output
3. Four AA batteries (6 V) in series with a 5 V regulator
4. A 9 V battery with a 5 V regulator
5. A rechargeable battery (or batteries in series) with a 5 V regulator
6. A full-featured instrumentation power supply

Other alternatives for powering projects include a computer power supply, or large batteries (e.g., car or motorcycle lead-acid batteries), especially if you have high current demands.

A wall transformer (6 V, 9 V, or 12 V) will provide current up to its rating and must be used with a 5 V regulator to control the level of the output voltage. Be sure that the current rating of the wall transformer exceeds (with a healthy

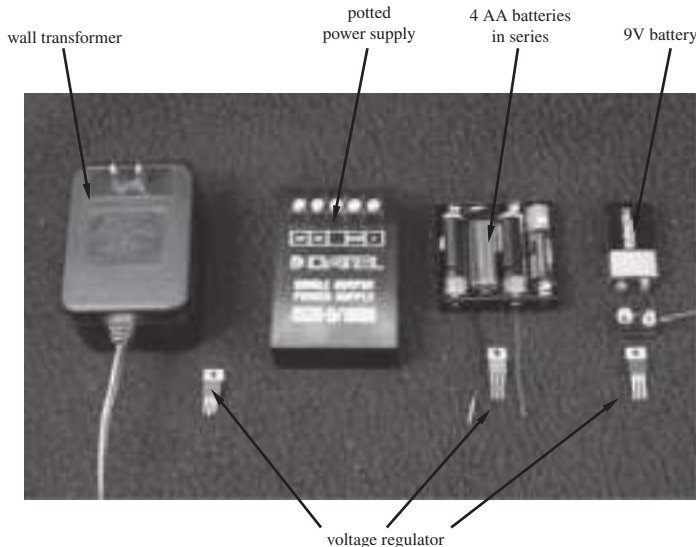


Figure 7.22 Low-cost power supply options.

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margin) the maximum current your circuit and actuators will draw. A potted power supply also has AC inputs and may provide one or more regulated DC outputs at its rated current. No voltage regulator is required if a 5 V output is provided. Four AA batteries can be connected in series with the 6 V output regulated down to 5 V with a voltage regulator. A 9 V battery must also be connected to a 5 V regulator. The battery options provide portability for your design but may not be able to supply enough current. Section 7.12.3 presents more information on different types of batteries and their characteristics. Generally, actuators such as motors and solenoids, as well as high-current LEDs, can draw substantial current. You should test your batteries to ensure that they will provide sufficient supply (do not simply assume that they will). Digital circuitry, on the other hand, usually draws very little current.

Figure 7.23 shows an example of a full-featured instrumentation power supply. This particular model (HP 6235A) is a triple-output power supply, with three adjustable voltage outputs, each independently current rated. A full-featured instrumentation power supply provides the easiest solution, but these are expensive, heavy, and generally not portable.

Except for the 5 V potted supply and the adjustable instrumentation power supply, voltage regulators are required to convert the output voltage down to the 5 V level. If your system is entirely CMOS, the regulation of the DC voltage is not required. Figure 7.24 illustrates a standard 7805 5 V voltage regulator and shows how it is properly connected to your unregulated power-supply output and your system. There must be a common ground from the power supply to your system. The mounting hole on the heat sink allows you to easily connect to the common ground. You should also include decoupling or bypass capacitors on the input and output of the voltage regulator, using capacitance values suggested by the manufacturer in any example circuit they provide, to help smooth voltage ripples and hold a more-stable output voltage.



Figure 7.23 Example of a full-featured instrumentation power supply.

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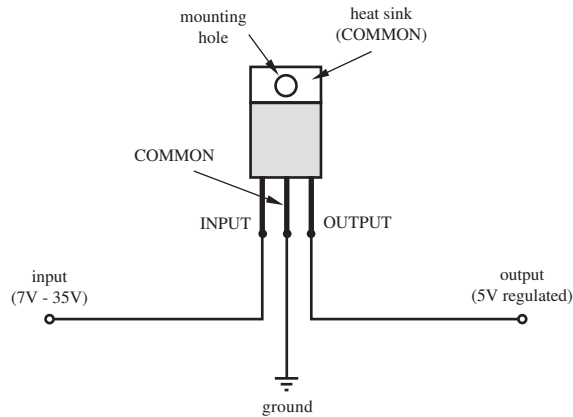


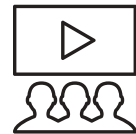
Figure 7.24 7805 voltage regulator connections.

Table 7.8 5 V power supply options summary

Device	Typical current	Relative size	Relative cost
instrumentation power supply	1 A – 5 A	large	very expensive (~ \$1,000) but many features
small potted, open frame, or enclosed power supply	1 A – 10 A	medium	moderately expensive (~ \$20–\$100)
wall transformer	1 A	small	cheap
9 V battery	100 mA	small	cheap
4 AA batteries	100 mA	small	cheap
rechargeable battery	See Section 7.12.3	small	moderate

When using a linear voltage regulator, one needs to be aware that if the voltage drop is large from the input to the output, and if significant current is drawn, the regulator will consume significant power and get very hot. A heat sink, and maybe a fan blowing on the heat sink, might be required to help dissipate this heat. If the voltage regulator gets too hot, it can be damaged. An alternative to dealing with the heat is to use a voltage source (or sources) better matched to the project needs, so the voltage regulator doesn't need to drop the voltage as much. Another good approach is to use different voltage sources for different voltage requirements. For example, use a source close to 5V to power your digital circuits, and use a different and dedicated source, and voltage regulator if necessary, to power devices (e.g., motors) that require different voltage levels. Another option is to use a voltage regulator or dc-to-dc converter that can drop the voltage more efficiently (e.g., a “switching” type buck converter instead of a “linear” type voltage regulator). Video Demos 7.10 and 7.11 cover this topic very well.

Table 7.8 provides a summary of how the various power supply options compare in terms of current ratings, size, and cost. Figure 7.25 shows an example specification



Video Demo

7.10 Switch mode power supply tutorial: DC-DC buck converters

7.11 Buck converter vs. linear voltage regulator—practical comparison



Figure 7.25 Specifications for an example closed-frame power supply.

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sheet for an enclosed power supply. Before selecting or purchasing a supply for your design, it is important to first review the specifications, especially the current rating (2.5 A in this case).

7.12.3 Battery Characteristics

This section presents some of the important terms, considerations, and specifications in the proper selection of a battery as a power source. The most important specification for a battery (besides its rated voltage) is the **amp-hour capacity**. This is defined as the current a battery can provide for one hour before it reaches its end-of-life point. The current that a battery can deliver is limited by its **equivalent series resistance**, which is the internal resistance that can be considered in series with an “ideal voltage source.” The load current times the internal resistance results in a voltage drop reducing the effective voltage of the battery. Furthermore, there will be power dissipated by the internal resistance, which at high currents may result in considerable heat production.

Batteries are composed of **cells**, the electrochemical construct that supplies voltage and current. Cells can be combined in series or parallel within a battery for larger current and voltage capacities. The voltage of a cell will differ among the types of batteries, due to their chemistry. **Primary cell batteries** are not rechargeable and are meant for one-time use. Devices that are used infrequently or that require very low drain currents are good candidates for primary cells. **Secondary cell batteries** are rechargeable, and their effectiveness may be replenished many

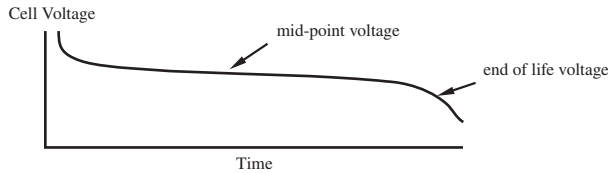


Figure 7.26 Example battery discharge curve.

times. Devices that require daily use with higher drain currents are good candidates for secondary cells.

The plot of a **battery discharge curve** is important in determining the stability of the voltage output. Figure 7.26 shows a typical shape for a discharge curve. One desires a broad plateau representing a long effective life.

The salient factors a designer must consider in selecting a power source for a mechatronic design are:

- Voltage required by the load
- Current required by the load
- Duty cycle of the system
- Cost
- Size and weight (specific energy)
- Need for rechargeability

As shown in Table 7.9, the chemistry of a cell will determine its open circuit voltage. Multiple cells can be connected in series and/or parallel in a battery pack to create different voltage and current ratings. A higher voltage is created with cells in series, and a higher current rating is created with cells in parallel. The voltages of cells in parallel must be carefully matched and maintained for good performance.

High peak-current-demand devices are good candidates for lead-acid and nickel-cadmium (NiCd) batteries. If a device is in storage most of the time, alkaline batteries are appropriate. Because batteries may be the heaviest component of a mechatronic system design, the very light lithium-ion (Li-ion) and lithium-polymer chemistries may be good candidates. Lithium chemistries provide the highest energy per unit weight (specific energy) and per volume (energy density) of all types of batteries.

Most rechargeable batteries will function well even after hundreds of charge-discharge cycles. They are significantly more expensive than primary cell batteries. Nickel-metal-hydride (NiMH) batteries should be deep-discharged several times when put into service, for best performance. NiCd batteries can suffer from an effect called “memory” where the battery capacity can diminish over time. This is caused by shallow charge cycles where the battery is only partially discharged and then fully charged repeatedly. Sometimes, you need to give the battery a deep discharge periodically for best performance.

Table 7.9 Characteristics for various types of batteries

Type	Voltage (open circuit)	Type	Typical Ah Capacity	R internal (Ω)
9 V (heavy duty)	9 V	primary	0.30 @ 1 mA 0.15 @ 10 mA	35
9 V alkaline	9 V	primary	0.60 @ 25 mA	2
9 V lithium	9 V	primary	1.0 @ 25 mA	18
alkaline D	1.5 V	primary	17.1 @ 25 mA 0.95 @ 80 mA	0.1
alkaline C	1.5 V	primary	7.9 @ 25 mA	0.2
alkaline AA	1.5 V	primary	2.7 @ 25 mA	0.4
alkaline AAA	1.5 V	primary	1.2 @ 25 mA	0.6
BR-C PCMF-Li	3 V	primary	5.0 @ 5 mA	
CR-V3 MnLi	3 V	primary	3.0 @ 100 mA	
NiCd D	1.3 V	secondary	4.0 @ 800 mA 3.5 @ 4 A	0.009
NiCd 9 V	8.1 V	secondary	0.1 @ 10 mA	0.84
Lead-acid D	2.0 V	secondary	2.5 @ 25 mA 2.0 @ 1 A	0.006
NiMH AAA	1.2 V	secondary	0.55 @ 200 mA	
NiMH AA	1.2 V	secondary	1.3 @ 200 mA	
NiMH C	1.2 V	secondary	3.5 @ 200 mA	
NiMH D	1.2 V	secondary	7.0 @ 200 mA	
NiMH 9 V	8.4 V	secondary	0.13 @ 200 mA	
ML2430 MnLi	3 V	secondary	0.12 @ 300 mA	
Lithium Ion	3.6 V	secondary	0.76 @ 200 mA	

**Internet Link**

7.33 Battery
University

7.34 Battery
information
resource page

7.35 All about
circuits—batteries
and power systems

Excellent resources for battery information can be found online at Internet Links 7.33 and 7.34. Also, Internet Link 7.35 offers good practical advice for using batteries effectively.

An alternative to a battery for energy storage is a **supercapacitor** or **ultracapacitor** that stores energy in an electric field instead of chemically as in a battery. A typical supercapacitor cannot store as much energy as a battery of similar size, but it has the advantage of being able to operate efficiently over a much wider temperature range. Supercapacitors can also last much longer over many more charge and discharge cycles; although, supercapacitors have a higher self-discharge rate than typical batteries (i.e., they drain down faster when not being used). Supercapacitors usually have a higher power capacity, being able to sink or source much higher currents; although, the voltage changes as the capacitor charge changes. This can be regulated, but it is a limitation and a portion of the stored energy will not be usable. Supercapacitors also contain no heavy metals like batteries, so they offer a cost-effective and environmentally friendly solution. Because supercapacitors have high-power capacity while batteries have high-energy capacity, a combination of the two technologies can work well in electric-vehicle applications where both

features are desirable. A battery provides a large storage of energy for long-term use (e.g., powering lights and accessories when the engine is not running, and providing reliable long-term storage of energy for starting the engine after a long downtime), and a supercapacitor can provide or enhance large peak currents when necessary (e.g., during starting, fast acceleration, or regenerative braking).

7.12.4 Other Considerations for Project Prototyping and Design

For basic prototype circuit assembly and troubleshooting advice, see Section 2.10.2. For advice dealing with how to limit and address electromagnetic interference, see Section 2.10.6. And for advice concerning debugging circuits with PIC microcontrollers, see Section 7.12.1. Here are some other practical suggestions when prototyping and designing projects:

- When ordering ICs, make sure you specify DIP (dual in-line package) or PDIP (plastic dual in-line package), and not SOIC (small-outline integrated circuit) or SSOP (shrink small outline package) surface-mount packages. DIP chips are well suited to use in breadboards and protoboards. Surface-mount ICs require printed circuit boards (PCBs) and special soldering equipment.
- Make sure your power supply can provide adequate current for the entire design. If necessary, use separate power supplies for your signal and power circuits.
- Use breadboards with caution and care because connections can be unreliable, and the base plate adds capacitance to your circuits. Hardwired and soldered protoboards or printed circuit boards (PCBs) can be much more reliable (see Section 2.10.4 for more information). For soldered prototypes, be sure to use sockets for all ICs, to prevent damage during soldering and to allow easy replacement of the ICs. Also, if you have a working breadboard circuit, it is advisable to use duplicate components (where possible) for the soldered board (i.e., don't cannibalize components from a working prototype circuit, in case something goes wrong or gets damaged when soldering your board).
- Use a storage or bulk capacitor (e.g., 10–100 μf tantalum or aluminum electrolytic type) across the main power and ground lines of a power supply that does not have built-in output capacitance (e.g., batteries, wall transformers, and regulated voltages) to minimize voltage swings during output current spikes. Also, use “bypass” or “decoupling” capacitors (e.g., 0.1 μf ceramic type) across the power and ground lines of all individual ICs to suppress any current and voltage spikes. Also use bypass or filtering capacitors across the leads of DC motors to reduce the effects of voltage and current spikes caused by commutation (see Section 10.4).
- Be careful with grounding and electromagnetic interference (EMI). Section 2.10.6 presents various methods to reduce EMI, specifically using optoisolators, single point grounding, ground planes, coaxial or twisted pair cables, and decoupling capacitors.

- Don't leave IC pins floating (especially with CMOS devices). In other words, connect all functional pins to signals or power or ground. As an example, do not assume that leaving a microcontroller's reset pin disconnected will keep a microcontroller from resetting itself. You should connect the reset pin to 5 V for an active-low reset or ground for an active-high reset, and not leave the pin floating where its state can be uncertain.
- Be aware of possible switch bounce in your digital circuits and add debounce circuits or software to eliminate the bounce (see Section 6.10.1).
- Use flyback diodes on motors, solenoids, and other high-inductance devices that are being switched (see Section 3.3).
- Use buffers, line drivers, and inverters where current demand is large for a digital output.
- Use Schmitt triggers (see Section 6.12.2) on all noisy digital inputs (e.g., a Hall-effect proximity sensor or photo-interrupter).
- Use a common-emitter configuration with transistors (i.e., put the load on the high side) to avoid voltage biasing difficulties and emitter degeneration (see Section 3.4.2).
- Be careful to identify and properly interface any open-collector or open-drain outputs (see Section 6.11.2) on digital ICs (e.g., pin RA4 on the PIC16F84).
- For reversible DC motors, use "off-the-shelf" commercially available H-bridge drivers instead of building your own. For more information, see Section 10.5.3.

For much more advice concerning project planning and design, see Section 11.4 which present case studies and online resources very helpful to students working on microcontroller-based projects.

QUESTIONS AND EXERCISES

Section 7.4 Programming a PIC

- 7.1. Document a complete and thorough answer to Class Discussion Item 7.2.

Section 7.5 PicBasic Pro

- 7.2. Write an assembly language program to turn an LED on and off at 0.5 Hz. Draw the wiring diagram required for your solution.
- 7.3. Write a PicBasic Pro program to turn an LED on and off at 1 Hz while a pushbutton switch is held down. Draw the wiring diagram required for your solution.
- 7.4. Write a PicBasic Pro program to perform the functionality of the *Pot* statement (see Class Discussion Item 7.8).
- 7.5. Write a PicBasic Pro subroutine to provide a software debounce on pin RB0 (see Class Discussion Item 7.9). The code should wait for the pushbutton switch to be pressed and released while ignoring the switch bounce.

- 7.6. Write a PicBasic Pro program to perform the functionality of Design Example 6.1 in Chapter 6.
- 7.7. Microcontrollers usually do not include D/A converters, but you can easily create a crude version of one using a single digital I/O pin. This can be done by outputting a variable-width pulse train to an RC circuit. See the documentation for the PWM statement in the PicBasic Pro compiler manual for more information. Write a PicBasic Pro subroutine that uses pin RA0 to output a constant voltage (between 0 and 5 V) that is proportional to the value of a byte variable called *digital_value*, whose value can range from 0 to 255. The subroutine should hold this voltage for approximately 1 sec.
- 7.8. For the home security system in Example 7.5, explain what would happen if a burglar closes an opened door or window after setting off the alarm? Consider all pertinent operating states. How could the design be improved to overcome any perceived limitations?

Section 7.6 Using Interrupts

- 7.9. Write a PicBasic Pro program to implement an interrupt-driven solution to the home security system presented in Example 7.9.

Section 7.7 The Arduino Prototyping Platform

- 7.10. Write an Arduino C program for the PicBasic Pro code in Design Example 7.2.
- 7.11. Write an Arduino C program for the problem in Question 7.13.
- 7.12. Write an Arduino C program for the problem in Question 7.14.

Section 7.8 Interfacing Common PIC Peripherals

- 7.13. Write a PicBasic Pro program to display the value of a potentiometer as a percentage on an LCD display. The message should have the form *pot value = X%*, where *X* is the percentage value ranging from 0 to 100. Draw the wiring diagram required for your solution.
- 7.14. Write a PicBasic Pro program that allows the user to enter a set of a multidigit numbers (up to five digits) on a numeric keypad. Have the # key serve as an enter key; and when a number is entered, it should appear on a two-line LCD display. The first number should appear on the first line, the second number should appear on the second line, and subsequent numbers should appear on the second line with the previous number moving up to the first line. Draw the wiring diagram required for your solution.
- 7.15. In Figure 7.14, explain why there is a 1 k resistor attached from 5 V to RA4. How does this interface differ from connecting RA4 directly to the V_{ee} pin of the LCD (with no resistor or 5 V connection)?

Section 7.11 Method to Design a Microcontroller-Based System

- 7.16. Apply the procedure presented in Section 7.9 to solving the problem stated in Question 6.47. Perform every step in detail. Do as much as possible in software (e.g., instead of using flip-flops).

- 7.17. Solve Question 7.15 based on the revised requirements in Question 6.61.
- 7.18. Using a PIC16F84 and two 7447 display decoders (see Design Example 7.1), write a PicBasic Pro program to implement a counter with a two-digit display controlled by three pushbutton switches: one to reset the count to 0, one to increment the count by 1, and the third to decrement the count by 1. If the count is less than 10, the first digit should be blank. Incrementing past 99 should reset the count to 0, and decrementing below 0 should not be allowed. Make sure you debounce the switch input where necessary and prevent repeats while the pushbutton switches are held down. Use the design procedure presented in Section 7.9 and show the results for each step.
- 7.19. Visit Microchip's website and select a flash-memory PIC microcontroller available as a DIP package that has at least 16 lines of digital I/O and 2 A/D converters. Select the lowest cost model that meets these requirements, and list the approximate cost, the number of I/O pins, the number of A/D converters (along with their resolutions), and the total number of pins on the package.
- 7.20. Draw a detailed flowchart illustrating all of the functionality of Threaded Design Example A.
- 7.21. Draw a flowchart illustrating the functionality of the main program (not including details for the subroutines) for Threaded Design Example B.
- 7.22. Draw a detailed flowchart illustrating all of the functionality of the *move* subroutine in Threaded Design Example B. Include details for the *move_steps* and *step_motor* subroutines.
- 7.23. Draw a detailed flowchart illustrating all of the functionality of the *speed* subroutine in Threaded Design Example B. Include details for the *get_AD_value* subroutine.
- 7.24. Draw a detailed flowchart illustrating all of the functionality of the *position* subroutine in Threaded Design Example C. Include details for the *get_encoder* subroutine.
- 7.25. Draw a detailed flowchart illustrating all of the functionality of the *slave* PIC code in Threaded Design Example C.

BIBLIOGRAPHY

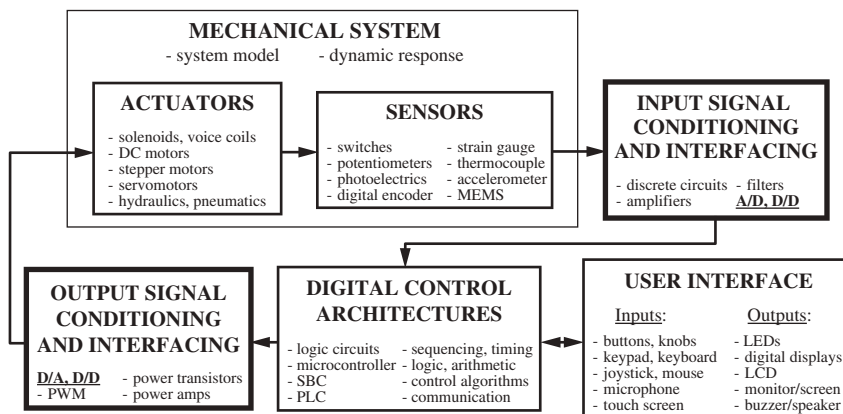
- Arduino website, www.arduino.cc, 2016.
- Blum, J., *Exploring Arduino*, Wiley, Indianapolis, IN, 2013.
- Gibson, G. and Liu, Y., *Microcomputers for Engineers and Scientists*, Prentice Hall, Englewood Cliffs, NJ, 1980.
- Herschede, R., "Microcontroller Foundations for Mechatronics Students," master's thesis, Colorado State University, summer 1999.
- Horowitz, P. and Hill, W., *The Art of Electronics*, 3rd Edition, Cambridge University Press, New York, 2015.
- Microchip Technology, Inc., www.microchip.com, 2016.
- Microchip Technology, Inc., *PIC16F8X Data Sheet*, Chandler, AZ, 1998.
- Microchip Technology, Inc., *MPASM User's Guide*, Chandler, AZ, 1999.
- Microchip Technology, Inc., *MPLAB User's Guide*, Chandler, AZ, 2000.
- microEngineering Labs, Inc., www.melabs.com, 2016.
- microEngineering Labs, Inc., *PicBasic Pro Compiler*, Colorado Springs, CO, 2013.

- Motorola Technical Summary, “MC68HC11EA9/MC68HC711EA9 8-bit Microcontrollers,” document number MC68HC11EA9TS/D, Motorola Advanced Microcontroller Division, Austin, TX, 1994.
- Peatman, J., *Design with Microcontrollers*, McGraw-Hill, New York, 1988.
- Predko, M., *Programming and Customizing PICmicro Microcontrollers*, 3rd Edition, McGraw-Hill, New York, 2007.
- Stiffler, A., *Design with Microprocessors for Mechanical Engineers*, McGraw-Hill, New York, 1992.
- Texas Instruments, *TTL Linear Data Book*, Dallas, TX, 1992.
- Texas Instruments, *TTL Logic Data Book*, Dallas, TX, 1988.

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Data Acquisition

This chapter presents the concepts involved with converting between analog and digital signals. This is important when interfacing digital circuits and devices to analog components in mechatronic systems. The concept of virtual instrumentation is also introduced along with LabVIEW software examples from National Instruments. ■



CHAPTER OBJECTIVES

After you read, discuss, study, and apply ideas in this chapter, you will:

1. Understand how to properly sample a signal for digital processing
2. Understand how digitized data are coded

The authors express their thanks to Jim Cahow of National Instruments (Austin, TX) for providing resources and support for the editing of this chapter.

3. Know the components of an A/D converter
4. Understand how A/D and D/A converters function, and recognize their limitations
5. Be aware of commercially available hardware and software tools for data acquisition and control
6. Understand the basics of LabVIEW programming and data acquisition
7. Understand the effects of sampling rate and resolution on music sampling

8.1 INTRODUCTION

Microprocessors, microcontrollers, single-board computers, and personal computers are in widespread use in mechatronic and measurement systems. It is increasingly important for engineers to understand how to directly access information and analog data from the surrounding environment with these devices. As an example, consider a signal from a sensor as illustrated by the analog signal in Figure 8.1. One could record the signal with an analog device such as a chart recorder, which physically plots the signal on paper, or display it with an oscilloscope. Another option is to store the data using a microprocessor or computer. This process is called computer **data acquisition**, and it provides more compact storage of the data (magnetic, optical, or flash media vs. long rolls of paper), can result in greater data accuracy, allows use of the data in a real-time control system, and enables data processing long after the events have occurred.

To be able to input analog data to a digital circuit or microprocessor, the analog data must be transformed into coded digital values. The first step is to numerically evaluate the signal at discrete instants in time. This process is called **sampling**, and the result is a **digitized signal** composed of discrete values corresponding to each sample, as illustrated in Figure 8.1. Therefore, a digitized signal is a sequence of numbers that is an approximation to an analog signal. The time at which each sample occurs need not be recorded separately if the sampling is done at a consistent and predefined sampling interval. The collection of sampled data points forms a data array (sequence of numbers), and although this representation is no longer continuous, it can accurately describe the original analog signal.

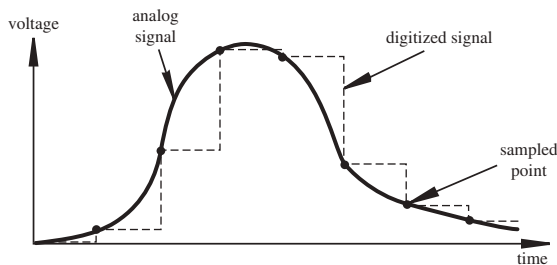


Figure 8.1 Analog signal and sampled equivalent.

An important question is how fast or often the signal should be sampled to obtain an accurate representation. The naive answer might be “as fast as you possibly can.” The problems with this conclusion are that specialized, high-speed hardware is required and a large amount of computer memory is needed to store the data. A better answer is to select the minimal sampling rate required for a given application that retains all important signal information.

The **sampling theorem**, also called **Shannon’s sampling theorem**, states that we need to sample a signal at a rate more than two times the maximum frequency component in the signal to retain all frequency components. In other words, to faithfully represent the analog signal, the digital samples must be taken at a frequency f_s such that

$$f_s > 2f_{\max} \quad (8.1)$$

where $f_{\max}$ is the highest frequency component in the input analog signal. The term f_s is referred to as the **sampling rate**, and the limit on the minimum required rate ($2f_{\max}$) is called the **Nyquist rate**. If we approximate a signal by a truncated Fourier series, the maximum frequency component is the highest harmonic frequency. The time interval between the digital samples is

$$\Delta t = 1/f_s \quad (8.2)$$

As an example, if the sampling rate is 5000 Hz, the time interval between samples would be 0.2 ms.

If a signal is sampled at less than two times its maximum frequency component, **aliasing** can result. Figure 8.2 illustrates an example of this with an analog sine wave sampled regularly at the points shown. Twelve equally spaced samples are taken over 10 cycles of the original signal. Therefore, the sampling frequency is $1.2f_0$, where f_0 is the frequency of the original sine wave. Because the sampling frequency is not greater than $2f_0$, we do not capture the frequency in the original signal. Furthermore, the apparent frequency in the sampled signal is $0.2f_0$ (2 aliased signal cycles for ten original signal cycles). You can think of this as a “phantom” frequency, which is an alias of the true frequency. Therefore, undersampling not only results in errors but also creates information that is not really there! Video Demo 8.1 demonstrates the concepts of sampling rate, Nyquist rate and aliasing, applied to a sine wave signal, and Video Demo 8.2 provides an interesting visual example of aliasing.



8.1 Sampling rate, Nyquist rate, and aliasing

8.2 Tuning fork super-slow-motion video aliasing

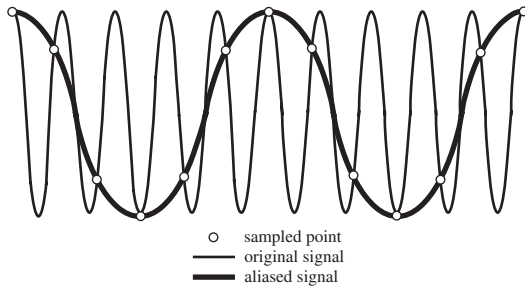


Figure 8.2 Aliasing.

The method of Fourier decomposition presented in Chapter 4 provides a means to determine the frequency components of an arbitrary analog signal. Representing a signal in terms of its frequency components allows us to identify the bandwidth and correctly apply the sampling theorem.

■ CLASS DISCUSSION ITEM 8.1

Wagon Wheels and the Sampling Theorem

Relate the sampling theorem and its implications about correct and incorrect data representation to the use of a movie camera to film a rotating wagon wheel in a Western movie. The camera shutter can be considered a sampling device, where the shutter speed is the sampling rate. Typically, the sampling rate is 30 Hz to provide a flicker-free image to the human eye. What effects would you expect in the movie, when viewed, if the wagon wheel is turning rapidly?

Sampling Theorem and Aliasing

EXAMPLE 8.1

Consider the function

$$F(t) = \sin(at) + \sin(bt)$$

Using a trigonometric identity for the sum of two sinusoidal functions, we can rewrite $F(t)$ as the following product:

$$F(t) = \left[2 \cos\left(\frac{a-b}{2}t\right) \right] \cdot \sin\left(\frac{a+b}{2}t\right)$$

If frequencies a and b are close in value, the bracketed term has a very low frequency in comparison to the sinusoidal term on the right. Therefore, the bracketed term modulates the amplitude of the higher frequency sinusoidal term. The resulting waveform exhibits what is called a **beat frequency** that is common in optics, mechanics, and acoustics when two waves close in frequency add. For more information and an audio example of beat frequency, see Internet Link 8.1 and Video Demo 8.3.

To illustrate aliasing associated with improper sampling, the waveform is plotted in the following figures using two different sampling frequencies. If a and b are chosen as

$$a = 1 \text{ Hz} = 2\pi \frac{\text{rad}}{\text{sec}} \quad b = 0.9a$$

then to sample the signal $F(t)$ properly, the sampling rate must be more than twice the highest frequency in the signal:

$$f_s > 2a = 2 \text{ Hz}$$

Therefore, the time interval between samples (plotted points) must be

$$\Delta t = \frac{1}{f_s} < 0.5 \text{ sec}$$

(continued)



Internet Link

8.1 Beat frequency



Video Demo

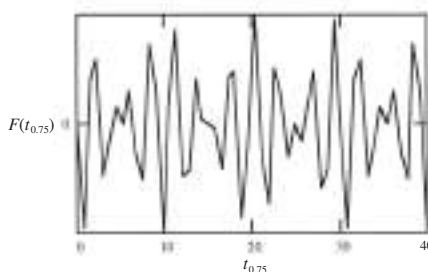
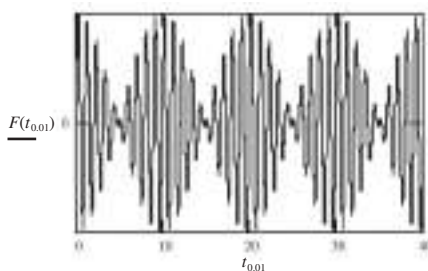
8.3 Beat frequency from mixing signals of similar frequency

(concluded)

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8.1 Sampling theorem, aliasing, beat frequency

The first data set is plotted with a time interval of 0.01 sec (100 Hz sampling rate), providing an adequate representation of the waveform. The second data set is plotted with a time interval of 0.75 sec (1.33 Hz sampling rate), which is less than twice the maximum frequency of the waveform (2 Hz). Therefore, the signal is undersampled, and aliasing results. The sampled waveform is an incorrect representation, and its observed maximum frequency appears to be approximately 0.4 Hz because there are approximately four cycles over 10 sec.



You might argue that neither plot is perfect. However, unlike the second plot, the first plot retains all the frequency information in the analog signal. Mathcad/Matlab Example 8.1 contains the analysis used to generate the plots above. You can easily edit the file to see the effects of different sampling rates.

■ CLASS DISCUSSION ITEM 8.2

Sampling a Beat Signal

What is the minimum sampling rate required to adequately represent the signal without aliasing in Example 8.1?



Lab Exercise

Lab 12 Data acquisition

Lab Exercise 12 explores the effects of using different sampling rates when digitizing a sine wave signal and audio from a music player. Video Demos 8.4 and 8.5 demonstrate the results. Video Demo 8.6, which contains only audio, and Video Demo 8.7 illustrate the effects of sampling rate on various tones and music recordings. For

many more video demonstrations of various music, sound, and vibration concepts, see Internet Link 8.3.

8.2 RECONSTRUCTION OF SAMPLED SIGNALS

Section 8.1 introduced Shannon's Sampling Theorem stating that to represent a sampled analog signal accurately without frequency aliasing the signal must be sampled at a rate above the Nyquist rate, which is twice the highest frequency component in the signal. In this section, we will see how sampled data can be used to reconstruct an analog signal with high fidelity.

As an example of a continuous analog signal we wish to digitize through sampling, and then reconstruct, Figure 8.3 shows 15 cycles of a sine wave of frequency 1 Hz. The Nyquist rate for this signal is 2 Hz; so for an alias-free representation, we need to sample at a rate faster than this. Figure 8.4 shows the results of sampling at 2.1 Hz. The plot of the sampled data does not appear to be an adequate representation of the original signal, but the original signal can in fact be reconstructed accurately from this set of samples. The theory behind this process is beyond the scope of this book, but it can be found at Internet Link 8.2, and the technique and results are shown below.

The technique used to reconstruct a continuous analog signal from a set of sampled data is called a **sinc reconstruction filter**. The equation used to perform the reconstruction is as follows:

$$f(t) = \sum_{i=0}^{N_s} F_i \cdot \text{sinc} \left(\pi \cdot \frac{(t - t_i)}{\Delta t} \right) \quad (8.3)$$

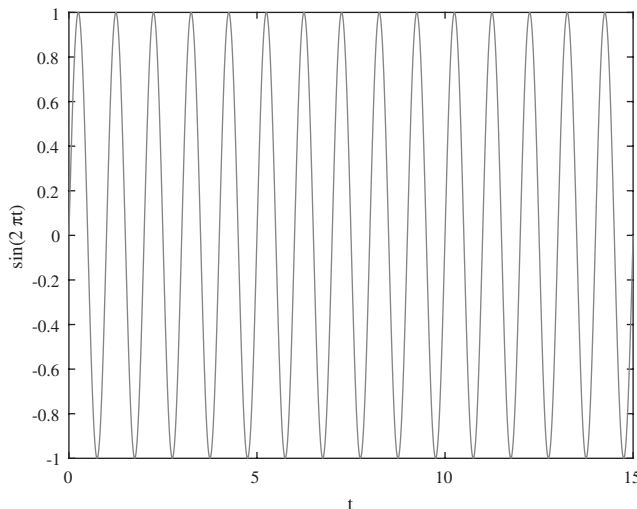


Figure 8.3 Original sine wave signal to be sampled



Video Demo

8.4 Data acquisition experiment

8.5 LabVIEW data acquisition and music sampling

8.6 Sampling rate and its effect on sound and music (audio only)

8.7 Music sampling rate and resolution effects



Internet Link

8.2 Nyquist-Shannon sampling theorem

8.3 Music, sound, and vibration demonstrations

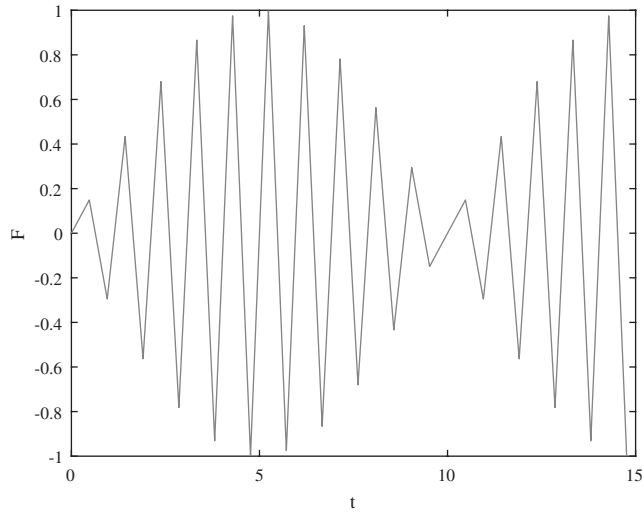


Figure 8.4 Sine wave signal sampled at a rate slightly faster than the Nyquist rate

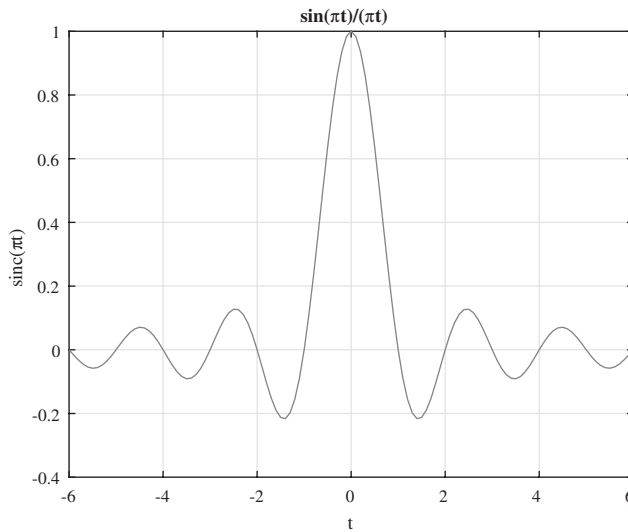
where $f(t)$ is the reconstructed analog signal, based on $N_s + 1$ samples F_i recorded at times t_i a fixed interval Δt apart (i.e., $t_i = i\Delta t$, where $i = 0$ to N_s). The sinc (pronounced “sink”) function is defined as:

$$\text{sinc}(x) = \frac{\sin(x)}{x} \quad (8.4)$$

A plot of the sinc function, with x scaled by π (as in Equation 8.3), is shown in Figure 8.5. Notice that the amplitude of the sinc function is 1 when the argument (πt) is zero. This can be seen in Figure 8.5 and proved with l’Hopital’s Rule from Calculus. The unity amplitude causes sample F_i to be counted entirely when the evaluation time t is at sample time t_i . And in this case, all other samples (F_j , where $j \neq i$) would be excluded in the sum since the arguments of the sinc functions would be integer multiples of π (since the samples are fixed time intervals Δt apart), where $\sin$ and sinc are both zero (see the zero-crossings in Figure 8.5 at the integer values of t in the plot). When the evaluation time t is not at a sample time t_i , the resulting sinc-weighted average of all of the samples, given by Equation 8.3, still amazingly reproduces the original signal with high fidelity. Again, see Internet Link 8.2 for a mathematical proof.

Applying the sinc filter in Equation 8.3 to the sampled data in Figure 8.4 yields the reconstructed continuous analog signal shown in Figure 8.6. Notice how well the reconstructed wave matches the original analog signal over the entire middle range of the plot. The match is poor only at the beginning and end of the sampling interval, where the signal is started and stopped abruptly, with no samples outside of the end points.

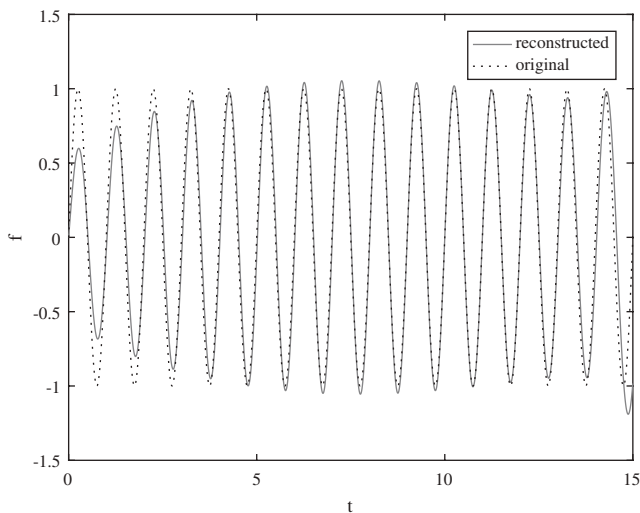
Any analog signal with any number of frequency components can be reproduced in a similar fashion (as demonstrated above) with high fidelity, assuming there

**Figure 8.5** Sinc wave

are enough samples on both sides of the areas of interest. And even then, the filter can be modified to handle the beginning and ends more gracefully (which is beyond the scope of this limited introduction). MathCAD/Matlab Example 8.2 contains the analysis used to generate the plots above. You can easily edit the file to try out the reconstruction technique with other more-complicated functions.

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8.2 Recovering
a signal from
sampled data
using the sinc
reconstruction filter

**Figure 8.6** Reconstructed signal, compared to the original

8.3 QUANTIZING THEORY

Now we look at the process required to change a sampled analog voltage into digital form. The process, called analog-to-digital conversion, conceptually involves two steps: quantizing and coding. **Quantizing** is defined as the transformation of a continuous analog input into a set of discrete output states. **Coding** is the assignment of a digital code word or number to each output state. Figure 8.7 illustrates how a continuous voltage range is divided into discrete output states, each of which is assigned a unique code. Each output state covers a subrange of the overall voltage range. The stair-step signal represents the states of a digital signal generated by sampling a ramp of an analog signal occurring over the voltage range shown.

An **analog-to-digital converter**, also called an A/D converter or an ADC, is an electronic device that converts an analog voltage to a digital code. The output of the A/D converter can be directly interfaced to digital devices such as microcontrollers and computers. The **resolution** of an A/D converter is the number of bits used to digitally approximate the analog value of the input. The number of possible states N is equal to the number of bit combinations that can be output from the converter:

$$N = 2^n$$

(8.5)

where n is the number of bits. For the example illustrated in Figure 8.7, the 3-bit device has 2^3 or 8 output states as listed in the first column. The output states are usually numbered consecutively from 0 to $(N - 1)$. The corresponding code word for



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8.3 Music, sound, and vibration demonstrations

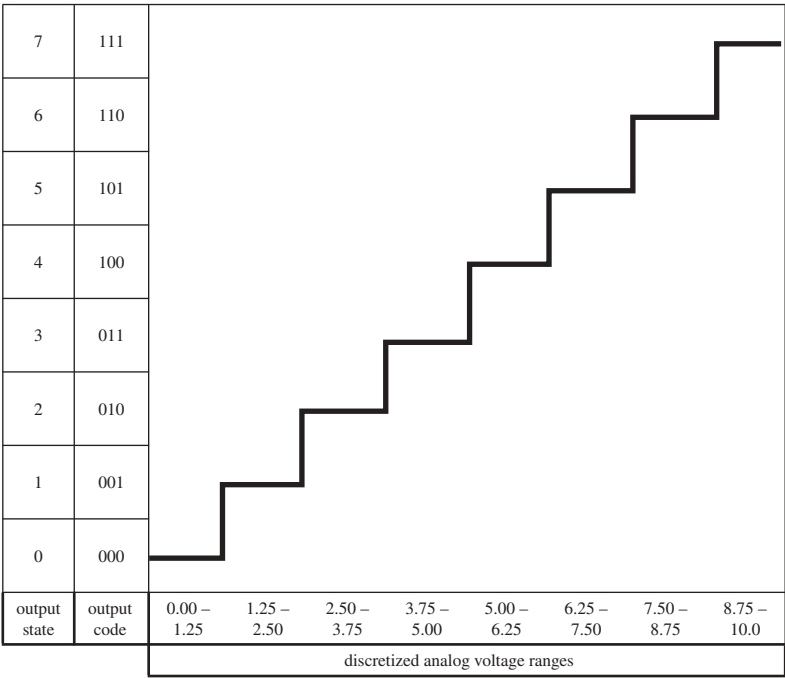


Figure 8.7 Analog-to-digital conversion.

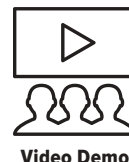
each output state is listed in the second column. Most commercial A/D converters are 8-, 10-, or 12-bit devices that resolve 256, 1024, and 4096 output states, respectively.

The number of analog **decision points** that occur in the process of quantizing is $(N - 1)$. In Figure 8.7, the decision points occur at 1.25 V, 2.50 V, . . . , and 8.75 V. The **analog quantization size** Q , sometimes called the **code width**, is defined as the full-scale range of the A/D converter divided by the number of output states:

$$Q = (V_{\max} - V_{\min})/N \quad (8.6)$$

It is a measure of the analog change that can be resolved by the converter. Although the term resolution is defined as the number of output bits from an A/D converter, sometimes it is used to refer to the analog quantization size. For our example, the analog quantization size is $10/8 \text{ V} = 1.25 \text{ V}$. This means that the amplitude of the digitized signal has an error of at most 1.25 V. Therefore, the A/D converter can only resolve a voltage to within 1.25 V of the exact analog voltage.

Video Demo 8.7 demonstrates how both sampling rate and A/D resolution affect the fidelity of digitized music.



Video Demo

8.7 Music sampling rate and resolution effects

■ CLASS DISCUSSION ITEM 8.3

Laboratory A/D Conversion

Why is a 12-bit A/D converter satisfactory for most laboratory measurements?

8.4 ANALOG-TO-DIGITAL CONVERSION

8.4.1 Introduction

To properly acquire an analog voltage signal for digital processing, the following components must be properly selected and applied in this sequence:

1. buffer amplifier
2. low-pass filter
3. sample and hold amplifier
4. analog-to-digital converter
5. computer

The components required for A/D conversion along with an illustration of their respective outputs are shown in Figure 8.8. The buffer amplifier (see Section 5.6) isolates the output from the input (i.e., it draws negligible current and power from the input) and provides a signal in a range (with a gain) close to but not exceeding the full input voltage range of the A/D converter. The low-pass filter is necessary to remove any undesirable high-frequency components in the signal that could produce aliasing. This filter is usually referred to as an **antialiasing filter**. The cutoff frequency of the low-pass filter should be no greater than 1/2 the sampling rate. The sample and hold amplifier (see Section 5.12) maintains a fixed input value (from an instantaneous sample) during the short conversion time of the A/D converter.

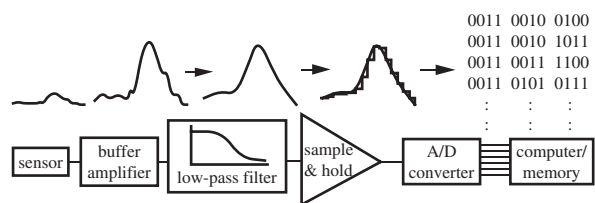


Figure 8.8 Components used in A/D conversion.



Figure 8.9 Typical data acquisition hardware (NI cDAQ-9172)

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Internet Link

8.4 Data acquisition online resources and vendors

8.5 National Instruments' LabVIEW software

The converter should have a resolution and analog quantization size appropriate to the system and signal. The computer must be properly interfaced to the A/D converter system to store and process the data. The computer must also have sufficient memory and permanent storage media to hold all of the data.

The A/D system components described above can be found packaged in a variety of commercial products called data acquisition (DAC or DAQ) cards or modules. Figure 8.9 shows an example of typical data acquisition hardware. This is a multi-slot USB chassis with a variety of plug-in I/O modules available for different applications. Internet Link 8.4 provides links to vendors and sources of information for various products available on the market.

Data acquisition cards and modules usually support various high-level language interfaces (e.g., C++ and Visual Basic) that give easy access to the product's features. Easy-to-use software applications are also available to provide graphical interfaces to program a DAC module to acquire, process, and output signals. National Instruments' LabVIEW software is an example (see Internet Link 8.5 and Section 8.6 for more information). With a commercial DAC system, interfacing signals between a mechatronic system or laboratory experiment and a desktop computer is a simple matter of calling a function from a custom-written program or clicking and dragging icons in a graphical user interface. Lab Exercise 12 explores the basics of how to use the LabVIEW software to sample and store an external voltage signal, including sampled music. Video Demo 8.5 demonstrates all of the steps in the process, and Section 8.7 explores the details.

In addition to A/D converters, commercial DAC systems usually provide other input and output functionality including binary (TTL-compatible) I/O, D/A converters, counters and timers, and signal conditioning circuitry. Important features when

selecting a DAC system include the A/D and D/A resolutions (the number of bits used) and the maximum sampling rate supported. These features are key to accuracy and reliability in computer monitoring and control applications. An example inexpensive data acquisition and control module that can be interfaced to a PC (via a USB port) is shown in Figure 8.10. Its internal architecture is illustrated by the block diagram printed on the device. The module includes two 16-bit A/D converters and two 16-bit D/A converters, both of which can process 20,000 samples/sec, 8 lines of digital I/O, and a 32-bit counter/timer. It also includes audio, powersupply, and digital-multimeter functions, all in a compact and portable USB device.

The process of analog-to-digital conversion requires a small but finite interval of time that must be taken into consideration when assessing the accuracy of the results. The **conversion time**, also called **settling time**, depends on the design of the converter, the method used for conversion, and the speed of the components used in the electronic design. Because analog signals change continuously, the uncertainty about when in the sample time window the conversion occurs causes corresponding uncertainty in the digital value. This is of particular concern if there is no sample and hold amplifier on the A/D input. The term **aperture time** refers to the duration of the time window and is associated with any error in the digital output due to changes in the input during this time. The relationship between the aperture time and the uncertainty in the input amplitude is shown in Figure 8.11. During the aperture time ΔT_a , the input signal changes by ΔV , where

$$\Delta V \approx \frac{dV(t)}{dt} \Delta T_a \quad (8.7)$$

Sampling at a rate above the Nyquist rate will yield the correct frequency components in a signal. However, to also obtain accurate amplitude resolution, we must have an A/D converter with a sufficiently small aperture time (see Example 8.2). It is often in the nanosecond range for 10- and 12-bit resolution.



Lab Exercise

Lab 12 Data acquisition



Video Demo

8.5 LabVIEW data acquisition and music sampling



Figure 8.10 USB DAC module (NI myDAQ)

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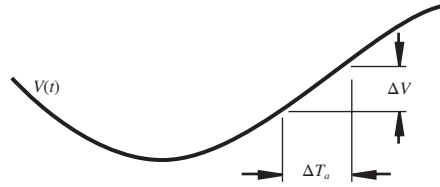


Figure 8.11 A/D conversion aperture time.

EXAMPLE 8.2

Aperture Time

Consider a sinusoidal signal $A \sin(\omega t)$ as an input to an A/D converter. The time rate of change of the signal $A\omega \cos(\omega t)$ has a maximum value of $A\omega$. Using Equation 8.7, the maximum change in the input voltage during an aperture time ΔT_a is

$$\Delta V = A\omega \Delta T_a$$

To eliminate uncertainty in the value of the digital output, we need to ensure that ΔV is less than the analog quantization size:

$$\Delta V < \frac{2A}{N}$$

where $2A$ is the total voltage range and N is the number of output states. At the limit of this constraint,

$$\Delta V = \frac{2A}{N}$$

Therefore, the required aperture time, if a sample and hold amplifier is not being used, is

$$\Delta T_a = \frac{\Delta V}{A\omega} = \frac{2}{N\omega}$$

Consider, for example, converting a signal using 10-bit resolution, which provides 2^{10} (1024) output states. If the signal were speech (from a microphone) with a bandwidth of 10 kHz, ΔT_a would have to be less than

$$\Delta T_a = \frac{2}{N\omega} = \frac{2}{1024(2\pi \cdot 10,000)} = 3.2 \times 10^{-8} = 32 \text{ nsec}$$

This is a very short required aperture time compared to the required minimum sample period given by $1/[2(10 \text{ kHz})] = 50 \text{ } \mu\text{sec}$. Even for this low-resolution converter, the required aperture time (32 nsec) is much smaller than the required sample period (50,000 nsec).

8.4.2 Analog-to-Digital Converters

A/D converters are designed based on a number of different principles: successive approximation, flash or parallel encoding, single-slope and dual-slope integration, switched capacitor, and delta sigma. We consider the first two because they occur

most often in commercial designs. The **successive approximation** A/D converter is very widely used because it is relatively fast and cheap. As shown in Figure 8.12, it uses a D/A converter in a feedback loop. D/A converters are described in the next section. When the start signal is applied, the sample and hold (S&H) amplifier latches the analog input. Then the control unit begins an iterative process, where the digital value is approximated, converted to an analog value with the D/A converter, and compared to the analog input with the comparator. When the D/A output equals the analog input, the end signal is set by the control unit, and the correct digital output is available at the output.

If n is the resolution of the A/D converter, it takes n steps to complete the conversion. More specifically, the input is compared to combinations of binary fractions ($1/2, 1/4, 1/8, \dots, 1/2^n$) of the full-scale (FS) value of the A/D converter. The control unit first turns on the most significant bit (MSB) of the register, leaving all lesser bits at 0, and the comparator tests the DAC output against the analog input. If the analog input exceeds the DAC output, the MSB is left on (high); otherwise, it is reset to 0. This procedure is then applied to the next lesser significant bit and the comparison is made again. After n comparisons have occurred, the converter is down to the least significant bit (LSB). The output of the DAC then represents the best digital approximation to the analog input. When the process terminates, the control unit sets the end signal signifying the end of the conversion.

As an example, a 4-bit successive approximation procedure is illustrated graphically in Figure 8.13. The MSB is $1/2$ FS, which in this case is greater than the signal value; therefore, the bit is turned off. The second bit is $1/4$ FS and is less than the

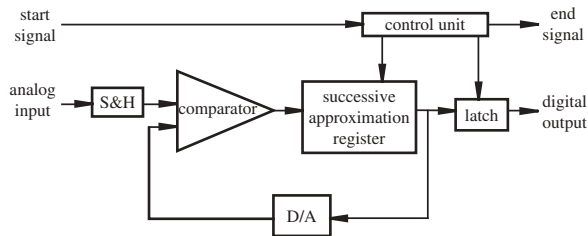


Figure 8.12 Successive approximation A/D converter.

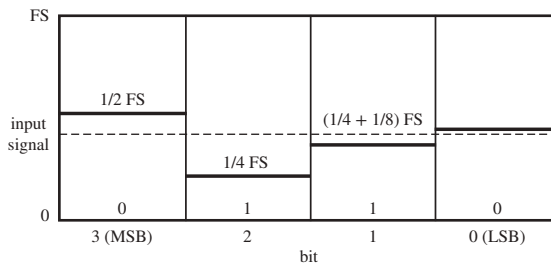


Figure 8.13 4-bit successive approximation A/D conversion.

signal, so it is left on. The third bit gives $1/4 + 1/8$ of FS, which is still less than the analog signal, so the third bit is left on. The fourth provides $1/4 + 1/8 + 1/16$ of FS and is greater than the signal, so the fourth bit is turned off and the conversion is complete. The digital result is 0110. Higher resolution would produce a more accurate value.

An n -bit successive approximation A/D converter has a conversion time of $n\Delta T$, where ΔT is the cycle time for the D/A converter and control unit. Typical conversion times for 8-, 10-, and 12-bit successive approximation A/D converters range from 1 to 100 μs .

The fastest type of A/D converter is known as a **flash converter**. As Figure 8.14 illustrates, it consists of a bank of input comparators acting in parallel to identify the signal level. The output of the latches is in a coded form easily converted to the required binary output with combinational logic. The flash converter illustrated in Figure 8.14 is a 2-bit converter having a resolution of four output states. Table 8.1

■ CLASS DISCUSSION ITEM 8.4

Selecting an A/D Converter

What are some reasons why a designer might select a 10-bit A/D converter instead of a 12-bit or higher resolution converter?

Table 8.1 2-bit flash converter output

State	Code ($G_2G_1G_0$)	Binary (B_1B_0)	Voltage Range
0	000	00	0–1
1	001	01	1–2
2	011	10	2–3
3	111	11	3–4

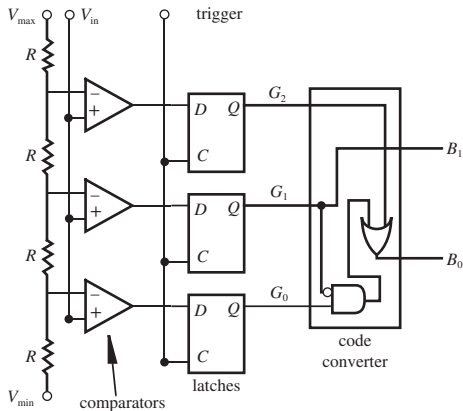


Figure 8.14 A/D flash converter.

lists the comparator output codes and corresponding binary outputs for each of the states, assuming an input voltage range of 0 to 4 V. The voltage range is set by the $V_{\min}$ and $V_{\max}$ supply voltages shown in Figure 8.14 (0 V and 4 V in this example). The code converter is a simple combinational logic circuit. For the 2-bit converter, the relationships between the code bits G_i and the binary bits B_i (Question 8.12) are

$$B_0 = G_0 \cdot \overline{G_1} + G_2 \quad (8.8)$$

$$B_1 = G_1 \quad (8.9)$$

Adding more resolution is a simple matter of adding more resistors, comparators, and latches. The combinational logic code converter would also be different. Unlike with the successive approximation converter, adding resolution does not increase the time required for a conversion.

Several analog signals can be digitized by a single A/D converter if the analog signals are multiplexed at the input to the A/D converter. An analog **multiplexer** simply switches among several analog inputs using transistors or relays and control signals. This can significantly reduce the cost of a system's design. In addition to cost, other parameters important in selecting an A/D converter are the input voltage range, output resolution, and conversion time.

8.5 DIGITAL-TO-ANALOG CONVERSION

Often we need to reverse the process of A/D conversion by changing a digital value to an analog voltage. This is called **digital-to-analog (D/A) conversion**. A D/A converter, also called a DAC, allows a computer or other digital device to interface with external analog circuits and devices.

The simplest type of D/A converter is a resistor ladder network connected to an inverting summer op amp circuit as shown in Figure 8.15. This particular converter is a 4-bit R - $2R$ resistor ladder network, which requires only two precision resistance values (R and $2R$). The digital input to the DAC is a 4-bit binary number represented by bits b_0 , b_1 , b_2 , and b_3 , where b_0 is the least significant bit and b_3 is the most significant bit. Each bit in the circuit controls a switch between ground and the inverting input of the op amp. To understand how the analog output voltage V_{out} is related to the input binary

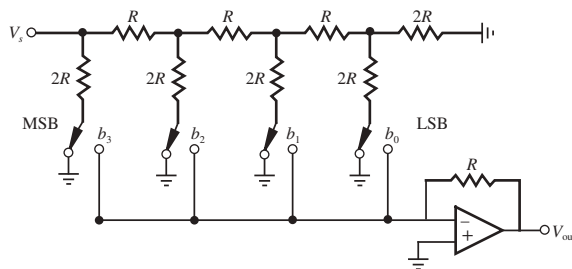


Figure 8.15 4-bit resistor ladder D/A converter.

number, we can analyze the four different input combinations 0001, 0010, 0100, and 1000 and apply the principle of superposition for an arbitrary 4-bit binary number.

If the binary number is 0001, the b_0 switch is connected to the op amp, and the other bit switches are grounded. The resulting circuit is as shown in Figure 8.16. Because the noninverting input of the op amp is grounded, the inverting input is also at ground. The equivalent resistance between node V_0 and ground is R , which is the parallel combination of two $2R$ values. Therefore, V_0 is the result of voltage division of V_1 across two series resistors of equal value R :

$$V_0 = \frac{1}{2} V_1 \quad (8.10)$$

Similarly, we can show that

$$V_1 = \frac{1}{2} V_2 \quad \text{and} \quad V_2 = \frac{1}{2} V_3 \quad (8.11)$$

Therefore,

$$V_0 = \frac{1}{8} V_3 = \frac{1}{8} V_s \quad (8.12)$$

V_0 is the input to the inverting amplifier circuit, which has a gain of

$$-\frac{R}{2R} = -\frac{1}{2} \quad (8.13)$$

Therefore, the analog output voltage corresponding to the binary input 0001 is

$$V_{\text{out}_0} = -\frac{1}{16} V_s \quad (8.14)$$

Similarly, we can show (Questions 8.17 through 8.19) that, for the input 0010,

$$V_{\text{out}_1} = -\frac{1}{8} V_s \quad (8.15)$$

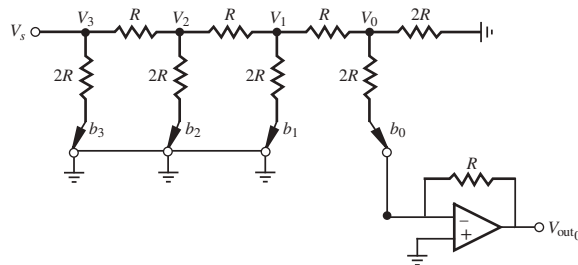


Figure 8.16 4-bit resistor ladder D/A with digital input 0001.

and for the input 0100,

$$V_{\text{out}_2} = -\frac{1}{4}V_s \quad (8.16)$$

and for the input 1000,

$$V_{\text{out}_3} = -\frac{1}{2}V_s \quad (8.17)$$

The output for any combination of bits comprising the input binary number can now be found using the principle of superposition:

$$V_{\text{out}} = b_3V_{\text{out}_3} + b_2V_{\text{out}_2} + b_1V_{\text{out}_1} + b_0V_{\text{out}_0} \quad (8.18)$$

If V_s is 10 V, the output ranges from 0 V to $(-15/16)10$ V for the 4-bit binary input, which has 16 values ranging from 0000 (0) to 1111 (15). A negative reference voltage V_s can be used to produce a positive output voltage range. Either case yields a **unipolar** output, which is either positive or negative but not both. A **bipolar** output, which ranges over negative and positive values, can be produced by replacing all ground references in the circuit with a reference voltage whose sign is opposite to V_s .

■ CLASS DISCUSSION ITEM 8.5

Bipolar 4-Bit D/A Converter

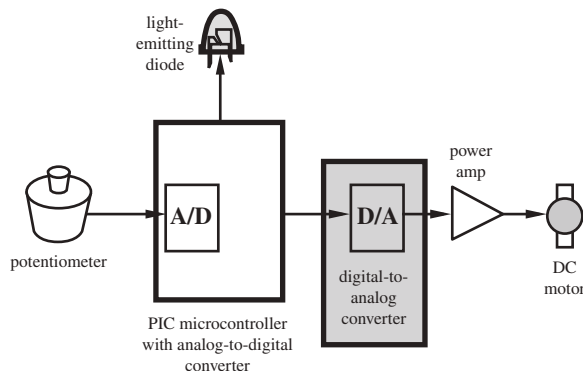
If $V_s = 10$ V and the ground reference is replaced by a -10 V reference, what output voltage would correspond to each possible binary input applied to a 4-bit D/A R-2R ladder network?

THREADED DESIGN EXAMPLE

DC motor power-op-amp speed controller—D/A converter interface

A. 5

The figure below shows the functional diagram for Threaded Design Example A (see Section 1.3 and Video Demo 1.6), with the portion described here highlighted.



Video Demo

1.6 DC motor power-op-amp speed controller

The D/A used in this design is an external 8-bit TLC7524 converter. Detailed information about the device can be found in the data sheet at Internet Link 7.28. As shown in the figure below, the PIC interfaces to the D/A converter via two control lines and 8 data lines (the entire PORTB register). One control line is the chip select pin that is used to activate the D/A converter. The other is a write line that signals to the D/A when to perform the conversion and update the output voltage. Both lines are “active low.”

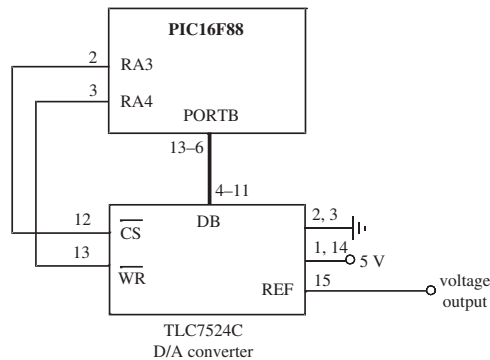
The code required to initialize the PIC outputs and to activate the D/A converter follows:

```
da_cs Var PORTA.3      ' external D/A converter chip select
                        (low:activate)
da_wr Var PORTA.4      ' external D/A converter write (low: write)
TRISB = 0              ' initialize PORTB pins as outputs
High da_wr             ' initialize the A/D converter write line
Low da_cs              ' activate the external D/A converter
```



Internet Link

7.28 TLC7524
D/A converter



The code required to update the voltage output from the D/A converter follows. The voltage is stored as a scaled value in the PIC in a byte variable (*ad_byte*). The value ranges from 0 (corresponding to 0 V) to 255 (corresponding to 5 V). The entire byte (all 8 bits) is transmitted in parallel to the D/A converter through PORTB. Note the small pause after the write command to ensure that the conversion has completed before the write is disabled.

```
' Send the potentiometer byte to the external D/A
PORTB = ad_byte
Low da_wr
Pauseus 1      ' wait 1 microsec for the D/A to settle
High da_wr
```

Figure 8.17 illustrates the roles that A/D and D/A converters play in a mechatronic control system. An analog voltage signal from a sensor (e.g., a thermocouple) is converted to a digital value, the computer uses this value in a control algorithm, and the computer outputs an analog signal to an actuator (e.g., an electric motor) to cause some change in the system being controlled. This topic is explored more in the next section and in Chapter 11. Sensors and actuators are the topics of the next two chapters.

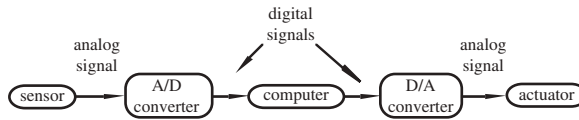


Figure 8.17 Computer control hardware.

■ CLASS DISCUSSION ITEM 8.6

Audio CD Technology

A compact disk (CD) stores music (an analog signal) in a digital format. How is this done? How is the digital data reconverted to the music you hear? Given that audible frequencies range from 20 Hz to 20 kHz, what is an appropriate sampling frequency? For this sampling rate, how many bits must be stored on a CD to produce 45 minutes of listening pleasure, assuming the music is stored uncompressed (e.g., as a WAV file and not as an MP3 file)? Assume just the raw data is stored, without the sophisticated error correction and compensation schemes described in Internet Link 8.6.



Internet Link

8.6 Audio CD format information

■ CLASS DISCUSSION ITEM 8.7

Digital Guitar

A digital guitar is a standard electric guitar equipped with additional components that send MIDI signals to a digital synthesizer. MIDI stands for musical instrument digital interface, and a MIDI signal consists of digital bytes containing amplitude and frequency codes for musical notes. What system components are required to do this?

8.6 VIRTUAL INSTRUMENTATION, DATA ACQUISITION, AND CONTROL

A **virtual instrument** consists of a personal computer equipped with data acquisition hardware and software to perform the functions of traditional instruments. Stand-alone traditional instruments such as oscilloscopes and waveform generators are very powerful, but they can be very expensive and sometimes limiting. The user generally cannot extend or customize the instrument's functionality. The knobs and buttons on the instrument, the built-in circuitry, and the functions available to the user are all specific to the instrument. Virtual instrumentation provides an inexpensive and versatile alternative.

Software is the most important component of a virtual instrument. It can be used to create custom applications by designing and integrating the routines that a particular process requires. The software also allows one to create an appropriate user interface that best suits the purpose of the application and the users who will interact with it. The LabVIEW software from National Instruments (see Internet Link 8.5) is an example of an easy-to-use application development environment designed



Internet Link

8.5 National Instruments' LabVIEW software

specifically for creating virtual instruments. LabVIEW offers powerful features that make connecting to a wide variety of hardware and other software easy.

One of the most powerful features of LabVIEW is its graphical programming environment. Custom graphical user interfaces can be designed to allow a user to operate the instrumentation program, control selected hardware, analyze acquired data, and display results graphically, all on the PC screen. One can customize virtual front panels with knobs, buttons, dials, and graphs to emulate control panels of traditional instruments, create custom test panels, or visually represent the control and operation of processes. Figure 8.18 shows an example graphical user interface that can easily be created. Figure 8.19 shows the block diagram used to create the user interface and to perform the acquisition, analysis, and display functions. LabVIEW is known as a visual programming environment, because to create a custom application and user interface, you simply drag, drop, and connect icons on the screen. Computer programming skills are not required. Note that the LabVIEW examples in this chapter might look a little different from what results from the latest version of LabVIEW, but the concepts and process are similar.

LabVIEW, in addition to its virtual instrumentation and data acquisition capabilities, provides many tools for model-based control system design. Tools are available for characterizing (modeling) a system through data acquisition of test data (a process called **system identification**), designing a controller for a system, simulating how the system will respond to various control inputs, and embedding



Video Demo

- 8.8 National Instruments' DC motor demo
- 8.9 National Instruments' LabVIEW DC motor controller design

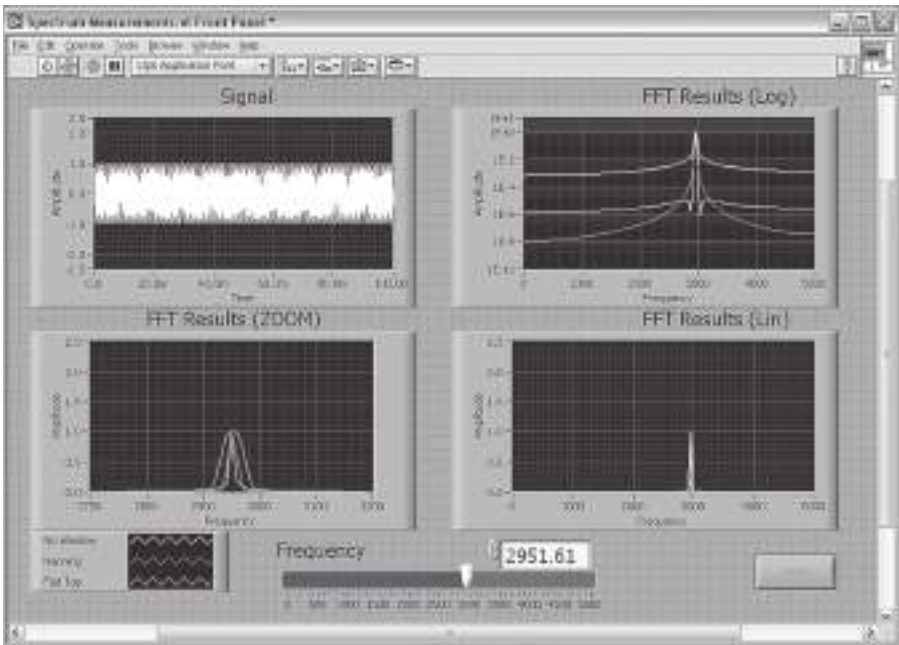


Figure 8.18 Example custom graphical user interface created with LabVIEW.
contributed by David Alciatore

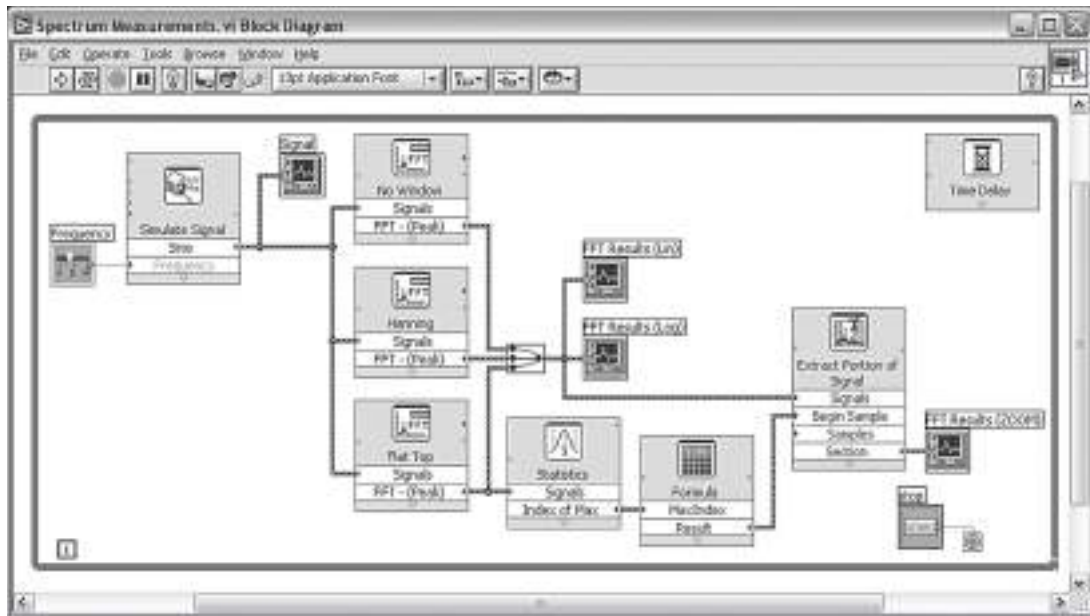


Figure 8.19 Example LabVIEW block diagram.

contributed by David Alciatore

the controller into hardware to perform real-time control. Video Demo 8.8 shows a demonstration of how these tools can be used to develop a speed controller for a simple DC motor system. LabVIEW is used to send a command signal to the DC motor and to monitor the resulting motion by acquiring a feedback signal from a tachometer. Video Demo 8.9 provides much more background and detailed demonstrations of the individual steps in the process. Also, the basics of control theory are presented in Section 11.3.

National Instruments also offers pre-programmed virtual-instrument software along with a useful Laboratory platform for prototyping, powering, and taking measurements within electrical circuits. The platform is called the NI ELVIS and is shown in Figure 8.20. It includes breadboards, connector interfaces, power supplies, a function generator, and a computer interface that provides access to virtual instruments including a multimeter, a function generator, variable power supplies, and an oscilloscope. The multimeter can be used to measure AC and DC voltage and current as well as resistance, capacitance, inductance, diode function, and continuity. The function generator can output a sine, triangle, or square wave at a frequency from 200 mHz to 5 MHz, and the amplitude can be adjusted from 0 to 10.0 V_{pp} with DC offsets from -5.0 V to 5.0 V. A frequency sweep can also be generated by inputting the desired frequency range, step, and interval. The variable power supply can output between 0 V and 12 V, positive and negative, and generate a voltage sweep. The software interface for the oscilloscope, which is full-featured, is shown in Figure 8.21.

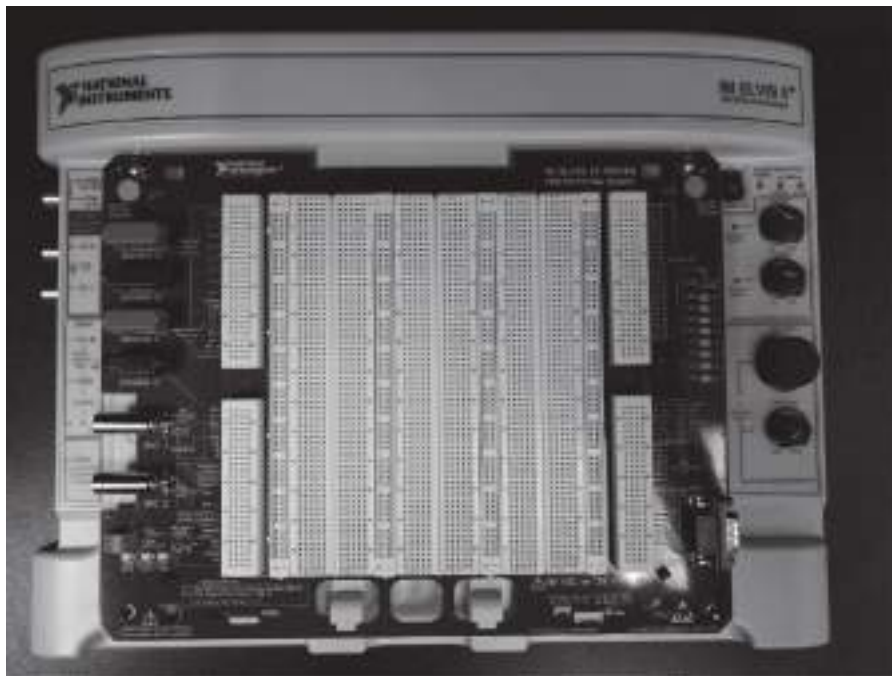


Figure 8.20 NI ELVIS II+ Laboratory Platform

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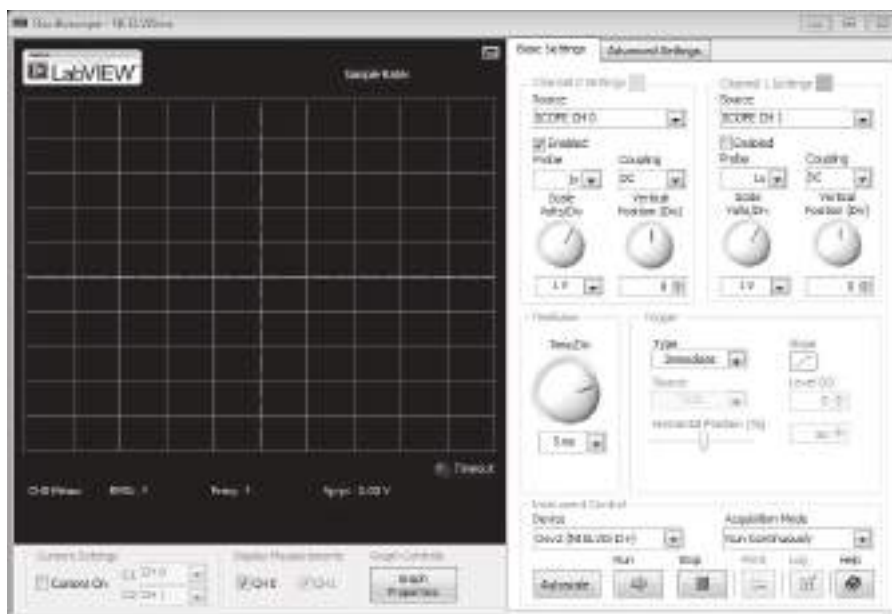


Figure 8.21 NI ELVIS Virtual Oscilloscope.

contributed by David Alciatore

The NI ELVIS is a very useful platform for an educational-laboratory environment where students can easily prototype circuits and take measurements. This is the platform we currently use for the Laboratory Exercises mentioned throughout this book that our students work through in the mechatronics course at Colorado State University. A video demonstration of many of the NI ELVIS features can be viewed online at Video Demo 8.10, and helpful hints and tips documents can be found at Internet Link 8.7. The video provides an introduction to the NI ELVIS hardware and virtual-instrument software, and shows how to use the system to measure voltages and currents in a circuit, how to power a circuit in various ways, how to generate AC signals with the function generator, and how to use the oscilloscope to display an AC signal acquired from a circuit.

8.7 PRACTICAL CONSIDERATIONS

This section introduces detailed procedures required to use the **LabVIEW** software and a USB data acquisition module to sample and display analog signals. Specific tools for sampling, displaying, and replaying audio signals are also presented. Detailed instructions are provided for the National Instruments USB 6009, a specific USB data acquisition module, to show how the software is used in practice. Lab Exercise 12 provides even more detail and explores the effects of sampling rate.

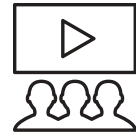
8.7.1 Introduction to LabVIEW Programming

LabVIEW is a user-friendly graphical programming environment. It has many built-in features for data acquisition and works well with many commercial DAC cards and modules. A brief description of the basics of LabVIEW is presented below.

There are two primary windows in LabVIEW, the **Block Diagram** and **Front Panel** window (see Figures 8.22 and 8.23). The Block Diagram window contains the graphical program that you create, and the Front Panel window contains the user interface. The user interface is used to input control parameters, run the program, and visualize the results (e.g., the plot of a waveform).

Additional windows called **palettes** contain the libraries of built-in LabVIEW functions. The **Functions** palette is a library of blocks that can be used in the Block Diagram window (it is only available when the Block Diagram window is active). The **Controls** palette is a library of the functions available for the front panel (it is available only when the Front Panel window is active). The **Tools** palette is used to modify the function of the cursor. Different tools are used to perform different functions. For example, *connect wire*  is used to connect blocks, and *operate value*  is used to change the value of a control (described below). Alternatively, the *automatic tool selection*  will automatically change which tool you are using depending on the location of the cursor.

A LabVIEW VI (pronounced “vee eye”) file is made up of **objects** (or blocks) with connections between the objects. There are two types of objects: **nodes** and **terminals**. The nodes perform functions such as acquiring a digital signal from a data acquisition module, multiplication, and signal processing. Terminals are the connections between



Video Demo

8.10 NI ELVIS
Laboratory Platform
and Virtual
Instrumentation



Internet Link

8.7 NI ELVIS
Laboratory Platform
Tips and Tricks



Lab Exercise

Lab 12 Data
Acquisition

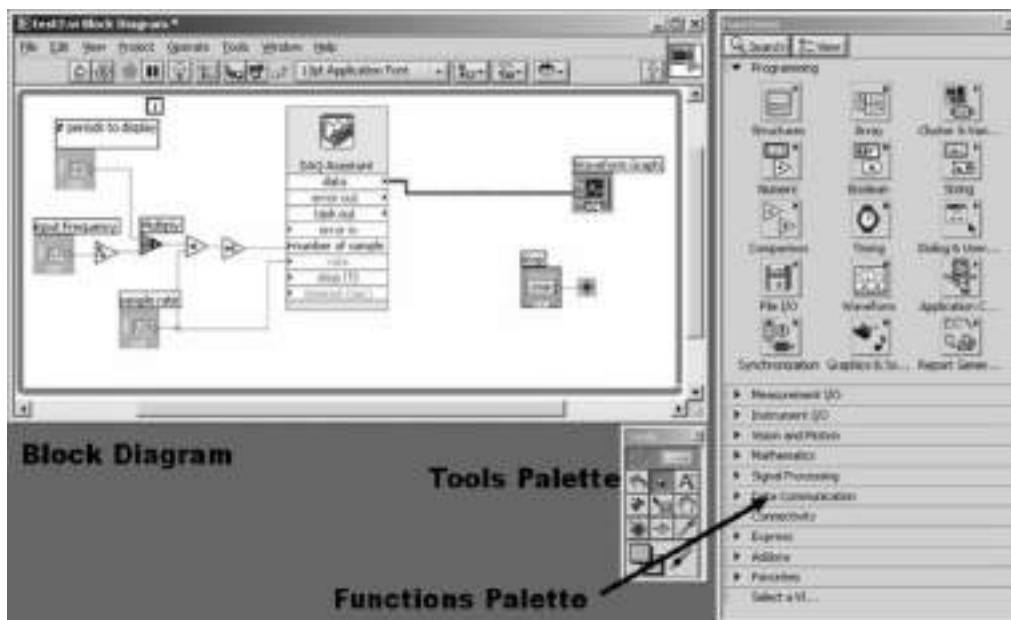


Figure 8.22 Example block diagram.
contributed by David Alciatore

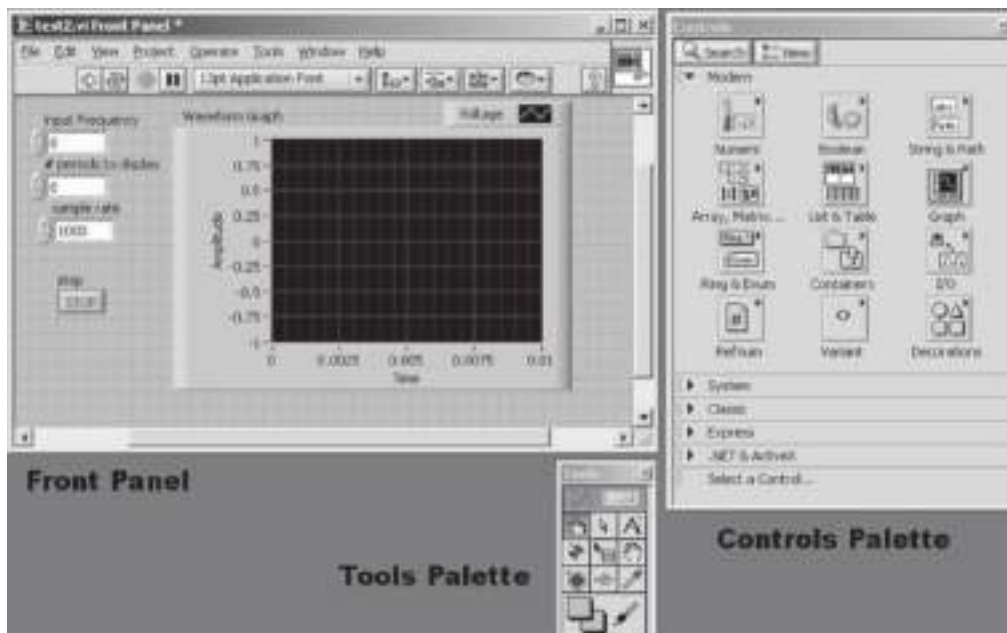


Figure 8.23 Example front panel.
contributed by David Alciatore

the block diagram and the front panel. Everything in the front panel appears as a terminal on the block diagram. Every object has inputs, outputs, and parameters that determine its function. For example, an analog-to-digital conversion block will have an analog signal as its input (hardware input), a digital-value signal as its output, and parameters such as sampling rate. The output of an A/D conversion block can be an input to a block that graphically displays the waveform (terminal). The parameters of a block can be set in different ways. One way is to open the properties window for the block (by right-clicking and selecting properties) and enter the values for the parameters. Some of the parameters cannot be changed independently of other parameters (e.g., parameters that define the configuration or mode of the block) and can be set only within the properties window. The parameters that can be set independently of the others (such as sample rate and number of samples for an A/D converter block) may be set using inputs. This can be done using **constant** or **control** terminals. A constant is set in the block diagram, and a control is set in the front panel. Figure 8.22 contains control blocks on the left labeled *# periods to display*, *input frequency*, and *sample rate*. Figure 8.23 shows the corresponding controls in the front panel. These figures define the VI file to perform A/D conversion using the National Instruments USB 6009 DAC module.

8.7.2 The USB 6009 Data Acquisition Module

The National Instruments USB 6009 is a typical small external data acquisition module that is connected to a computer through a USB port. The device is pictured in Figure 8.24. It has A/D conversion capabilities as well as D/A conversion, digital I/O, and counters/timers. The I/O lines are connected with wire (16-28 AWG) to the detachable screw terminals.

As shown in Tables 8.2 and 8.3, screw terminals 1–16 are used for analog I/O, and terminals 17–32 are used for digital I/O and counter/timer functions. Notice

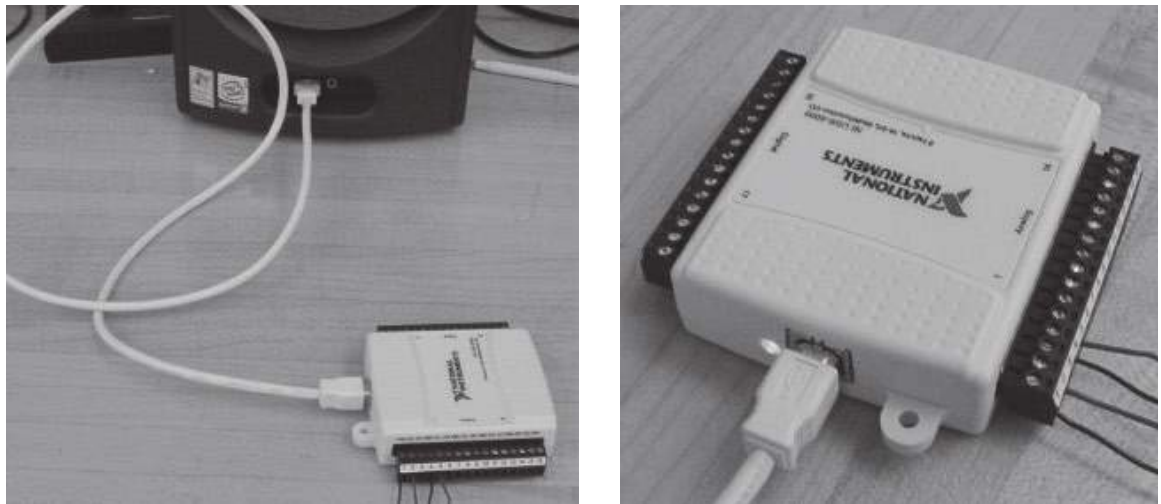


Figure 8.24 The USB 6009 connected to the computer with the screw terminals attached.

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Table 8.2 Analog (1–16) and Digital (17–32) pin assignments of the USB 2009

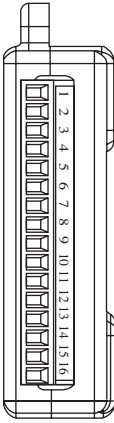
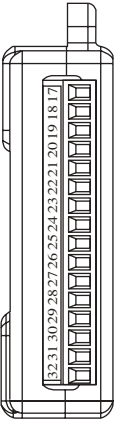
Module	Terminal	Signal, Single-Ended Mode	Signal, Differential Mode
	1	GND	GND
	2	AI 0	AI 0+
	3	AI 4	AI 0–
	4	GND	GND
	5	AI 1	AI 1+
	6	AI 5	AI 1–
	7	GND	GND
	8	AI 2	AI 2+
	9	AI 6	AI 2–
	10	GND	GND
	11	AI 3	AI 3+
	12	AI 7	AI 3–
	13	GND	GND
	14	AO 0	AO 0
	15	AO 1	AO 1
	16	GND	GND
Module	Terminal	Signal	
	17	P0.0	
	18	P0.1	
	19	P0.2	
	20	P0.3	
	21	P0.4	
	22	P0.5	
	23	P0.6	
	24	P0.7	
	25	P1.0	
	26	P1.1	
	27	P1.2	
	28	P1.3	
	29	PFI 0	
	30	+2.5 V	
	31	+5 V	
	32	GND	

Table 8.3 Signal descriptions for the USB 6009

Signal Name	Reference	Direction	Description
GND	—	—	Ground —The reference point for the single-ended AI measurements, bias current return point for differential mode measurements, AO voltages, digital signals at the I/O connector, +5 VDC supply, and the +2.5 VDC reference.
AI <0..7 >	Varies	Input	Analog Input Channels 0 to 7 —For single-ended measurements, each signal is an analog input voltage channel. For differential measurements, AI 0 and AI 4 are the positive and negative inputs of differential analog input channel 0. The following signal pairs also form differential input channels: <AI 1, AI 5 > , <AI 2, AI 6> , and <AI 3, AI 7> .
AO 0	GND	Output	Analog Channel 0 Output —Supplies the voltage output of AO channel 0.
AO 1	GND	Output	Analog Channel 1 Output —Supplies the voltage output of AO channel 1.
P1.<0..3> P0.<0..7>	GND	Input or Output	Digital I/O Signals —You can individually configure each signal as an input or output.
+2.5 V	GND	Output	+2.5 V External Reference —Provides a reference for wrap-back testing.
+5 V	GND	Output	+5 V Power Source —Provides +5 V power up to 200 mA.
PFI 0	GND	Input	PFI 0 —This pin is configurable as either a digital trigger or an event counter input.

that the analog terminals are different depending on which mode the device is in, single-ended mode (also known as RSE) or differential mode. In single-ended mode the positive voltage signal is connected to an AI terminal and the negative voltage or ground signal is connected to a GND terminal. This mode uses two terminals, meaning there are eight analog inputs available (AI0–AI7). The maximum voltage range in this mode is -10V to 10V . Differential mode can be used to get a larger voltage range. This mode measures the difference between two signals, AI+ and AI–, each referenced to GND. A voltage range of -20V to 20V can be achieved, but the maximum voltage on one pin (AI+ or AI–) referenced to ground is $\pm 10\text{V}$. Differential mode uses one more wire than single-ended mode, so only four analog inputs are available in this mode.

Another difference between differential and single-ended mode is the resolution of the analog inputs. Differential mode has a resolution of 14 bits whereas single-ended mode has a resolution of 13 bits.

The analog input converter type is successive approximation, and the maximum sampling rate is 48000 samples per second (kS/s). The device contains one analog-to-digital converter that is multiplexed to each input.

8.7.3 Creating a VI and Sampling Music

This example is based on LabVIEW version 8.0, but should be fairly compatible with previous or later versions. The procedure also assumes that the USB 6009 is already set up to interface with the computer according to the instructions that come with the device.

Opening a blank VI file

1. Start LabVIEW with *Start > Programs > National Instruments > LabVIEW 8.0 > LabVIEW*.
2. Click *Blank VI* to start a new project. The *Block Diagram* window and the *Front Panel* window should appear. If only one is open, then under the *Windows* menu click *Show Block Diagram* or *Show Front Panel*. Some other small windows may also be open.
3. Open the *Functions* palette if it is not open. From the *Block Diagram* window, under the *View* menu, click *Functions palette* to open the *Functions* palette.

Creating node blocks

1. From the *Functions* palette, select *Measurement I/O > NI - DAQmx*. Drag the *DAQ Assist* icon onto the *Block Diagram*. A DAQ Assistant window should appear.
2. Connect the USB 6009 device to the computer. The green light should start blinking. From the DAQ Assistant window, select *Analog Input > Voltage > ai0 > Finish*. If the ai0 does not appear, then press the plus next to “Dev1 (USB-6009)” to display the available analog input channels.
3. A new window will open displaying the properties of the DAQ Assistant block (see next page).



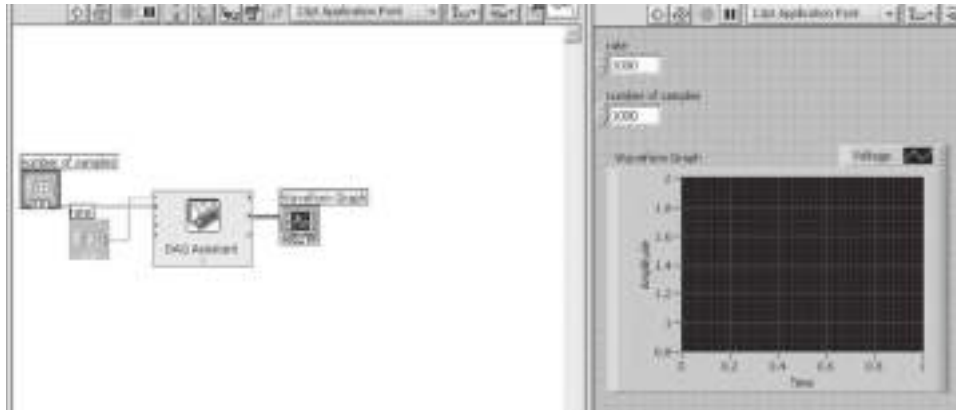
contributed by David Alciatore

4. Under *Settings*, set the maximum and minimum values for the *Signal Input Range* based on the amplitude of the input and the desired quantization size.
5. Under *Settings*, set the *Terminal Configuration* to *RSE* (single-ended mode).
6. Under the *Task Timing* tab, set the acquisition mode to *N samples*. The wiring diagram can be viewed by selecting the *Connection Diagram* tab toward the bottom of the window, assuming an appropriate range was selected ($\text{max} \leq 10$ and $\text{min} \geq -10$).
7. Select *Ok* to close the DAQ Assistant properties window. This may be opened later by right-clicking on the *DAQ Assistant* block.

Creating terminal blocks

1. Select the wire spool icon  from the *Tools* palette (or the automatic icon). Right-click on the *rate* input (arrow on the side of the block) on the *DAQ Assistant* block and select *create > control*. A block labeled *rate* should appear with a wire connected to the *DAQ Assistant* block.
2. Repeat this to create a control for the *number of samples* input. These two controls will appear in the *Front Panel* window.
3. Activate the *Front Panel* window and open the *controls* palette if it is not open. From the *Front Panel* window, under the *View* menu, select *Controls Palette* to open the *Controls* palette.
4. From the *Controls* palette, select *modern > graph* and drag the *Waveform Graph* icon onto the *Front Panel* window. A block labeled “Waveform graph” will appear in the *Block Diagram* window.

5. Right-click on the graph and select *properties*. Under the *Scales* tab select *Amplitude (Y-axis)* in the top pull-down menu. Deselect *Autoscale* and set the maximum and minimum to the values used for the signal input range on the DAQ Assistant block. Click *Ok* to close the properties window.
6. Select the *Block Diagram* window and select the wire spool icon  (or automatic icon) on the *Tools* palette. Click on the *data* output of the *DAQ Assistant* block and then on the *Waveform Graph* block. A wire will now connect the two blocks and it should look like the window below.



contributed by David Alciatore

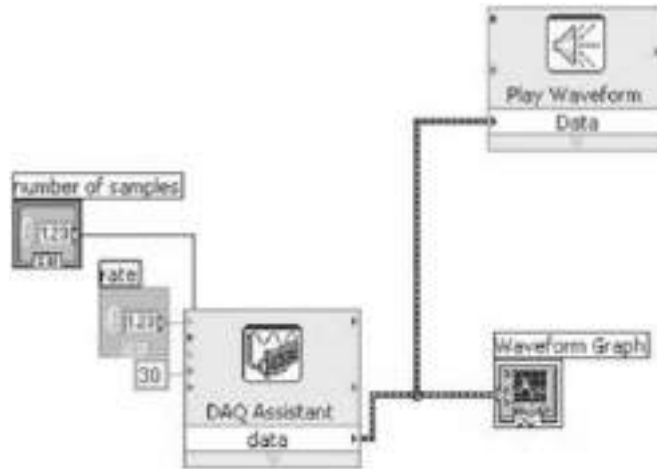
Sampling an analog signal

1. Connect an analog signal to the USB 6009. The positive side is connected to screw terminal 2 (AI0), and the negative side is connected to screw terminal 1 (GND).
2. Select the *Front Panel* window and select the *operate value*  icon from the *Tools* palette (or automatic icon).
3. Set the *rate* and *number of samples* controls to appropriate values.
4. Under the *Operate* menu, select *run* to run the program. A waveform should appear on the *Waveform Graph*. A picture of the waveform can be saved to a file by right-clicking on the waveform and selecting *Data Operations > Export Simplified Image...*

Sampling music

1. Connect the output of an audio device (e.g., speaker wires from an amplifier, or the headphone wires of an MP3 player) to the inputs of the USB 6009.
2. Select a sampling rate of 44,000 kHz (the standard high-fidelity music sampling rate) to capture all audio frequencies without aliasing. Because human hearing is generally limited to the 20 Hz to 20 kHz range, any rate less than or equal to 40,000 (from Shannon's Sampling Theorem) can result in aliasing (poor fidelity).
3. Add the *Play Waveform* block to the block diagram, which can be found in the *Functions* palette: *Programming, Graphics and Sound, Sound, Output*. Press *OK*

when the configuration dialog window appears. Wire the *data* input of the *Play Waveform* block to the *data* output of the *DAQ Assistant* block. Create a constant for the *timeout* input of the *DAQ Assistant* (using the same method used to create a control for the rate input) and set it to 30 (the letter icon will need to be selected from the Tools palette). Setting the timeout to 30 allows up to 30 seconds of music to be recorded. The block diagram should now look like the following figure.



Video Demo

8.5 LabVIEW data acquisition and music sampling

8.7 Music sampling rate and resolution effects



Internet Link

8.8 LabVIEW Graphical Programming online course

4. Sample the music and listen to the recorded waveform.

Video Demo 8.5 demonstrates all of the steps in the process, including the playback of sampled music at different sampling rates. Video Demo 8.7 illustrates the effects of sampling in more detail and also demonstrates the effects of reduced resolution. Excellent online tutorials dealing with various aspects of LabVIEW can be found at Internet Link 8.8.

QUESTIONS AND EXERCISES

Section 8.1 Introduction

- 8.1. Why is it not possible to connect sensors such as thermocouples, strain gages, and accelerometers directly to a digital computer or microprocessor?
- 8.2. Assuming that the bandwidth of an audio music track is 15 kHz, what is the minimum sampling rate necessary to digitize the track with high fidelity for storage on an audio CD?
- 8.3. Suppose you want to digitize the raw signals coming from the following sources:
 - a. thermocouple sensing room temperature
 - b. stereo amplifier output
 What is the minimum sampling frequency that you would choose in each of these cases? Be sure to state and justify any assumptions you make.
- 8.4. Plot two periods of the function $V(t) = \sin(t) + \sin(2t)$ at time intervals corresponding to $1/3$, $2/3$, 2, and 10 times the Nyquist rate. Comment on the results.

- 8.5. Generate plots for the function in Example 8.1 with sample intervals of 0.5 sec, 1 sec, and 10 sec. Explain the results in light of the sampling theorem.
- 8.6. Document a complete and thorough answer to Class Discussion Item 8.2.

Section 8.2 Reconstruction of Sampled Signals

- 8.7. Apply the sinc reconstruction filter technique presented in Section 8.2 to the beat signal in Example 8.1. Sample over two beat frequency cycles at 2.5-times the highest frequency component in the signal. Plot an accurate representation of the beat signal, the sampled representation, and the reconstructed wave.

Section 8.3 Quantizing Theory

- 8.8. Given a 12-bit A/D converter operating over a voltage range from -5 V to 5 V , how much does the input voltage have to change, in general, in order to be detectable?
- 8.9. A signal's values have a range of $\pm 5\text{ V}$, and you wish to make measurements with an analog quantization size no more than 5 mV . What minimum resolution A/D converter is required to perform this task?
- 8.10. If an 8-bit A/D converter with a 0 to 10 V voltage range is used to sample an analog sensor's voltage, what digital output code would correspond to each of the following sensor values:
 - a. 0.0 V
 - b. 1.0 V
 - c. 5.0 V
 - d. 7.5 V

Section 8.4 Analog-to-Digital Conversion

- 8.11. How much computer memory (in bytes) would be required to store 10 seconds of a sensor signal sampled by a 12-bit A/D converter operating at a sampling rate of 5 kHz ?
- 8.12. Derive Equations 8.6 and 8.7 from the truth table in Table 8.1.
- 8.13. Generate a plot similar to Figure 8.14 for a 5-bit converter if the input signal is 2.25 V and the input range is -5 V to 5 V . What is the correct digital output?
- 8.14. As a mechatronic designer moves progressively from an 8-bit to 10-bit to 12-bit A/D converter, what problems might be incurred in the design of the data acquisition system?
- 8.15. Visit Microchip's website (www.microchip.com) and find specifications for the MCP32X series of A/D converters. What is their resolution? What type of architecture is used in obtaining the binary representation of the analog value?
- 8.16. Using the Internet, look up the specifications for the National Semiconductor (www.national.com) ADC0800 8-bit A/D converter. Determine the maximum sampling rate and the method for performing the conversion. Also define each of the inputs and outputs.

Section 8.5 Digital-to-Analog Conversion

- 8.17. Prove Equation 8.15.
- 8.18. Prove Equation 8.16.
- 8.19. Prove Equation 8.17.
- 8.20. Document a complete and thorough answer to Class Discussion Item 8.5.
- 8.21. Document a complete and thorough answer to Class Discussion Item 8.6.

BIBLIOGRAPHY

Datel Intersil, *Data Acquisition and Conversion Handbook*, Mansfield, MA, 1980.

Gibson, G. and Liu, Y., *Microcomputers for Engineers and Scientists*, Prentice Hall, Englewood Cliffs, NJ, 1980.

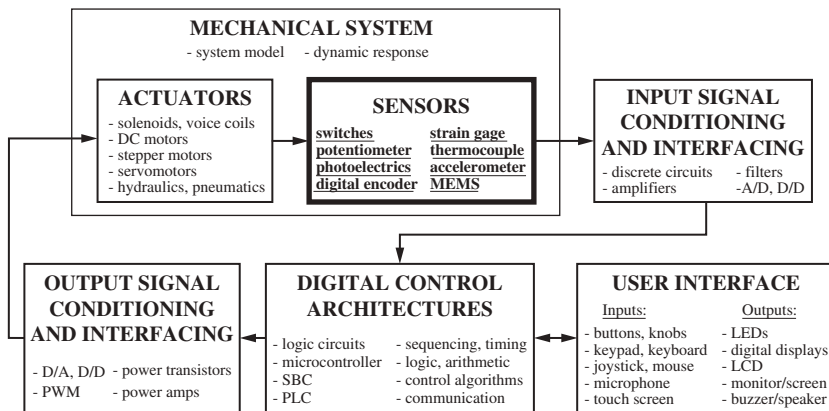
Horowitz, P. and Hill, W., *The Art of Electronics*, 3rd Edition, Cambridge University Press, New York, 2015.

O'Connor, P., *Digital and Microprocessor Technology*, 2nd Edition, Prentice Hall, Englewood Cliffs, NJ, 1989.

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Sensors

This chapter describes various sensors that are important in mechatronic system design. ■



CHAPTER OBJECTIVES

After you read, discuss, study, and apply ideas in this chapter, you will:

1. Understand the fundamentals of simple electromechanical sensors, including proximity sensors and switches, potentiometers, linear variable differential transformers, optical encoders, strain gages, load cells, thermocouples, and accelerometers
2. Be able to describe how natural and binary codes are used to encode linear and rotational position in digital encoders
3. Be able to apply engineering mechanics principles to interpret data from a single strain gage or strain gage rosette

4. Be able to make accurate temperature measurements using thermocouples
5. Know how to measure acceleration and understand the frequency response of accelerometers
6. Understand what a microelectromechanical (MEM) system is

9.1 INTRODUCTION

A **sensor** is an element in a mechatronic or measurement system that detects the magnitude of a physical parameter and converts it into a signal that can be processed by the system. Often the active element of a sensor is referred to as a **transducer**. Monitoring and control systems require sensors to measure physical quantities such as position, distance, force, strain, temperature, vibration, and acceleration. The following sections present devices and techniques for measuring these and other physical quantities.

Sensor and transducer design always involves the application of some law or principle of physics or chemistry that relates the quantity of interest to some measurable event. Appendix B summarizes many of the physical laws and principles that have potential application in sensor and transducer design. Some examples of applications are also provided. This list is useful to a transducer designer who is searching for a method to measure a physical quantity. Practically every transducer applies one or more of these principles in its operation.

Internet Link 9.1 provides links to numerous vendors and online resources for a wide range of commercially available sensors and transducers. The Internet is a good resource for finding the latest products in the mechatronics field. This is especially true for sensors, where new technologies and improvements evolve continuously.



Internet Link

9.1 Sensor online resources and vendors

9.2 POSITION AND SPEED MEASUREMENT

Other than electrical measurements (e.g., voltage, current, and resistance), the most commonly measured quantity in mechatronic systems is position. We often need to know where various parts of a system are in order to control the system. Section 9.2.1 presents proximity sensors and limit switches that are a subset of position sensors that detect whether or not something is close or has reached a limit of travel. Section 9.2.2 presents the potentiometer, which is an inexpensive analog device for measuring rotary or linear position. Section 9.2.3 presents the linear variable differential transformer, which is an analog device capable of accurately measuring linear displacement. Finally, Section 9.2.4 presents the digital encoder, which is useful for measuring a position with an output in digital form suitable for direct interface to a computer or other digital system.

Because most applications involve measuring and controlling shaft rotation (e.g., in robot joints, numerically controlled lathe and mill axes, motors, and

generators), rotary position sensors are more common than linear sensors. Also, linear motion can often be easily converted to rotary motion (e.g., with a belt, gear, or wheel mechanism), allowing the use of rotary position sensors in linear motion applications.

Speed measurements can be obtained by taking consecutive position measurements at known time intervals and computing the time rate of change of the position values. A tachometer is an example of a speed sensor that does this for a rotating shaft.

9.2.1 Proximity Sensors and Switches

A proximity sensor consists of an element that changes either its state or an analog signal when it is close to, but often not actually touching, an object. Many different sensors types are available that operate based on magnetic, capacitive, inductive, ultrasonic, eddy current, or photo-optic effects. For more information about these sensor technologies, and for examples of how they are used, see Internet Links 9.2 through 9.4. Video Demo 9.1 shows an example application for a magnetic proximity sensor.

Photo-optic proximity sensors are very common and use a **photoemitter-detector pair** represents another approach, where interruption or reflection of a beam of light is used to detect an object in a noncontact manner. The emitter can be a laser or focused LED, and the detector is usually a phototransistor or photodiode. Various configurations for photoemitter-detector pairs are illustrated in Figure 9.1. In the opposed and retroreflective configurations, the object interrupts the beam; and in the proximity configuration, the object reflects the beam. Video Demo 9.2 shows an interesting student project example of the proximity configuration. Common applications for proximity sensors and limit switches are detecting the presence of an object (e.g., a man in front of a public urinal), counting moving objects (e.g., passing by on a conveyor belt), and in limiting the traverse of a mechanism (e.g., by detecting the end of travel of a slider or joint).



Internet Link

9.2 Hall effect sensors

9.3 Capacitive proximity sensors

9.4 Inductive proximity sensors



Video Demo

9.1 Magnetic pickup tachometer used in a PID speed controller test-stand

9.2 Automated laboratory rat exercise machine with infrared sensor and stepper motor

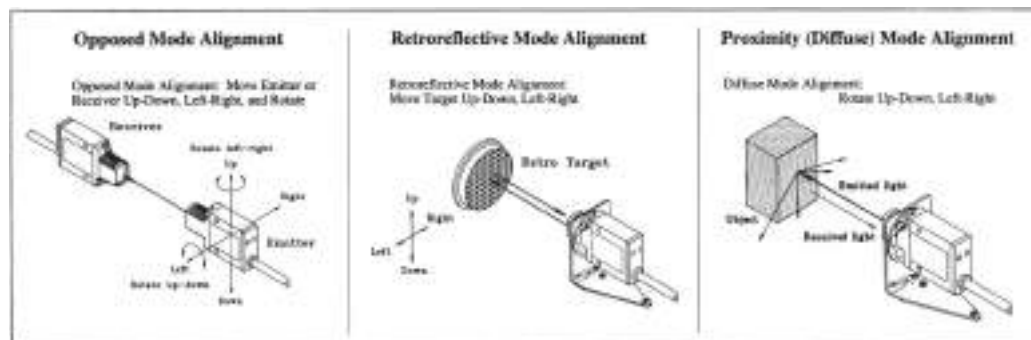


Figure 9.1 Various configurations for photoemitter-detector pairs.

Source: Banner Engineering, Minneapolis, MN.

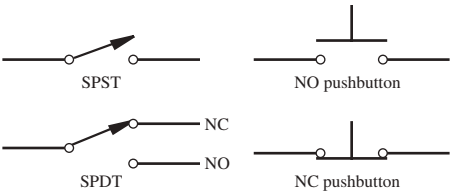


Figure 9.2 Switches.

There are many designs for limit **switches**, including pushbutton and levered microswitches. All switches are used to open or close connections within circuits. As illustrated in Figure 9.2, switches are characterized by the number of poles (P) and throws (T) and whether connections are **normally open** (NO) or **normally closed** (NC). A **pole** is a moving element in the switch that makes or breaks connections, and a **throw** is a contact point for a pole. The SPST switch is a single-pole (SP), single-throw (ST) device that opens or closes a single connection. The SPDT switch changes the pole between two different throw positions. There are many variations on the pole and throw configurations of switches, but their function is easily understood from the basic terminology. Figure 9.3 and Video Demo 9.3 show various types of switches with the appropriate designations. Video Demo 9.4 shows an interesting example of a normally open mercury switch that is used to turn on or off an air conditioning or heating unit when a bimetallic strip coil (see Section 9.4.2) rotates a certain amount. Switch terminology also applies to electromechanical relays (see Section 10.5.4 for more information and examples).



Video Demo

9.3 Switches

9.4 Thermostat with bimetallic strip and mercury switch

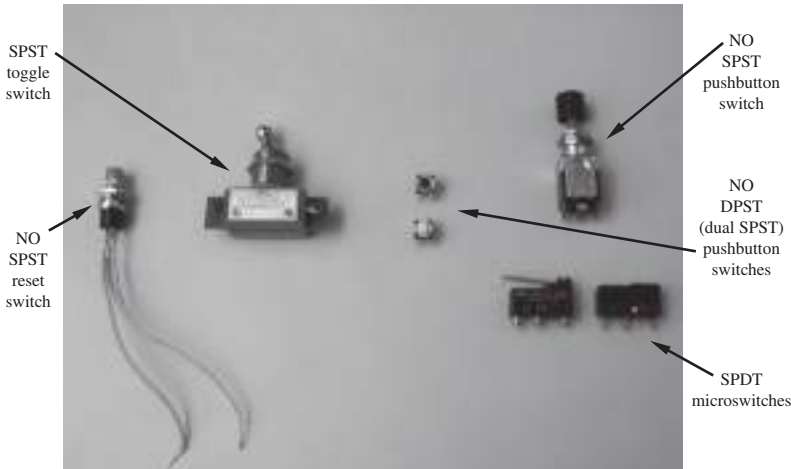


Figure 9.3 Photograph of various types of switches.
©David Alciatore

■ CLASS DISCUSSION ITEM 9.1

Household Three-Way Switch

A household three-way switch is used to allow lights to be controlled from two locations (e.g., at the top and bottom of a stairwell). Note that the term three-way refers to the number of terminals (3) on each switch and not the number of switches (2). A three-way switch is the SPDT variety. Draw a schematic of how AC power and the two switches can be wired to a light fixture to achieve the desired functionality, where either switch can be used to turn the light on or off.

When mechanical switches are opened or closed, they often exhibit switch bounce, where many break-reconnect transitions occur before a new state is established. If a switch is connected to a digital circuit that requires a single transition, the switch output must be debounced using a circuit or software as described in Section 6.10.1.

9.2.2 Potentiometer

The rotary **potentiometer** (aka **pot**) is a variable resistance device that can be used to measure angular position. It consists of a wiper that makes contact with a resistive element, and as this point of contact moves, the resistance between the wiper and end leads of the device changes in proportion to the angular displacement. Figure 9.4 illustrates the form and internal schematic for a typical rotary potentiometer. Figure 9.5 shows two common types of potentiometers. The one on the left is called a **trim pot**. It has a small screw on the left side that can be turned with a screwdriver to accurately make small changes in resistance (i.e. “trim” or adjust the resistance). On the right is a standard rotary pot with a knob allowing a user to easily make adjustments by hand. Through voltage division, the change in resistance of a pot can be used to create an output voltage that is directly proportional to the input displacement. This relationship was derived in Section 4.8. Linear potentiometers are also available, usually in slider form (e.g., the sliders on an audio mixer). They work the same way as rotary potentiometers but measure linear displacement instead.

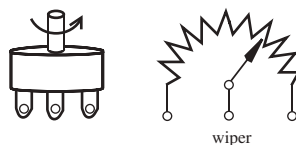


Figure 9.4 Potentiometer.



Figure 9.5 Photograph of a trim pot and a rotary pot.

©David Alciatore

9.2.3 Linear Variable Differential Transformer

The **linear variable differential transformer (LVDT)** is a transducer for measuring linear displacement. As illustrated in Figure 9.6, it consists of primary and secondary windings and a movable iron core. It functions much like a transformer, where voltages are induced in the secondary coil in response to excitation in the primary coil. The LVDT must be excited by an AC signal to induce an AC response in the secondary. The core position can be determined by measuring the secondary response.

With two secondary coils connected in the series-opposing configuration as shown, the output signal describes both the magnitude and direction of the core motion. The primary AC excitation V_{in} and the output signal V_{out} for two different core positions are shown in Figure 9.6. There is a midpoint in the core's position where the voltage induced in each coil is of the same amplitude and 180° out of phase, producing a “null” output. As the core moves from the null position, the output amplitude increases a proportional amount over a linear range around the null as shown in Figure 9.7. Therefore, by measuring the output voltage amplitude, we can easily and accurately determine the magnitude of the core displacement. The output voltage can be slightly out of phase with the excitation voltage, due to inductive impedance effects, but that is not an issue because we are concerned only with the signal amplitude. Internet Link 9.5 points to an interesting animation that illustrates how the output voltage of the LVDT changes with core displacement.



Internet Link

9.5 Animation of LVDT function

To determine the direction of the core displacement, the secondary coils can be connected to a demodulation circuit as shown in Figure 9.8. The diode bridges in this circuit produce a positive or negative rectified sine wave, depending on which side of the null position the core is located (see Class Discussion Item 9.2).

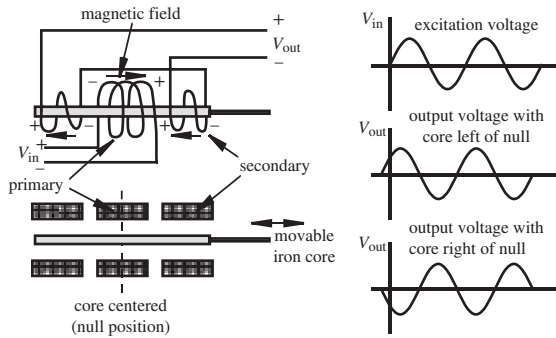


Figure 9.6 Linear variable differential transformer.

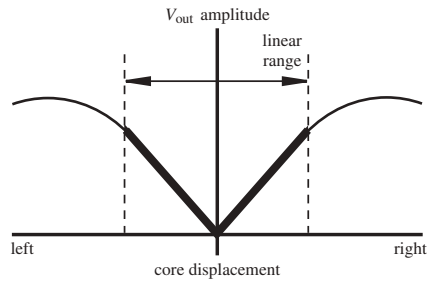


Figure 9.7 LVDT linear range.

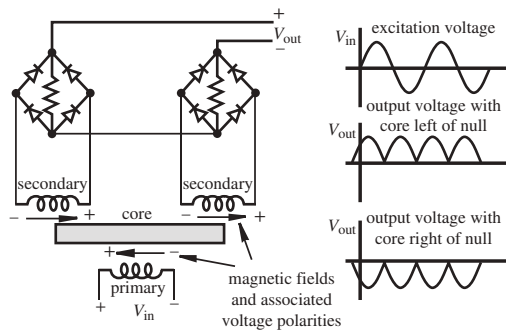


Figure 9.8 LVDT demodulation.

■ CLASS DISCUSSION ITEM 9.2

LVDT Demodulation

Trace the currents through the diodes in the demodulation circuit shown in Figure 9.8 for different core positions (null, left of null, and right of null) and explain why the output voltage behaves as shown. Hint: See Section 3.3.1. Assume ideal diodes. Also, explain why the output is 0 when the core is in the null or center position.

As illustrated in Figure 9.9, a low-pass filter may also be used to convert the rectified output into a smoothed signal that tracks the core position. The cutoff frequency of this low-pass filter must be chosen carefully to filter out the high frequencies in the rectified wave but not the frequency components associated with the core motion. The excitation frequency is usually chosen to be at least 10 times the maximum expected frequency of the core motion to yield a good representation of the time-varying displacement.

Commercial LVDTs, such as the ones shown at Internet Link 9.5, are available in cylindrical forms with different diameters, lengths, and strokes. Often, they include circuitry that provides a DC voltage proportional to displacement.

The advantages of the LVDT are accuracy over the linear range and the analog output that may not require amplification. Also, it is less sensitive to large changes in temperature than other position transducers (e.g., potentiometers, encoders, and semiconductor devices). The LVDT's disadvantages include limited range of motion and limited frequency response. The overall frequency response is limited by inertial effects associated with the core's mass and the choice of the primary excitation frequency and the filter cutoff frequency.

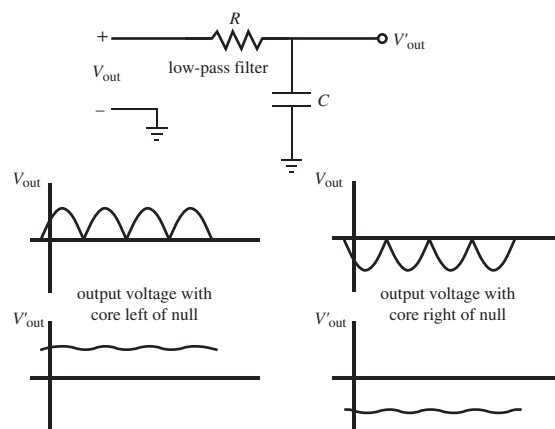


Figure 9.9 LVDT output filter.

■ CLASS DISCUSSION ITEM 9.3

LVDT Signal Filtering

Given the spectrum of a time-varying core displacement, what effect does the choice of the primary excitation frequency have, and how should the low-pass filter be designed to produce an output most representative of the displacement?

A **resolver** is an analog rotary position sensor that operates very much like the LVDT. It consists of a rotating shaft (rotor) with a primary winding and a stationary housing (stator) with two secondary windings offset by 90° . When the primary is excited with an AC signal, AC voltages are induced in the secondary coils, which are proportional to the sine and cosine of the shaft angle. Because of this, the resolver is useful in applications where trigonometric functions of position are required.

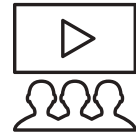
Two other types of linear position sensors that measure linear displacement directly, based on magnetic principles, are the **voice coil** and **magnetostrictive** position transducers. Video Demos 9.5 and 9.6 show two example devices and describe how they work.

9.2.4 Digital Optical Encoder

A **digital optical encoder** is a device that converts motion into a sequence of digital pulses. By counting a single bit or decoding a set of bits, the pulses can be converted to relative or absolute position measurements. Encoders have both linear and rotary configurations, but the most common type is rotary. Rotary encoders are manufactured in two basic forms: the absolute encoder where a unique digital word corresponds to each rotational position of the shaft, and the incremental encoder, which produces digital pulses as the shaft rotates, allowing measurement of relative displacement of the shaft. As illustrated in Figure 9.10, most rotary encoders are composed of a glass or plastic code disk with a printed or photographically-deposited radial pattern organized in tracks. As radial lines in each track interrupt the beam between a photoemitter-detector pair, digital pulses are produced. Digital encoders can also be constructed with magnetic or inductive sensors instead of optical (e.g., using Hall Effect sensors), but these are not as common.

Video Demo 9.7 shows and describes all of the internal components of a small digital optical encoder. In this case the code disk is made of stamped sheet metal. Video Demos 9.8 and 9.9 describe two interesting applications of encoders: a computer mouse and an industrial robot. View Video Demos 1.1 and 1.2 to see a demonstration of how the robot works and how the encoders are incorporated into the internal design. Video Demo 1.5 shows another application of encoders where cost is a major concern and a custom design is necessary.

The optical disk of the **absolute encoder** is designed to produce a digital word that distinguishes N distinct positions of the shaft. For example, if there are eight tracks, the encoder is capable of measuring 256 (2^8) distinct positions corresponding to an angular resolution of 1.406° ($360^\circ/256$). The most common types of numerical encoding used in the absolute encoder are gray and natural binary codes. To illustrate the action of an absolute encoder, the gray code and natural binary code disk track patterns for a simple four-track (4-bit) encoder are illustrated in Figures 9.11 and 9.14. The linear patterns and associated timing diagrams are what



Video Demo

9.5 Voice coil

9.6 Magnetostrictive position sensor



Video Demo

9.7 Encoder components

9.8 Computer mouse relative encoder

9.9 Adept robot digital encoder components

1.1 Adept One robot demonstration (8.0 MB)

1.2 Adept One robot internal design and construction (4.6 MB)

1.5 Inkjet printer components with DC motors and piezoelectric inkjet head

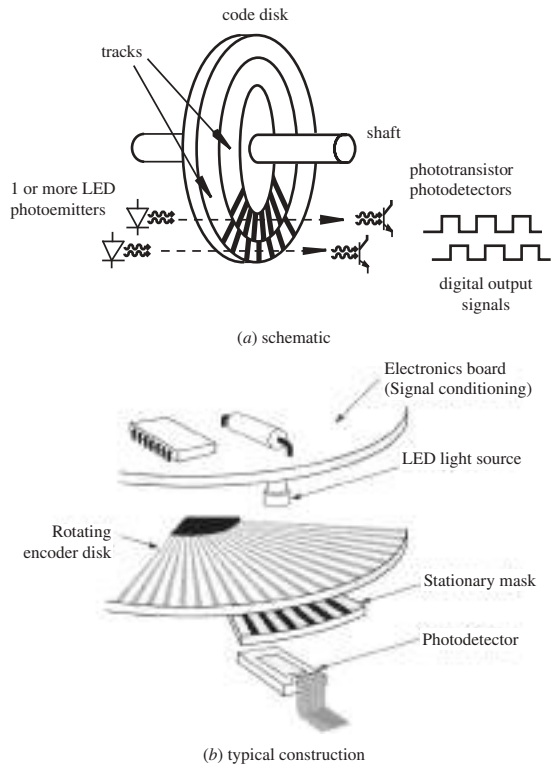


Figure 9.10 Components of an optical encoder.
Source: Lucas Ledex Inc., Vandalia, OH

the photo-detectors sense as the code disk circular tracks rotate with the shaft. The output bit codes for both coding schemes are listed in Table 9.1.

The **gray code** is designed so that only one track (one bit) changes state for each count transition, unlike the binary code where multiple tracks (bits) can change during count transitions. This effect can be seen clearly in Figures 9.11 and 9.12 and in the last two columns of Table 9.1. For the gray code, the uncertainty during a transition is only one count, unlike with the binary code, where the uncertainty could be multiple counts.

■ **CLASS DISCUSSION ITEM 9.4**

Encoder Binary Code Problems

What is the maximum count uncertainty for a 4-bit gray code absolute encoder and a 4-bit natural binary absolute encoder? At what decimal code transitions does the maximum count uncertainty occur in a 4-bit natural binary absolute encoder?

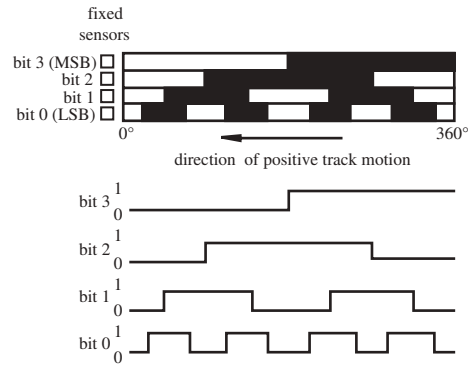
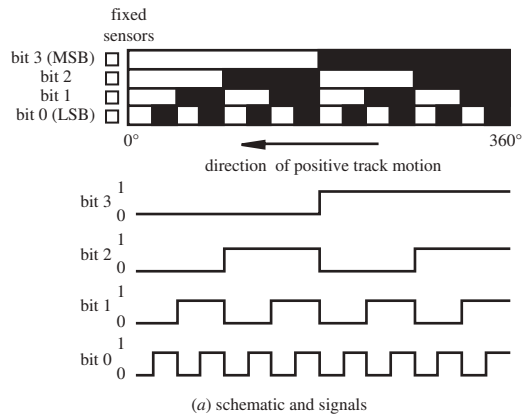


Figure 9.11 4-bit gray code absolute encoder disk track patterns.



(a) schematic and signals



(b) actual disk

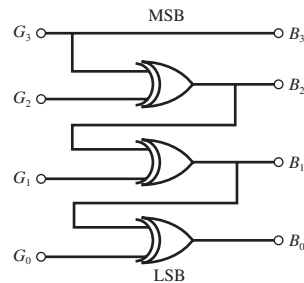
Figure 9.12 4-bit natural binary absolute encoder disk track patterns.

Source: Parker Compumotor Division, Rohnert Park, CA.

Because the gray code provides data with the least uncertainty while the natural binary code is the preferred choice for direct interface to computers and other digital devices, a circuit to convert from gray to binary code is desirable. Figure 9.13 shows a simple circuit that utilizes Exclusive OR (XOR) gates to perform this

Table 9.1 4-bit gray and natural binary codes

Decimal Code	Rotation Range (°)	Natural binary code ($B_3B_2B_1B_0$)	Gray code ($G_3G_2G_1G_0$)
0	0–22.5	0000	0000
1	22.5–45	0001	0001
2	45–67.5	0010	0011
3	67.5–90	0011	0010
4	90–112.5	0100	0110
5	112.5–135	0101	0111
6	135–157.5	0110	0101
7	157.5–180	0111	0100
8	180–202.5	1000	1100
9	202.5–225	1001	1101
10	225–247.5	1010	1111
11	247.5–270	1011	1110
12	270–292.5	1100	1010
13	292.5–315	1101	1011
14	315–337.5	1110	1001
15	337.5–360	1111	1000

**Figure 9.13** Gray-code-to-binary-code conversion.

function. The Boolean expressions that relate the binary bits (B_i) to the gray code bits (G_i) are

$$\begin{aligned}
 B_3 &= G_3 \\
 B_2 &= B_3 \oplus G_2 \\
 B_1 &= B_2 \oplus G_1 \\
 B_0 &= B_1 \oplus G_0
 \end{aligned}
 \tag{9.1}$$

For gray-code-to-binary-code conversion of any number of bits N (e.g., $N = 4$ as previously), the most significant bits of the binary and gray codes are always identical ($B_{N-1} = G_{N-1}$), and for each other bit, the binary bit is the XOR combination: $B_i = B_{i+1} \oplus G_i$ for $i = 0$ to $N - 2$. This pattern can be easily seen in the 4-bit example above (Equations 9.1).

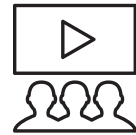
■ CLASS DISCUSSION ITEM 9.5

Gray-to-Binary-Code Conversion

Examine the validity of Equations 9.1 by applying them to the last two columns in Table 9.1.

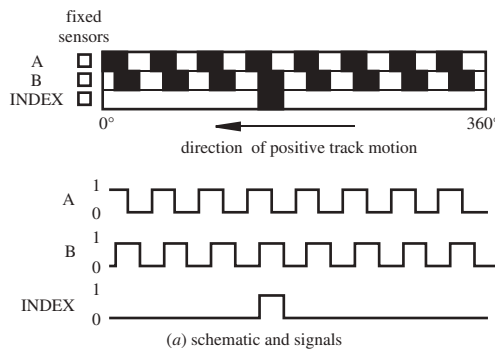
The **incremental encoder**, sometimes called a **relative encoder**, is simpler in design than the absolute encoder. It consists of two tracks and two sensors whose outputs are designated A and B. As the shaft rotates, pulse trains occur on A and B at a frequency proportional to the shaft speed, and the lead-lag phase relationship between the signals yields the direction of rotation as described in detail below. The code disk pattern and output signals A and B are illustrated in Figure 9.14. By counting the number of pulses and knowing the resolution of the disk, the angular motion can be measured. A and B are 1/4 cycle out of phase with each other and are known as **quadrature signals**. Often a third output, called INDEX, yields one pulse per revolution, which is useful in counting full revolutions. It is also useful to define a reference or zero position.

Figure 9.14a illustrates a configuration using two separate tracks for A and B, but a more common configuration uses a single track (see Figure 9.14b and Video Demo 9.7) with the A and B sensors offset a quarter cycle on the track to yield the same signal pattern. A single-track code disk is simpler and cheaper to manufacture.



Video Demo

9.7 Encoder components



(b) actual disk

Figure 9.14 Incremental encoder disk track patterns.

Source: Parker Compumotor Division, Rohnert Park, CA.

The quadrature signals A and B can be decoded to yield angular displacement and the direction of rotation as shown in Figure 9.15. Pulses appear on one of two output lines (CW and CCW) corresponding either to clockwise (CW) rotation or counterclockwise (CCW) rotation. Decoding transitions of A and B using sequential logic circuits can provide three different resolutions: 1X, 2X, and 4X. The 1X resolution provides an output transition at each negative edge of signal A or B, resulting in a single pulse for each quadrature cycle. The 2X resolution provides an output transition at every negative or positive edge of signal A or B, resulting in two times the number of output pulses. The 4X resolution provides an output pulse at every positive and negative edge of signal A or B, resulting in four times the number of output pulses. The direction of rotation is determined by the level of one quadrature signal during an edge transition of the second quadrature signal. For example, in the 1X mode, $A = \downarrow$ with $B = 1$ implies clockwise rotation, and $B = \downarrow$ with $A = 1$ implies counterclockwise rotation. If we only had one signal instead of both A and B, it would be impossible to determine the direction of rotation. Furthermore, shaft jitter around an edge transition in the single signal would result in erroneous pulses (see Class Discussion Item 9.6).

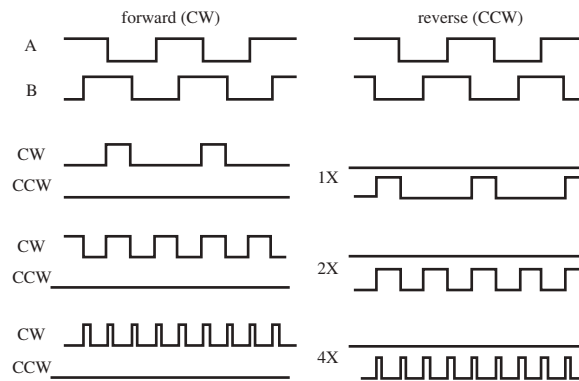


Figure 9.15 Quadrature direction sensing and resolution enhancement.

■ CLASS DISCUSSION ITEM 9.6

Encoder 1X Circuit with Jitter

An incremental encoder connected to a 1X quadrature decoder circuit is experiencing a small rotational vibration with an amplitude roughly equivalent to one quadrature pulse width. During this vibration, you observe many pulses on both the CW and CCW lines but no net change in the output of the up-down counter. Explain why this happens.

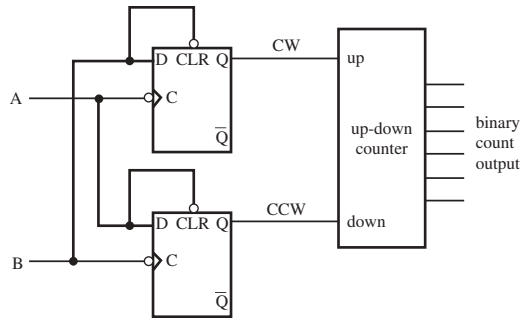


Figure 9.16 1X quadrature decoder circuit.

Figure 9.16 shows a circuit that will yield the 1X resolution by creating and counting pulses at specific negative edges of the quadrature signals. The D flip-flops decode whether the shaft is rotating clockwise or counterclockwise, and this information is used to drive an up-down counter to keep the current pulse count for the encoder rotation. In addition to the edges detected for the 1X resolution, circuits can be designed to detect other edges in the quadrature signals resulting in two times (2X) and four times (4X) the base resolution (1X). These quadrature decoder circuits can be constructed with discrete components, but they are also available on ICs (e.g., Avago Technologies' HCTL-2016). Quadrature decoding can also be done with software running on a microcontroller (Question 9.11).

Incremental encoders provide more resolution at lower cost than absolute encoders, but they measure only relative motion and do not provide absolute position directly. However, an incremental encoder can be used in conjunction with a limit switch to define absolute position relative to a reference position defined by the switch. Absolute encoders are chosen in applications where establishing a reference position is impractical or undesirable.

■ CLASS DISCUSSION ITEM 9.7

Robotic Arm with Encoders

When a robotic arm with absolute encoders on its joints is powered up, the robot knows exactly where its links are relative to its base. If the absolute encoders were replaced with incremental encoders, would this remain true? If not, how would the robot establish a home or zero reference position for the arm?

THREADED DESIGN EXAMPLE

DC motor position and speed controller—Digital encoder interface

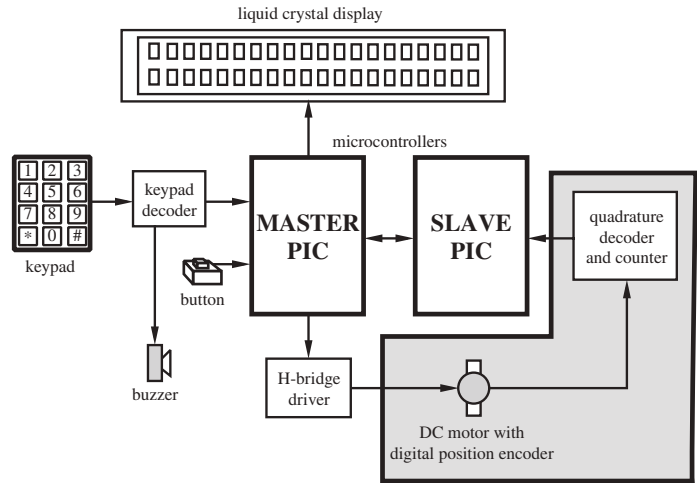
C.4

The figure below shows the functional diagram for Threaded Design Example C (see Section 1.3 and Video Demo 1.8), with the portion described here highlighted.



Video Demo

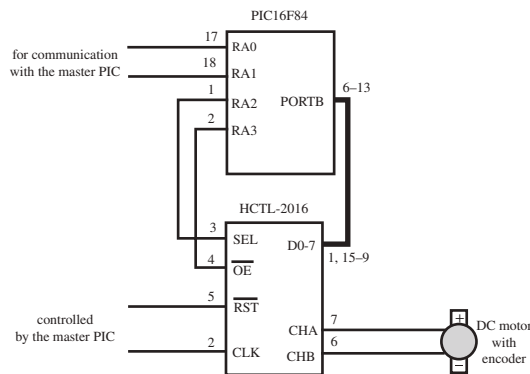
1.8 DC motor position and speed controller



Internet Link

9.6 HCTL/2017 quadrature decoder/counter

The following figure shows all components and interconnections required to read the digital encoder's position from the slave PIC. A commercially available quadrature decoder/counter interface IC, the HCTL-2016, is the main component in the design. Detailed information about this component can be found in the data sheet at Internet Link 9.6. The HCTL-2016 requires a clock signal to operate. In this design, it is provided by a clock output on the master PIC. The master PIC also resets the encoder counter at the appropriate time (via the $\overline{\text{RST}}$ line) to define a zero position. The digital encoder quadrature signals (channels A and B) are also connected to the HCTL-2016. Because the HCTL-2016 contains a 16-bit counter, and the interface to the slave PIC is via the 8-bit PORTB, the data must be retrieved one byte at a time. The thick line connecting PORTB on the PIC to D0-7 on the HCTL-2016 in the wiring diagram indicates multiple wires (in this case, an 8-wire cable). The SEL pin is used to indicate which byte is being read. Finally, the $\overline{\text{OE}}$ pin is used to latch the encoder values before they are read by the PIC.



Shown below is the slave PIC code, which monitors the digital encoder position and transmits the data back to the master PIC upon request. The full code for both PICs is

presented in Threaded Design Example C.3. The serial communication between the PICs is also described there.

```
' Define I/O pin names and constants

enc_start Var PORTA.0      ' signal line used to start encoder data transmission
enc_serial Var PORTA.1     ' serial line used to transmit encoder data
enc_sel Var PORTA.2        ' encoder data byte select (0:high 1:low)
enc_oe Var PORTA.3         ' encoder output enable latch signal (active low)
enc_mode Con 2             ' 9600 baud mode for serial communication

' Main loop
start:
    ' Wait for the start signal from the master PIC to go high
    While (enc_start == 0) : Wend

    ' Enable the encoder output (latch the counter values)
    Low enc_oe

    ' Send out the high byte of the counter
    SEROUT enc_serial, enc_mode, [PORTB]

    ' Wait for the start signal from the master PIC to go low
    While (enc_start == 1) : Wend

    ' Send out the low byte of the counter
    High enc_sel
    SEROUT enc_serial, enc_mode, [PORTB]

    ' Disable the encoder output
    High enc_oe
    Low enc_sel

goto start      ' wait for next request
```

9.3 STRESS AND STRAIN MEASUREMENT

Measurement of stress in a mechanical component is important when assessing whether or not the component is subjected to safe load levels. Stress and strain measurements can also be used to indirectly measure other physical quantities such as force (by measuring strain of a flexural element), pressure (by measuring strain in a flexible diaphragm), and temperature (by measuring thermal expansion of a material). The most common transducer used to measure strain is the electrical resistance strain gage. As we will see, stress values can be determined from strain measurements using principles of solid mechanics.

Basic stress and strain relations and planar stress analysis techniques are presented in Appendix C for your review if necessary.

9.3.1 Electrical Resistance Strain Gage

The most common transducer for experimentally measuring strain in a mechanical component is the bonded metal foil **strain gage** illustrated in Figure 9.17. It consists of a thin foil of metal, usually constantan, deposited as a grid pattern onto a thin plastic backing material, usually polyimide. The foil pattern is terminated at both ends with large metallic pads that allow leadwires to be easily attached with solder. The entire gage is usually very small, typically 5 to 15 mm long.

To measure strain on the surface of a machine component or structural member, the gage is adhesively bonded directly to the component, usually with epoxy or cyanoacrylate. The backing makes the foil gage easy to handle and provides a good bonding surface that also electrically insulates the metal foil from the component. Leadwires are then soldered to the solder tabs on the gage. When the component is loaded, the metal foil deforms, and the resistance changes in a predictable way (see below). If this resistance change is measured accurately, the strain on the surface of the component can be determined. Strain measurements allow us to determine the state of stress on the surface of the component, where stresses typically have their highest values. Knowing stresses at critical locations on a component under load can help a designer validate analytical or numerical results (e.g., from a finite element analysis) and verify that stress levels remain below safe limits for the material (e.g., below the yield strength). It is important to note that, because strain gages are finite in size, a measurement actually reflects an average of the strain over a small area. Hence, making measurements where stress gradients are large (e.g., where there is stress concentration) can yield poor results.

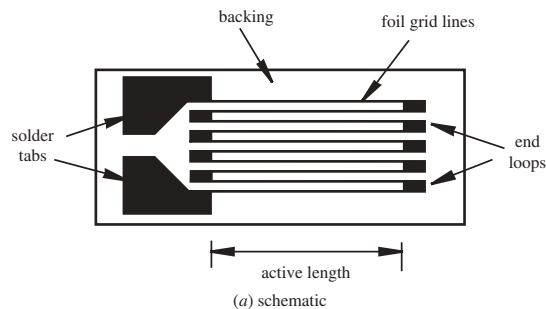


Figure 9.17 Metal foil strain gage construction.

Experimental stress analysis (e.g., with strain gages) and analytical or numerical stress analysis (e.g., with finite element analysis) are both important to design reliable mechanical parts. The two approaches should be considered complements to each other and not replacements. Finite element analysis involves many assumptions about material properties, load application, and boundary conditions that may not accurately model the actual component when it is manufactured and loaded. Strain gage measurements may also have some inaccuracies due to imperfect bonding and alignment on the component surface and due to uncompensated temperature effects. Also, only specific locations can be checked with strain gages because space and access on the component can be limiting factors.

Effects that are easily measured with strain gages but difficult to model with finite element analysis include stresses resulting from mechanical assembly of components and complex loading and boundary conditions. These and other effects are often difficult to predict and model accurately with analytical and numerical methods.

Experimental stress applications usually involve mounting a large number of strain gages on a mechanical component before it is loaded. Experimental strain values are usually acquired through an automated data acquisition system. The strain data can be converted to stresses in the object under different loading conditions, and the stresses can be compared to analytical and numerical finite element analysis results.

To understand how a strain gage is used to measure strain, we first look at how the resistance of the foil changes when deformed. The metal foil grid lines in the active portion of the gage (see Figure 9.17a) can be approximated by a single rectangular conductor as illustrated in Figure 9.18, whose total resistance is given by

$$R = \frac{\rho L}{A} \quad (9.2)$$

where ρ is the foil metal resistivity, L is the total length of the grid lines, and A is the grid-line cross-sectional area. The gage end loops and solder tabs have negligible effects on the gage resistance because they typically have a much larger cross section than the foil lines.

To see how the resistance changes under deformation, we need to take the differential of Equation 9.2. If we first take the natural logarithm of both sides,

$$\ln R = \ln \rho + \ln L - \ln A \quad (9.3)$$

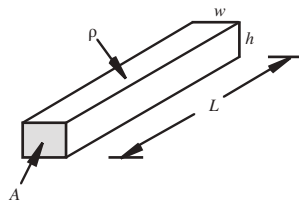


Figure 9.18 Rectangular conductor.

taking the differential yields the following expression for the change in resistance given material property and geometry changes in the conductor:

$$dR/R = d\rho/\rho + dL/L - dA/A \quad (9.4)$$

As we would expect, the signs in this equation imply that the resistance of the conductor increases ($dR > 0$) with increased resistivity and increased length and decreases with increased cross-sectional area. Because the cross-sectional area of the conductor is

$$A = wh \quad (9.5)$$

the area differential term is

$$\frac{dA}{A} = \frac{w \cdot dh + h \cdot dw}{w \cdot h} = \frac{dh}{h} + \frac{dw}{w} \quad (9.6)$$

From the definition of Poisson's ratio (see Appendix C),

$$\frac{dh}{h} = -\nu \frac{dL}{L} \quad (9.7)$$

and

$$\frac{dw}{w} = -\nu \frac{dL}{L} \quad (9.8)$$

so

$$\frac{dA}{A} = -2\nu \frac{dL}{L} = -2\nu \epsilon_{\text{axial}} \quad (9.9)$$

where ϵ_{axial} is the axial strain in the conductor (see Appendix C). When the conductor is elongated ($\epsilon_{\text{axial}} > 0$), the cross-sectional area decreases ($dA/A < 0$), causing the resistance to increase.

Using Equation 9.9, Equation 9.4 can be expressed as

$$dR/R = \epsilon_{\text{axial}}(1 + 2\nu) + d\rho/\rho \quad (9.10)$$

Dividing through by ϵ_{axial} gives the percentage change in resistance as a percentage of axial strain:

$$\frac{dR/R}{\epsilon_{\text{axial}}} = 1 + 2\nu + \frac{d\rho/\rho}{\epsilon_{\text{axial}}} \quad (9.11)$$

The first two terms on the right-hand side, 1 and 2ν , represent the change in resistance due to increased length and decreased area. The last term $(d\rho/\rho)/(\epsilon_{\text{axial}})$ represents the **piezoresistive effect** in the material, which explains how the resistivity of the material changes with strain. All three terms are approximately constant over the operating range of typical strain gage metal foils.

Commercially available strain gage specifications usually report a constant **gage factor F** to represent the right-hand side of Equation 9.11. This factor represents the material characteristics of the gage that relate the gage's change in resistance to strain:

$$F = \frac{\Delta R/R}{\epsilon_{\text{axial}}} \quad (9.12)$$

Thus, when a gage of known resistance R and gage factor F is bonded to the surface of a component and the component is then loaded, we can determine the strain in the gage ϵ_{axial} simply by measuring the change in resistance of the gage ΔR :

$$\epsilon_{\text{axial}} = \frac{\Delta R/R}{F} \quad (9.13)$$

This gage strain is the strain on the surface of the loaded component in the direction of the gage's longitudinal dimension.

For the bonded metal foil strain gage, the gage factor F is usually close to 2, and the gage resistance R is close to 120 Ω . Strain gage suppliers also report a **transverse sensitivity** for the gage, which is a measure of the resistance changes in the end loops and grid lines due to strain in the transverse direction. The transverse sensitivity for a bonded metal foil gage is usually close to 1%. This number predicts the gage's sensitivity to transverse strains: those perpendicular to the measuring axis of the gage. A gage experiencing 50 $\mu\epsilon$ (50×10^{-6} , read as “50 microstrain”) in the axial direction and 100 $\mu\epsilon$ in the transverse direction with a transverse sensitivity of 1% will sense 51 $\mu\epsilon$ ($50 + 1\%$ of 100), not 50 $\mu\epsilon$.

Strain Gage Resistance Changes

EXAMPLE 9.1

If a 120 Ω strain gage with gage factor 2.0 is used to measure a strain of 100 $\mu\epsilon$ (100×10^{-6}), how much does the resistance of the gage change from the unloaded state to the loaded state?

Equation 9.12 tells us that

$$\Delta R = R \cdot F \cdot \epsilon$$

so the change in resistance would be

$$\Delta R = (120 \Omega)(2.0)(0.000100) = 0.024 \Omega$$

■ CLASS DISCUSSION ITEM 9.8

Piezoresistive Effect in Strain Gages

For a typical metal foil strain gage with a gage factor of 2.0, how large is the piezoresistive effect in comparison to the effects of change in area and change in length?

9.3.2 Measuring Resistance Changes with a Wheatstone Bridge

To use strain gages to accurately measure strains experimentally, we need to be able to accurately measure small changes in resistance. The most common circuit used to do this is the Wheatstone bridge, which consists of a four-resistor network excited by a DC voltage. A Wheatstone bridge is better than a simple voltage divider because it can be easily balanced to establish an accurate zero position, it allows temperature compensation, and it can provide better sensitivity and accuracy. There are two different modes of operation of a Wheatstone bridge circuit: the static balanced mode and the dynamic unbalanced mode. For the **static balanced mode**, illustrated in Figure 9.19, R_2 and R_3 are precision resistors, R_4 is a precision potentiometer (variable resistor) with an accurate scale for displaying the resistance value, and R_1 is the strain gage resistance for which the change is to be measured. To balance the bridge, the variable resistor is adjusted until the voltage between nodes A and B is 0. In the balanced state, the voltages at A and B must be equal so

$$i_1 R_1 = i_2 R_2 \quad (9.14)$$

Also, because the high-input impedance voltmeter (Hi Z VM) between A and B is assumed to draw no current,

$$i_1 = i_4 = \frac{V_{\text{ex}}}{R_1 + R_4} \quad (9.15)$$

and

$$i_2 = i_3 = \frac{V_{\text{ex}}}{R_2 + R_3} \quad (9.16)$$

where V_{ex} is the DC voltage applied to the bridge called the **excitation voltage**. Substituting these expressions into Equation 9.14 and rearranging gives

$$\frac{R_1}{R_4} = \frac{R_2}{R_3} \quad (9.17)$$

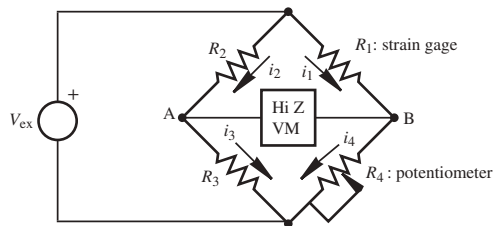


Figure 9.19 Static balanced bridge circuit.

If we know R_2 and R_3 accurately and we note the value for R_4 on the precision potentiometer scale, we can accurately calculate the unknown resistance R_1 as

$$R_1 = \frac{R_4 R_2}{R_3} \quad (9.18)$$

Note that this result is independent of the excitation voltage, V_{ex} (see Class Discussion Item 9.9).

The static balanced mode of operation can be used to measure a gage's resistance under fixed load, but usually balancing is done only as a preliminary step to measuring changes in gage resistance. In **dynamic deflection operation** (see Figure 9.20), again with R_1 representing a strain gage and R_4 representing a potentiometer, the bridge is first balanced, before loads are applied, by adjusting R_4 until there is no output voltage. Then changes in the strain gage resistance R_1 that occur under time-varying load can be determined from changes in the output voltage.

The output voltage can be expressed in terms of the resistor currents as

$$V_{\text{out}} = i_1 R_1 - i_2 R_2 = -i_1 R_4 + i_2 R_3 \quad (9.19)$$

and the excitation voltage can be related to the currents:

$$V_{\text{ex}} = i_1(R_1 + R_4) = i_2(R_2 + R_3) \quad (9.20)$$

Solving for i_1 and i_2 in terms of V_{ex} in Equation 9.20 and substituting these into the first expression in Equation 9.19 gives

$$V_{\text{out}} = V_{\text{ex}} \left(\frac{R_1}{R_1 + R_4} - \frac{R_2}{R_2 + R_3} \right) \quad (9.21)$$

When the bridge is balanced, V_{out} is 0 and R_1 has a known value. When R_1 changes value, as the strain gage is loaded, Equation 9.21 can be used to relate this voltage change ΔV_{out} to the change in resistance ΔR_1 . To find this relation, we can replace R_1 by its new resistance $R_1 + \Delta R_1$ and V_{out} by the output deflection voltage ΔV_{out} . Then Equation 9.21 gives

$$\frac{\Delta V_{\text{out}}}{V_{\text{ex}}} = \frac{R_1 + \Delta R_1}{R_1 + \Delta R_1 + R_4} - \frac{R_2}{R_2 + R_3} \quad (9.22)$$

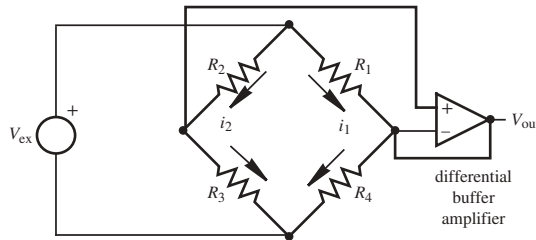


Figure 9.20 Dynamic unbalanced bridge circuit.

Rearranging this equation gives us the desired relation between the change in resistance and the measured output voltage:

$$\frac{\Delta R_1}{R_1} = \frac{\frac{R_4}{R_1} \left(\frac{\Delta V_{\text{out}}}{V_{\text{ex}}} + \frac{R_2}{R_2 + R_3} \right)}{\left(1 - \frac{\Delta V_{\text{out}}}{V_{\text{ex}}} - \frac{R_2}{R_2 + R_3} \right)} - 1 \quad (9.23)$$

By measuring the change in the output voltage ΔV_{out} , we can determine the gage resistance change ΔR_1 from Equation 9.23 and compute the gage strain from Equation 9.13. The differential buffer amplifier shown in Figure 9.20 provides high input impedance (i.e., it does not load the bridge) and high gain for the small change in voltage due to the small change in resistance.

A Wheatstone bridge can be used to measure a physical quantity of interest with any resistance-change-based sensor (not just a strain gage). For example, a thermistor's resistance changes with temperature, a photoresistor's resistance changes with light intensity, some pressure sensors and accelerometers detect resistance changes, and some inexpensive force and flex sensors use conductive-ink elements that change resistance with applied pressure or deformation. All of these sensors use resistance change to measure the quantity of interest, and the Wheatstone bridge works just as effectively as with a strain gage. Also, a Wheatstone bridge containing capacitors or inductors instead of resistors can be used to measure capacitance or inductance changes in sensors that rely on these effects (e.g., some position and proximity sensors, and some accelerometers). With this type of bridge, an AC excitation voltage of suitable frequency is used instead of a DC voltage input, and the component value changes are detected by measuring output signal magnitude and phase changes.

■ CLASS DISCUSSION ITEM 9.9

Wheatstone Bridge Excitation Voltage

What undesirable effects can the magnitude of the excitation voltage have on the resistance change measurements made with a Wheatstone bridge?

Figure 9.21 illustrates the effects of leadwires when using a strain gage located far from the bridge circuit. Figure 9.21a illustrates a two-wire connection from a strain gage to a bridge circuit. With this configuration, each of the leadwire resistances R' adds to the resistance of the strain gage branch of the bridge. The problem with this is that, if the leadwire temperature changes, it causes changes in the resistance of the bridge branch. This effect can be substantial if the leadwires are long and extend through environments where the temperature changes. Figure 9.21b illustrates a three-wire connection that solves this problem. With this configuration, equal leadwire resistances are added to adjacent branches in the bridge so the effects of changes in the leadwire resistances offset each other. The third leadwire is connected to the high-input impedance voltage measuring circuit, and its resistance has a negligible effect because it carries negligible current. The three wires are usually in the form of a small ribbon cable to ensure they experience the same temperature changes and to minimize electromagnetic interference due to inductive coupling. Figure 9.22 shows an actual mounted gage with a three-wire connection.

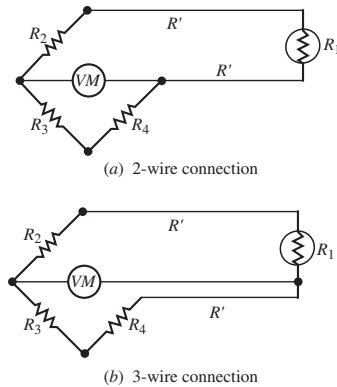


Figure 9.21 Leadwire effects in 1/4 bridge circuits.



Figure 9.22 Mounted gage with three-wire connection.
Courtesy of Measurements Group Inc., Raleigh, NC

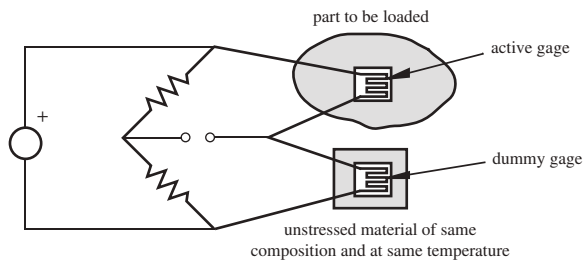


Figure 9.23 Temperature compensation with a dummy gage in a half bridge circuit.

■ CLASS DISCUSSION ITEM 9.10

Bridge Resistances in Three-Wire Bridges

What must be true about the bridge resistance R_4 for the three-wire configuration shown in Figure 9.21b to result in a balanced bridge ($V_o = 0$) in the no-strain condition? (Hint: Use Equation 9.21 and assume $R_2 = R_3$.)

In addition to temperature effects in leadwires, temperature changes in the part beneath the strain gage can cause significant changes in resistance, which would lead to erroneous measurements. A convenient method for eliminating this effect is to use the circuit (called a half bridge) illustrated in Figure 9.23, where two of the

four bridge legs contain strain gages. The gage in the top branch is the active gage used to measure surface strains on a component to be loaded. The second “dummy” gage is mounted to an unloaded sample of material identical in composition to the component. If this sample is kept at the same temperature as the component by keeping it in close proximity, the resistance changes in the two gages due to temperature cancel because they are in adjacent branches of the bridge circuit. Therefore, the bridge generates an unbalanced voltage only in response to strain in the active gage.

9.3.3 Measuring Different States of Stress with Strain Gages

Mechanical components may have complex shapes and are often subjected to complex loading conditions. In these cases, it is difficult to predict the orientation of principal stresses at arbitrary points on the component. However, with some geometries and loading conditions, the principal axes are known, and measuring the state of stress is easier.

If a component is loaded uniaxially (i.e., loaded in only one direction in tension or compression), the state of stress in the component can be determined with a single gage mounted in the direction of the load. Figure 9.24 illustrates a bar in tension and the associated state of stress. By measuring the strain ϵ_x , the stress is obtained using Hooke’s law (see Appendix C):

$$\sigma_x = E \epsilon_x \quad (9.24)$$

where the axial stress σ_x is given by

$$\sigma_x = \frac{P}{A} \quad (9.25)$$

where A is the bar’s cross-sectional area. Therefore, the force P applied to the bar can be determined from the strain gage measurement:

$$P = AE \epsilon_x \quad (9.26)$$

If a component is known to be loaded biaxially (i.e., loaded in two orthogonal directions in tension or compression), the state of stress in the component can be determined with two gages aligned with the stress directions. Figure 9.25 illustrates a pressurized tank and the associated state of stress. By measuring the strains ϵ_x and ϵ_y , the stresses in the tank shell can be determined from Hooke’s law generalized to two dimensions:

$$\epsilon_x = \frac{\sigma_x}{E} - \nu \frac{\sigma_y}{E} \quad (9.27)$$

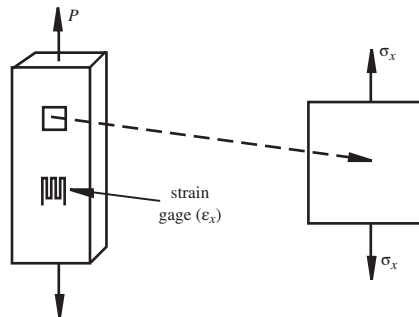


Figure 9.24 Bar under uniaxial stress.

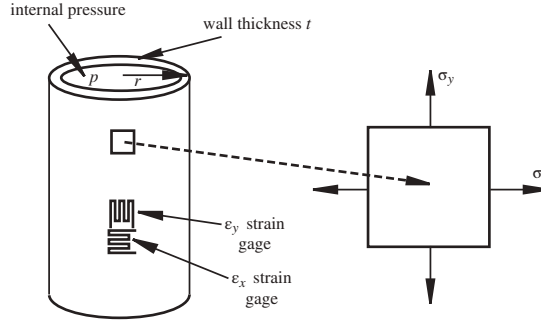


Figure 9.25 Biaxial stress in a long, thin-walled pressure vessel.

$$\epsilon_y = \frac{\sigma_y}{E} - \nu \frac{\sigma_x}{E} \quad (9.28)$$

Solving for the stress components gives

$$\sigma_x = \frac{E}{1 - \nu^2}(\epsilon_x + \nu\epsilon_y) \quad (9.29)$$

$$\sigma_y = \frac{E}{1 - \nu^2}(\epsilon_y + \nu\epsilon_x) \quad (9.30)$$

For a thin-walled pressure vessel (i.e., $t/r < 1/10$), the stresses are approximated by

$$\sigma_x = \frac{pr}{t} \quad \sigma_y = \frac{pr}{2t} \quad (9.31)$$

where p is the internal pressure, t is the wall thickness, and r is the mean radius of the vessel. The stress σ_x is the transverse or hoop stress, and σ_y is the axial or longitudinal stress. Either Equation 9.29 or 9.30 can be used to compute the pressure in the vessel based on the strain gage measurements, yielding

$$p = \frac{t\sigma_x}{r} = \frac{tE}{r(1 - \nu^2)}(\epsilon_x + \nu\epsilon_y) \quad (9.32)$$

or

$$p = \frac{2t\sigma_y}{r} = \frac{2tE}{r(1 - \nu^2)}(\epsilon_y + \nu\epsilon_x) \quad (9.33)$$

Either expression would yield the correct pressure value for an ideal thin-walled vessel and error-free measurements. In this example, the strain gages are serving as a pressure transducer.

For uniaxial and biaxial loading, we already know the directions of principal stresses in the component; hence, we need only one or two gages, respectively, to determine the stress magnitudes. However, when the loading is more complex or when the geometry is more complex, which is often the case in mechanical design, we have to use three gages mounted in three different directions as illustrated in Figure 9.26. This assembly of strain gages is referred to as a **strain gage rosette**.

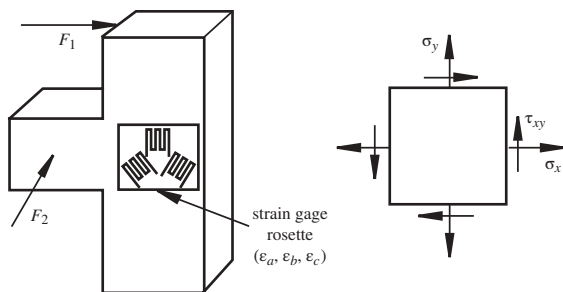


Figure 9.26 General state of planar stress on the surface of a component.



Figure 9.27 Assortment of different strain gage and rosette configurations.
Courtesy of Measurements Group Inc., Raleigh, NC

There is a wide variety of commercially available rosettes with two or more grid patterns accurately oriented on a single backing in close proximity. An assortment of rosettes and single-element gages illustrating the variety of shapes and sizes is shown in Figure 9.27.

The most common rosette patterns for measuring a general state of planar stress are illustrated in Figure 9.29, where the grids are shown as single lines labeled by letters. Of these, the rectangular strain gage is the most common configuration, where the strain gages are positioned 45° apart (see Figure 9.29). Figure 9.30 shows several commercially available three-gage rosettes.

Using principles of solid mechanics, the magnitude and direction of the principal stresses can be determined directly from three simultaneous strain measurements using any of the rosette patterns shown in Figure 9.28. The magnitude and direction of the principal stresses for the rectangular rosette are

$$\sigma_{\max, \min} = \frac{E}{2} \left[\frac{\epsilon_a + \epsilon_c}{1 - \nu} \pm \frac{1}{1 + \nu} \sqrt{2(\epsilon_a - \epsilon_b)^2 + 2(\epsilon_b - \epsilon_c)^2} \right] \quad (9.34)$$

$$\tau_{\max} = \frac{E}{2(1 + \nu)} \sqrt{2(\epsilon_a - \epsilon_b)^2 + 2(\epsilon_b - \epsilon_c)^2} \quad (9.35)$$

$$\tan 2\theta_p = \frac{2\epsilon_b - \epsilon_a - \epsilon_c}{\epsilon_a - \epsilon_c} \quad (9.36)$$

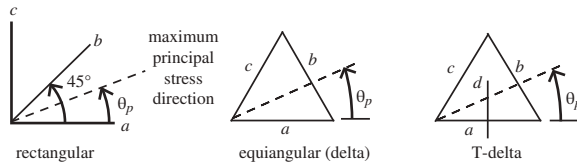


Figure 9.28 Most common strain gage rosette configurations.

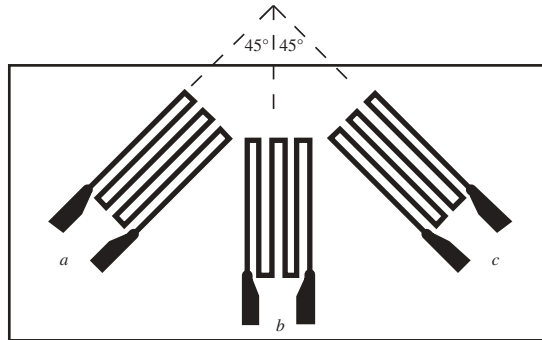


Figure 9.29 Rectangular strain gage rosette.

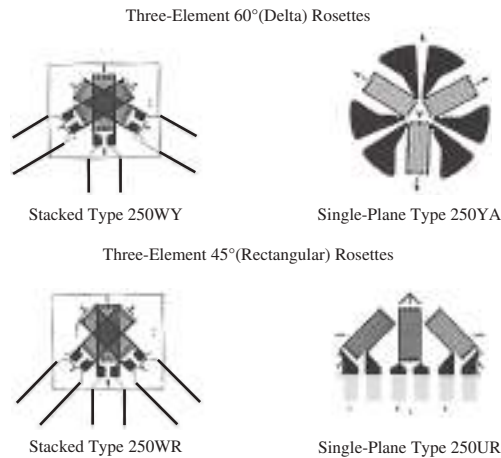


Figure 9.30 Various three-gage commercial rosettes.

Source: Measurements Group Inc., Raleigh, NC.

where ϵ_a , ϵ_b , and ϵ_c are the strains in each of the rosette gages, and θ_p is the angle from gage “a” to the direction of maximum principal stress. When using Equation 9.36 to calculate θ_p , you must use a quadrant-sensitive inverse tangent. If the numerator is positive ($\epsilon_b > (\epsilon_a + \epsilon_c)/2$), $2\theta_p$ lies in the first or second quadrant

so $0 < \theta_p < 90^\circ$. Otherwise, $2\theta_p$ lies in the third or fourth quadrant resulting in $-90^\circ < \theta_p < 0$.

The relations for the equiangular (delta) rosette are

$$\sigma_{\max, \min} = \frac{E}{3} \left[\frac{\epsilon_a + \epsilon_b + \epsilon_c}{1 - \nu} \pm \frac{1}{1 + \nu} \sqrt{2(\epsilon_a - \epsilon_b)^2 + 2(\epsilon_b - \epsilon_c)^2 + 2(\epsilon_c - \epsilon_a)^2} \right] \quad (9.37)$$

$$\tau_{\max} = \frac{E}{3(1 + \nu)} \sqrt{2(\epsilon_a - \epsilon_b)^2 + 2(\epsilon_b - \epsilon_c)^2 + 2(\epsilon_c - \epsilon_a)^2} \quad (9.38)$$

$$\tan 2\theta_p = \frac{\sqrt{3}(\epsilon_c - \epsilon_b)}{2\epsilon_a - \epsilon_b - \epsilon_c} \quad (9.39)$$



Lab Exercise

Lab 13 Strain gages

If the numerator in Equation 9.39 is positive ($\epsilon_c > \epsilon_b$), $2\theta_p$ lies in the first or second quadrant so $0 < \theta_p < 90^\circ$. Otherwise, $2\theta_p$ lies in the third or fourth quadrant resulting in $-90^\circ < \theta_p < 0$.

The relations for the T-delta rosette, which has four gages, are

$$\sigma_{\max, \min} = \frac{E}{2} \left[\frac{\epsilon_a + \epsilon_d}{1 - \nu} \pm \frac{1}{1 + \nu} \sqrt{(\epsilon_a - \epsilon_d)^2 + \frac{4}{3}(\epsilon_b - \epsilon_c)^2} \right] \quad (9.40)$$

$$\tau_{\max} = \frac{E}{2(1 + \nu)} \sqrt{(\epsilon_a - \epsilon_d)^2 + \frac{4}{3}(\epsilon_b - \epsilon_c)^2} \quad (9.41)$$

$$\tan 2\theta_p = \frac{2(\epsilon_c - \epsilon_b)}{\sqrt{3}(\epsilon_a - \epsilon_d)} \quad (9.42)$$

If the numerator in Equation 9.42 is positive ($\epsilon_c > \epsilon_b$), $2\theta_p$ lies in the first or second quadrant so $0 < \theta_p < 90^\circ$. Otherwise, $2\theta_p$ lies in the third or fourth quadrant resulting in $-90^\circ < \theta_p < 0$.

Lab Exercise 13 explores how to use a strain gage rosette and commercial strain gage instrumentation to make strain measurements. These measurements are used to compute corresponding stresses that can be compared to expected theoretical results. Video Demo 9.10 shows a demonstration of the experiment, Internet Link 9.7 points to a PDF file containing the underlying analysis with the theoretical results, and Video Demo 9.11 discusses the results of the analysis.



Video Demo

9.10 Strain gage rosette experiment

9.11 Strain gage rosette experiment analysis discussion



Internet Link

9.7 Strain gage rosette experiment analysis

■ CLASS DISCUSSION ITEM 9.11

Strain Gage Bond Effects

Does a strain gage bonded to a component have any influence on the stresses that are being measured? If so, how? In what cases are these effects significant?



(a) Courtesy of MTS Systems Corp., Minneapolis, MN



(b) Courtesy of Transducer Techniques, Temecula, CA

Figure 9.31 Typical axial load cells.

9.3.4 Force Measurement with Load Cells

A load cell is a sensor used to measure force. It contains an internal flexural element, usually with several strain gages mounted on its surface. The flexural element's shape is designed so that the strain gage outputs can be easily related to the applied force. The load cell is usually connected to a bridge circuit to yield a voltage proportional to the load. Two commercial load cells, which are used to measure uniaxial force, are shown in Figure 9.31. An example of the application of load cells is in commercially available laboratory materials testing machines for measuring forces applied to a test specimen. Load cells are also used in weight scales, and they are sometimes included as integral parts of mechanical structures to monitor forces in the structures.

A Strain Gage Load Cell for an Exteriorized Skeletal Fixator

Orthopedic biomechanics is a field that deals with the analysis of the loading of the skeletal system, engineering approaches to understanding the mechanical properties of biological tissues, and choosing appropriate systems to replace the tissues when they fail. It is a major growth industry in the health care field and offers many opportunities to engineers interested

(continued)

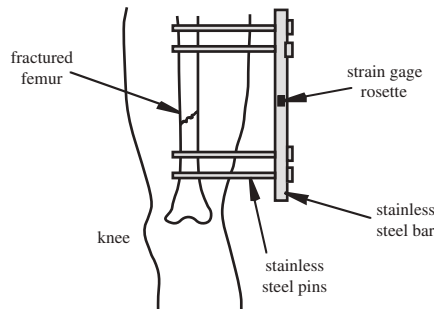
DESIGN EXAMPLE 9.1

(concluded)

in problems that have a biological or medical flavor. Many interesting engineering design problems are associated with the choice of implantable materials, the long-term strength of materials in the hostile environment of the body, and the specification of engineered materials that must attach securely to biological tissues. Replacement joints are among the most successful designs to date, and you probably know someone who has had a joint replaced with a stainless steel or titanium prosthesis.

An interesting bioengineering challenge involves the analysis of loading in the limbs in patients who have suffered severely broken bones. When one suffers a multiple fracture in a leg bone, the application of a simple plaster or fiberglass cast is not sufficient to allow the bone to heal. Bone is a living tissue constantly being naturally remodeled or replaced. Interestingly, stress is important in initiating the healing process and in maintaining healthy bones. As a case in point, astronauts in a weightless space environment for extended periods exhibit bone mass loss due to the lack of a gravitational stress.

With a severely broken bone, one that has been fractured into a number of pieces, an interesting biomechanical invention is often used to help the healing process. It is known as an exteriorized skeletal fixator. As illustrated in the following figure, it consists of a structural bar outside the body fastened to stainless steel pins that pierce and hold large bone fragments in place until the bone heals. The engineered structure therefore carries most of the load of the body when the person or animal walks.



It is important to understand how the fixator is loaded while the patient walks. This information is necessary in order to size the fixator so that it does not deform too much and prevent bone healing. One subtle feature of the healing process is that a very small amount of bone stress is necessary for healing. If all the stress is removed from the bone and no relative motion occurs between the fragments, the bone will not heal. But too much relative motion would hinder healing.

To measure the magnitude of loading for a verification study, we need to design a load cell as part of a skeletal fixator to monitor the complex loading profiles that occur during walking. We are interested in measuring the load profiles in the cylindrical stainless steel bar that supports the broken leg. Bone loads during walking are fairly complex and consist of axial stress, bending stress, and torsional stress.

Our objective is to design a load cell that allows us to easily and reliably determine the axial, bending, and torsional loads while the subject is walking. We can do this by mounting three rectangular strain gage rosettes on the bar 90° apart. The center (*b*) gage of each rosette (see Figure 9.29) will be aligned with the axis of the bar.

If the principal stresses are calculated at each rosette, the axial, bending, and torsion loads can be determined. The principal stresses in the axial direction can be used to determine the axial load and bending loads in two directions. The maximum shear stresses at each rosette can be averaged to determine the torsional load. Thus, the nine strain gages (from three rosettes) yield simultaneous measurements of axial load, bending load, and torsional load.

To obtain accurate measurements, the nine strain gages are now connected to strain gage bridge circuits. The analog outputs of the bridges can be digitized at an appropriate sampling frequency to yield the real-time stress profiles.

■ CLASS DISCUSSION ITEM 9.12

Sampling Rate Fixator Strain Gages

What is an appropriate sampling rate for the fixator strain gages in Design Example 9.1 assuming a typical human walking gait?

9.4 TEMPERATURE MEASUREMENT

Because temperature is such an important variable in many engineering systems, an engineer should be familiar with the basic methods of measuring it. Temperature sensors appear in buildings, chemical process plants, engines, transportation vehicles, appliances, computers, and many other devices that require monitoring and control of temperature.

Because many physical phenomena depend on temperature, we can use this dependence to indirectly measure temperature by measuring quantities such as pressure, volume, electrical resistance, and strain and then convert the values using the physical relationship between the quantity and temperature.

The temperature scales used to express temperature are

- Celsius (°C): Common SI unit of temperature.
- Kelvin (K): Standard SI unit of absolute thermodynamic temperature. Note the absence of the degree symbol.
- Fahrenheit (°F): English system unit of temperature.
- Rankine (°R): English system unit of absolute thermodynamic temperature.

The relationships between these scales are summarized here:

$$T_C = T_K - 273.15 \quad (9.43)$$

$$T_F = (9/5)T_C + 32 \quad (9.44)$$

$$T_R = T_F + 459.67 \quad (9.45)$$

where T_C is temperature in degrees celsius, T_K is temperature in kelvin, T_F is temperature in degrees fahrenheit, and T_R is temperature in degrees rankine.

The following subsections introduce common devices used for measuring temperature. They include the liquid-in-glass thermometer, bimetallic strip, resistance temperature device, thermistor, and thermocouple. There are also many IC temperature



Internet Link

9.8 LM35 IC
temperature sensor

9.9 Bimetallic strip

sensors available from semiconductor manufacturers. The LM35 at Internet Link 9.8 is a common example. These IC sensors are very convenient in microcontroller applications since they output either a voltage or digital value directly related to the measured temperature. IC temperature sensor operation is based on the fact that the forward-bias voltage of a silicon pn junction is directly proportional to temperature. The allowable temperature range of an IC temperature sensors (e.g., -40°C to 110°C for the LM35) is not as large as with other temperature sensors, but they are inexpensive and fairly accurate.

9.4.1 Liquid-in-Glass Thermometer

A simple nonelectrical temperature-measuring device is the liquid-in-glass thermometer. It typically uses alcohol or mercury as the working fluid, which expands and contracts in a glass container. The upper range is usually in the order of 600°F . When making measurements in a liquid, the depth of immersion is important, as it can result in different measurements. Because readings are made visually, and there can be a meniscus at the top of the working fluid (e.g. mercury), measurements must be made carefully and consistently.

9.4.2 Bimetallic Strip

Another nonelectrical temperature-measuring device used in simple control systems is the **bimetallic strip**. As illustrated in Figure 9.32, it is composed of two or more metal layers having different coefficients of thermal expansion. The strip can be straight, as shown in the figure, or coiled for a more compact design (e.g., in older thermostats such as that shown in Video Demo 9.4). Because these layers are permanently bonded together, the structure will deform when the temperature changes. This is due to the difference in the thermal expansions of the two metal layers. The deflection δ can be related to the temperature of the strip. Bimetallic strips are used in household and industrial thermostats where the mechanical motion of the strip makes or breaks an electrical contact to turn a heating or cooling system on or off. For more information, including an illustration and video demonstration of how a bimetallic strip deforms with temperature changes, see Internet Link 9.9.



Video Demo

9.4 Thermostat
with bimetallic strip
and mercury switch

9.4.3 Electrical Resistance Thermometer

A **resistance temperature device (RTD)** is constructed of metallic wire wound around a ceramic or glass core and hermetically sealed. The resistance of the metallic wire increases with temperature. The resistance-temperature relationship is usually approximated by the following linear expression:

$$R = R_0[1 + \alpha(T - T_0)] \quad (9.46)$$

where T_0 is a reference temperature, R_0 is the resistance at the reference temperature, and α is a calibration constant. The sensitivity (dR/dT) is $R_0\alpha$. The reference

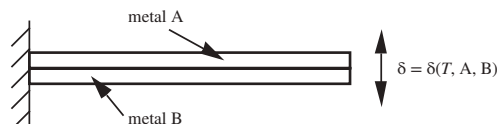


Figure 9.32 Bimetallic strip.

temperature is usually the ice point of water (0°C). The most common metal used in RTDs is platinum because of its high melting point, resistance to oxidation, predictable temperature characteristics, and stable calibration values. The operating range for a typical platinum RTD is -220°C to 750°C . Lower cost nickel and copper types are also available, but they have narrower operating ranges.

A **thermistor** is a semiconductor device, available in probes of different shapes and sizes, whose resistance changes exponentially with temperature. Its resistance-temperature relationship is usually expressed in the form

$$R = R_0 e^{\left[\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)\right]} \quad (9.47)$$

where T_0 is a reference temperature, R_0 is the resistance at the reference temperature, and β is a calibration constant called the **characteristic temperature** of the material. A well-calibrated thermistor can be accurate to within 0.01°C or better, which is better than typical RTD accuracies ($\pm 0.3^{\circ}\text{C}$). However, thermistors have much narrower operating ranges than RTDs. Note in Equation 9.47 that a thermistor's resistance actually decreases with increasing temperature (i.e., they have a negative temperature coefficient or NTC). This is very different from metal conductors that experience increasing resistance with increasing temperature (see Section 2.2.1).

9.4.4 Thermocouple

Two dissimilar metals in contact (see Figure 9.33) form a thermoelectric junction that produces a voltage proportional to the temperature of the junction. This is known as the **Seebeck effect**.

Because an electrical circuit must form a closed loop, thermoelectric junctions occur in pairs, resulting in what is called a **thermocouple**. We can represent a thermoelectric circuit containing two junctions as illustrated in Figure 9.34. Here we have wires of metals A and B forming junctions at different temperatures T_1 and T_2 , resulting in a potential V that can be measured. The thermocouple voltage V depends on the metal properties of A and B and the difference between the junction

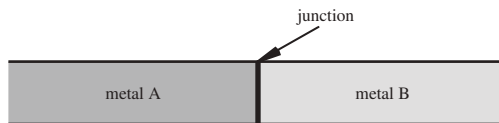


Figure 9.33 Thermoelectric junction.

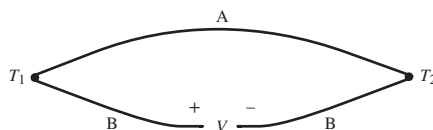


Figure 9.34 Thermocouple circuit.

temperatures T_1 and T_2 . The thermocouple voltage is directly proportional to the junction temperature difference:

$$V = \alpha(T_1 - T_2) \quad (9.48)$$

where α is called the **Seebeck coefficient**. As we will see later in this section, the relationship between voltage and temperature difference is not exactly linear. However, over a small temperature range, α is nearly constant.

Secondary thermoelectric effects, known as the Peltier and Thomson effects, are associated with current flow in the thermocouple circuit, but these are usually negligible in measurement systems (where the voltage measuring device has high input impedance) when compared with the Seebeck effect. However, when the current is large in a thermocouple circuit, these other effects become significant. The Peltier effect relates the current flow to heat flow into one junction and out of the other. This effect forms the basis of a **thermoelectric cooler (TEC)** or refrigerator.

To properly design systems using thermocouples for temperature measurement, it is necessary to understand the basic laws that govern their application. The five basic laws of thermocouple behavior follow.

1. *Law of leadwire temperatures.* The thermoelectric voltage due to two junctions in a circuit consisting of two different conducting metals depends only on the junction temperatures T_1 and T_2 . As illustrated in Figure 9.35, the temperature environment of the leads away from the junctions (T_3 , T_4 , T_5) does not influence the measured voltage. Therefore, we need not be concerned about shielding the leadwires from environmental conditions.
2. *Law of intermediate leadwire metals.* As illustrated in Figure 9.36, a third metal C introduced in the circuit constituting the thermocouple has no influence on the resulting voltage as long as the temperatures of the two new junctions (A-C and C-A) are the same ($T_3 = T_4$). As a consequence of this law, a voltage measurement device that creates two new junctions can be inserted into the thermocouple circuit without altering the resulting voltage.

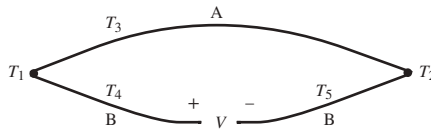


Figure 9.35 Law of leadwire temperatures.

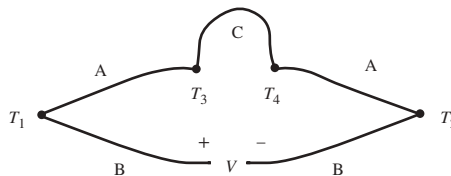


Figure 9.36 Law of intermediate leadwire metals.

3. *Law of intermediate junction metals.* As illustrated in Figure 9.37, if a third metal is introduced within a junction creating two new junctions (A-C and C-B), the measured voltage will not be affected as long as the two new junctions are at the same temperature ($T_1 = T_3$). Therefore, although soldered or brazed joints introduce thermojunctions, they have no resulting effect on the measured voltage. If $T_1 \neq T_3$, the effective temperature at C is the average of the two temperatures $((T_1 + T_3)/2)$.
4. *Law of intermediate temperatures.* Junction pairs at T_1 and T_3 produce the same voltage as two sets of junction pairs spanning the same temperature range (T_1 to T_2 and T_2 to T_3); therefore, as illustrated in Figure 9.38,

$$V_{1/3} = V_{1/2} + V_{2/3} \quad (9.49)$$

This equation can be read: The voltage resulting from measuring temperature T_1 relative to T_3 is the same as the sum of the voltages resulting from T_1 relative to T_2 and T_2 relative to T_3 . This result supports the use of a reference junction to allow accurate measurement of an unknown temperature based on a fixed reference temperature (described below).

5. *Law of intermediate metals.* As illustrated in Figure 9.39, the voltage produced between two metals A and B is the same as the sum of the voltages produced by each metal (A and B) relative to a third metal C according to:

$$V_{A/B} = V_{A/C} + V_{C/B} = V_{A/C} - V_{B/C} \quad (9.50)$$

This result supports the use of a standard reference metal (e.g., platinum) to be used as a basis to calibrate all other metals.

A standard configuration for thermocouple measurements is shown in Figure 9.40. It consists of wires of two metals, A and B, attached to a voltage-measuring device

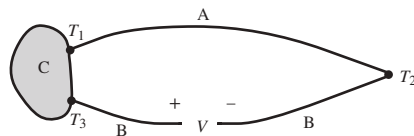


Figure 9.37 Law of intermediate junction metals.

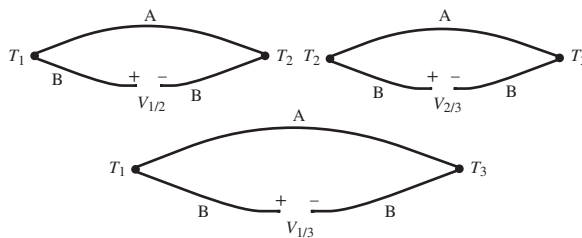


Figure 9.38 Law of intermediate temperatures.

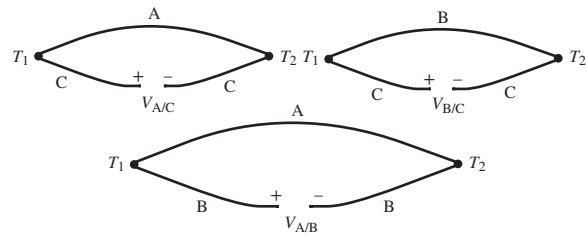


Figure 9.39 Law of intermediate metals.

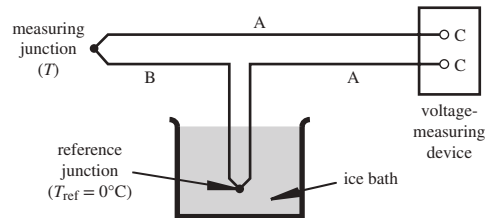


Figure 9.40 Standard thermocouple configuration.

with terminals made of metal C. The reference junction is used to establish a temperature reference for one of the junctions to ensure accurate temperature measurements at the other junction relative to the reference. A convenient reference temperature is 0°C , because this temperature can be accurately established and maintained with a distilled water ice bath (i.e., an ice-water mixture). If the terminals of the voltage measuring device are at the same temperature, the law of intermediate leadwire metals ensures that the measuring device terminal metal C has no effect on the measurement. For a given pair of thermocouple metals and a reference temperature, a standard reference table can be compiled for converting voltage measurements to temperatures.

An important alternative to using an ice bath is a semiconductor reference (e.g., a thermistor), which electrically establishes the reference temperature based on solid state physics principles. These reference devices are usually included in thermocouple instrumentation to eliminate the need for an external reference temperature. Video Demo 9.12 describes a commercially available digital thermometer, which can be used for accurate thermocouple temperature measurements.

Figure 9.41 illustrates a two-reference junction configuration, which allows independent choice of the leadwire metal. Copper is a good choice, because copper leadwires are inexpensive and no junctions are introduced at the voltmeter connections, which are usually copper.

Figure 9.42 illustrates the configuration for a **thermopile**, which combines N pairs of junctions, resulting in a voltage N times that of a single pair. In the example shown in the figure, the multiplication factor would be 3. If the measuring junctions (at T) are at different temperatures, the output would represent the average of these temperatures.



Video Demo

9.12 Thermocouple with a digital thermometer

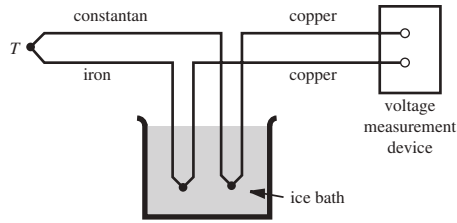


Figure 9.41 Attaching leadwires of selected metal.

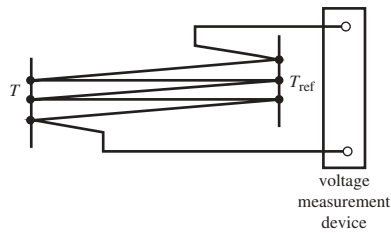


Figure 9.42 Thermopile.

Thermocouple Configuration with Nonstandard Reference

EXAMPLE 9.2

A standard two-junction thermocouple configuration is being used to measure the temperature in a wind tunnel. The reference junction is held at a constant temperature of 10°C . We have only a thermocouple table referenced to 0°C . A portion of the table follows. We want to determine the output voltage when the measuring junction is exposed to an air temperature of 100°C .

Junction Temperature ($^\circ\text{C}$)	Output Voltage (mV)
0	0
10	0.507
20	1.019
30	1.536
40	2.058
50	2.585
60	3.115
70	3.649
80	4.186
90	4.725
100	5.268

By applying the law of intermediate temperature for this example, we can write

$$V_{100/0} = V_{100/10} + V_{10/0}$$

(continued)

(concluded)

We wish to find $V_{100/10}$, the voltage measured for a temperature of 100°C relative to a reference junction at 10°C. We can get the other voltages in the equation, $V_{100/0}$ and $V_{10/0}$, from the table because both are referenced to 0°C. Therefore,

$$V_{100/10} = V_{100/0} - V_{10/0} = (5.268 - 0.507) \text{ mV} = 4.761 \text{ mV}$$

The six most commonly used thermocouple metal pairs are denoted by the letters E, J, K, R, S, and T. The 0°C reference junction calibration for each of the types is nonlinear and can be approximated with a polynomial. The metals in the junction pair, the thermoelectric polarity, the commonly used color code, the operating range, the accuracy, and the polynomial order and coefficients are shown for each type in Table 9.2. The general form for the polynomial using the coefficients in the table is

$$T = \sum_{i=0}^9 c_i V^i = c_0 + c_1 V + c_2 V^2 + c_3 V^3 + c_4 V^4 + c_5 V^5 + c_6 V^6 + c_7 V^7 + c_8 V^8 + c_9 V^9 \quad (9.51)$$

where V is the thermoelectric voltage measured in volts and T is the measuring junction temperature in °C, assuming a 0°C reference junction. Figure 9.43 shows the sensitivity curves for some commercially available thermocouple pairs. Even though we use a ninth-order polynomial to represent the temperature voltage relation, providing an extremely close fit, the relationship is close to linear as predicted by the Seebeck effect. Mathcad/Matlab Example 9.1 shows examples of how the polynomial coefficients in Table 9.2 can be used to make calculations for thermocouple voltage measurements.

MATLAB®
examples

9.1 Thermocouple calculations

9.5 VIBRATION AND ACCELERATION MEASUREMENT

An **accelerometer** is a sensor designed to measure acceleration, or rate of change of speed, due to motion (e.g., in a video game controller or smart phone shake detection), vibration (e.g., from rotating equipment), and impact events (e.g., to deploy an automobile airbag). Accelerometers capable of accurately measuring static acceleration can also be used to detect orientation (e.g., to determine inclination angle of a robot or vehicle, or to switch between portrait and landscape mode on a smart phone). Accelerometers are normally mechanically attached or bonded to an object or structure for which acceleration is to be measured. The accelerometer detects acceleration along one axis and is insensitive to motion in orthogonal directions. Strain gages, piezoelectric elements (described in Section 9.5.1), or capacitive elements (e.g., in MEMS IC accelerometers described in Section 9.7) constitute the sensing elements of accelerometers, converting acceleration into an electrical signal. As a simple example of acceleration sensing, Video Demo 9.13 shows a toy ball with blinking lights that can sense acceleration associated with a bounce. Its sensing element is simply a spring surrounding a metal post.



Video Demo

9.13 Bouncing ball accelerometer

Table 9.2 Thermocouple data

Metal pair	Type E	Type J	Type K	Type R	Type S	Type T
	Chromel (+) and constantan (−)	Iron (+) and constantan (−)	Chromel (+) and alumel (−)	87% platinum, 13% rhodium (+) and platinum (−)	90% platinum, 10% rhodium (+) and platinum (−)	Copper (+) and constantan (−)
Color code	Purple	Black	Yellow	Green	Green	Blue
Operating range	−100°C to 1000°C	0°C to 760°C	0°C to 1370°C	0°C to 1000°C	0°C to 1750°C	−160°C to 400°C
Accuracy	±0.5°C	±0.1°C	±0.7°C	±0.5°C	±0.1°C	±0.5°C
Approximate sensitivity (mV/°C)	0.079	0.054	0.042	0.012	0.011	0.049
Polynomial order	9	5	8	8	9	7
c_0	0.104967	−0.0488683	0.226585	0.263633	0.927763	0.100861
c_1	17,189.5	19,873.1	24,152.1	179,075.	169,527.	25,727.9
c_2	−282,639.	−218,615.	67,233.4	−4.88403 × 10 ⁷	−3.15684 × 10 ⁷	−767,346.
c_3	1.26953 × 10 ⁷	1.15692 × 10 ⁷	2.21034 × 10 ⁶	1.90002 × 10 ¹⁰	8.99073 × 10 ⁹	7.80256 × 10 ⁷
c_4	−4.48703 × 10 ⁸	−2.64918 × 10 ⁸	−8.60964 × 10 ⁸	−4.82704 × 10 ¹²	−1.63565 × 10 ¹²	−9.24749 × 10 ⁹
c_5	1.10866 × 10 ¹⁰	2.01844 × 10 ⁹	4.83506 × 10 ¹⁰	7.62091 × 10 ¹⁴	1.88027 × 10 ¹⁴	6.97688 × 10 ¹¹
c_6	−1.76807 × 10 ¹¹	—	−1.18452 × 10 ¹²	−7.20026 × 10 ¹⁶	−1.37241 × 10 ¹⁶	−2.66192 × 10 ¹³
c_7	1.71842 × 10 ¹²	—	1.38690 × 10 ¹³	3.71496 × 10 ¹⁸	6.17501 × 10 ¹⁷	3.94078 × 10 ¹⁴
c_8	−9.19278 × 10 ¹²	—	−6.33708 × 10 ¹³	−8.03104 × 10 ¹⁹	−1.56105 × 10 ¹⁹	—
c_9	2.06132 × 10 ¹³	—	—	—	1.69535 × 10 ²⁰	—

Source: G. Burns, M. Scroger, and G. Strouse, “Temperature-Electromotive Force Reference Functions and Tables for the Letter-Designated Thermocouple Types Based on the ITS-90,” NIST Monograph 175, April 1993.

ANSI DESIGNATION	ALLOY (Generic or Trade Names)
JP	Iron
JN, EN, or TN	Constantan, Cupron, Advance
KP or EP	Chromega, Tophel, T ₁ , Thermokanthal KP
KN	Alomega, Nial, T ₂ , Thermokanthal KN
TP	Copper
RN or SN	Pure Platinum
RP	Platinum 13% Rhodium
SP	Platinum 10% Rhodium

Trade Names: Advance T—Driver Harris Co., Chromega and Alomega—OMEGA Engineering, Inc., Cupron, Nial and Tophel—Wilbur B. Driver Co., Thermokanthal KP and Thermokanthal KN—The Kanthal Corporation.

ANSI LETTER DESIGNATIONS—Currently thermocouple and extension wire is ordered and specified by an ANSI letter designation. Popular generic and trade name examples are Chromega/Alomega—ANSI Type K: Iron/Constantan—ANSI Type J: Copper/Constantan—ANSI Type T: Chromega/Constantan—ANSI Type E: Platinum/Platinum 10% Rhodium—ANSI Type S: Platinum/Platinum 13% Rhodium—ANSI Type R. The position and negative legs are identified by letter suffixes P and N, respectively, as listed in the tables.

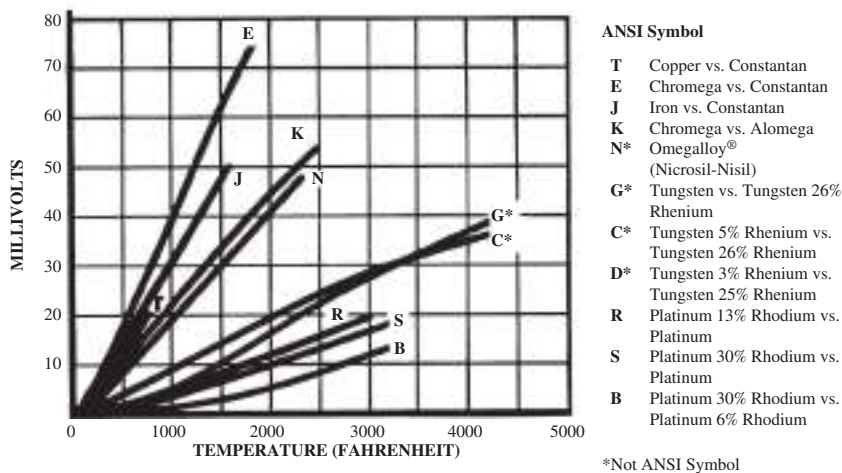


Figure 9.43 Thermocouple types and characteristics.

Source: OMEGA Engineering Inc., Stamford, CT.

The design of an accelerometer is based on the inertial effects associated with a mass connected to a moving object through a spring, damper, and displacement sensor. Figure 9.44 illustrates the components of an accelerometer along with the displacement references, terminology, and free-body diagram. When the object accelerates, there is relative motion between the housing and the seismic mass. A displacement transducer senses the relative motion. Through a frequency response analysis of the second-order system modeling the accelerometer, we can relate the displacement transducer output to either the absolute position or acceleration of the object.

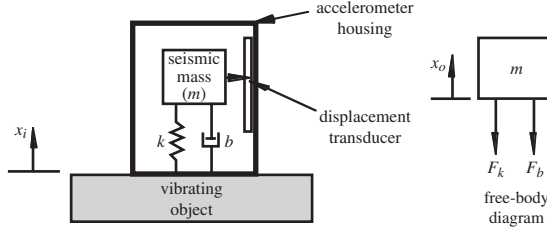


Figure 9.44 Accelerometer displacement references and free-body diagram.

To determine the frequency response of the accelerometer, we first express the forces shown in the free-body diagram. To do this, we define the relative displacement x_r between the seismic mass and the object as

$$x_r = x_o - x_i \quad (9.52)$$

It is measured by a position transducer between the seismic mass and the housing. Therefore, the spring force can be expressed as

$$F_k = k(x_o - x_i) = kx_r \quad (9.53)$$

and the damper force can be expressed as

$$F_b = b(\dot{x}_o - \dot{x}_i) = b\dot{x}_r \quad (9.54)$$

where the overdots represent time derivatives. Applying Newton's second law, the equation of motion for the seismic mass is

$$\sum F_{\text{ext}} = m\ddot{x}_o \quad (9.55)$$

or

$$-F_k - F_b = m\ddot{x}_o \quad (9.56)$$

The forces have negative signs in this equation because they are in the opposite direction from the reference direction x_o in the free-body diagram. Substituting Equations 9.53 and 9.54, the result is

$$-kx_r - b\dot{x}_r = m\ddot{x}_o \quad (9.57)$$

Because the relative displacement x_r is

$$x_r = x_o - x_i \quad (9.58)$$

we can replace $\ddot{x}_o$ with

$$\ddot{x}_o = \ddot{x}_r + \ddot{x}_i \quad (9.59)$$

Therefore, we can write Equation 9.57 as

$$-kx_r - b\dot{x}_r = m(\ddot{x}_r + \ddot{x}_i) \quad (9.60)$$

which can be rearranged as

$$m\ddot{x}_r + b\dot{x}_r + kx_r = -m\ddot{x}_i \quad (9.61)$$

This second-order differential equation relates the measured relative displacement x_r to the input displacement x_i . As in the analysis of a second-order system presented in Section 4.10, we can rewrite this equation as

$$\ddot{x}_r + 2\zeta\omega_n\dot{x}_r + \omega_n^2x_r = -\ddot{x}_i \quad (9.62)$$

where the natural frequency is

$$\omega_n = \sqrt{\frac{k}{m}} \quad (9.63)$$

and the damping ratio is

$$\zeta = \frac{b}{2\sqrt{km}} \quad (9.64)$$

■ CLASS DISCUSSION ITEM 9.13

Effects of Gravity on an Accelerometer

The free-body diagram and resulting equation of motion for the accelerometer do not show a gravitational force explicitly. Explain why.

For a frequency response analysis, the input displacement is assumed to be composed of sinusoidal terms of the form:

$$x_i(t) = X_i \sin(\omega t) \quad (9.65)$$

Because the system is linear, the resulting relative output displacement is also sinusoidal of the same frequency but different phase:

$$x_r(t) = X_r \sin(\omega t + \phi) \quad (9.66)$$

Using the procedure presented in Section 4.10.2, the frequency response analysis results in the amplitude ratio (Question 9.27)

$$\frac{X_r}{X_i} = \frac{(\omega/\omega_n)^2}{\left(\left[1 - \left(\frac{\omega}{\omega_n} \right)^2 \right]^2 + 4\zeta^2 \left(\frac{\omega}{\omega_n} \right)^2 \right)^{1/2}} \quad (9.67)$$

and the phase angle

$$\phi = -\tan^{-1} \left(\frac{2\zeta(\omega/\omega_n)}{1 - \left(\frac{\omega}{\omega_n} \right)^2} \right) \quad (9.68)$$

To relate the relative output displacement signal x_r to the input acceleration $\ddot{x}_i$, we differentiate Equation 9.65, resulting in

$$\ddot{x}_i(t) = -X_i \omega^2 \sin(\omega t) \quad (9.69)$$

Note that the amplitude of the input acceleration is

$$X_i \omega^2 \quad (9.70)$$

Rearranging Equation 9.67, we have

$$H_a(\omega) = \frac{X_r \omega_n^2}{X_i \omega^2} = \frac{1}{\left(\left[1 - \left(\frac{\omega}{\omega_n} \right)^2 \right]^2 + 4\zeta^2 \left(\frac{\omega}{\omega_n} \right)^2 \right)^{1/2}} \quad (9.71)$$

where $H_a(\omega)$ is used to represent the ratio $(X_r \omega_n^2)/(X_i \omega^2)$ as a function of frequency ω . Figures 9.45 and 9.46 illustrate this term and the phase angle relationship (Equation 9.68) graphically for different values of damping ratio.

The denominator of $H_a(\omega)$ is the input acceleration amplitude $X_i \omega^2$, and the numerator is the product of the output displacement amplitude X_r and the square of the natural frequency ω_n^2 . Therefore, we can relate the measured output displacement amplitude to the input acceleration amplitude as

$$X_r = \left(\frac{1}{\omega_n^2} \right) H_a(\omega) (X_i \omega^2) \quad (9.72)$$

so the input acceleration amplitude can be expressed as

$$(X_i \omega^2) = \frac{X_r \omega_n^2}{H_a(\omega)} \quad (9.73)$$

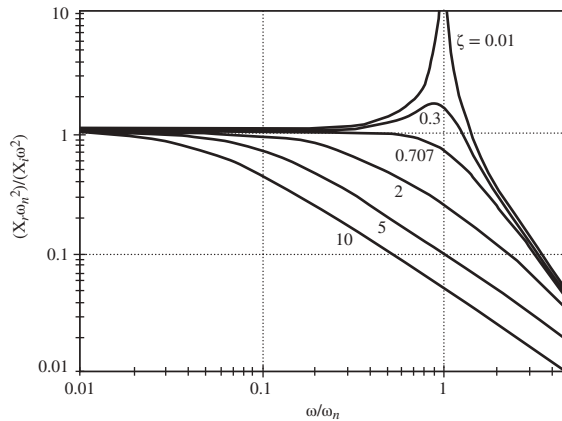


Figure 9.45 Ideal accelerometer amplitude response.

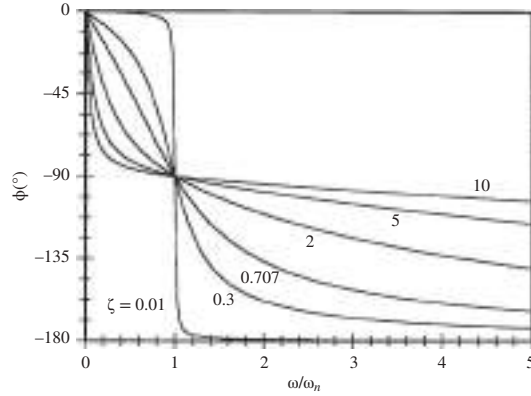


Figure 9.46 Ideal accelerometer phase response.

If we design the accelerometer so that $H_a(\omega)$ is nearly 1 over a large frequency range, then the input acceleration amplitude is given directly in terms of the relative displacement amplitude scaled by a constant factor ω_n^2 :

$$(X_i \omega^2) = (\omega_n^2) X_r \quad (9.74)$$

As can be seen in Figure 9.45, the largest frequency range resulting in a unity amplitude ratio occurs when the damping ratio ζ is 0.707 and the natural frequency ω_n is as large as possible. Also, as is clear in Figure 9.46, a ζ of 0.707 results in the best phase linearity for the system. We can make the natural frequency large by choosing a small seismic mass and a large spring constant. This is easy to accomplish in the very small package common to commercial accelerometers.

Equation 9.74 applies to every frequency component ω lying within the bandwidth of the sensor. If we have an arbitrary input composed of a number of frequencies that lie within the bandwidth, each frequency contributes to the signal according to Equation 9.74. Therefore, the total acceleration, due to all frequency components, is also directly related to the total measured relative displacement:

$$\ddot{x}_i(t) = \omega_n^2 x_r(t) \quad (9.75)$$

The same spring-mass-damper configuration used to measure acceleration can be designed to measure displacement instead. This type of device is called a **vibrometer**. The amplitude ratio given in Equation 9.67 provides us with the necessary relationship between the input and output displacements. As we did in the accelerometer analysis, we can now define a displacement ratio as

$$H_d(\omega) = \frac{X_r}{X_i} \quad (9.76)$$

Figure 9.47 illustrates the amplitude ratio to frequency relationship for different values of the damping ratio. The phase angle relationship is the same as for the

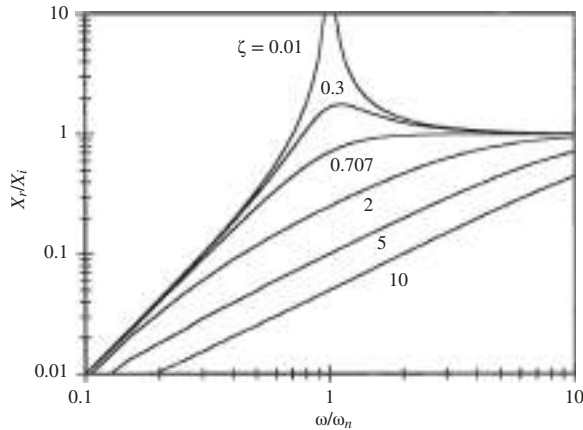


Figure 9.47 Vibrometer amplitude response.

accelerometer (see Figure 9.46). The input displacement amplitude X_i is related to the measured relative displacement amplitude X_r as

$$X_i = \frac{X_r}{H_d(\omega)} \quad (9.77)$$

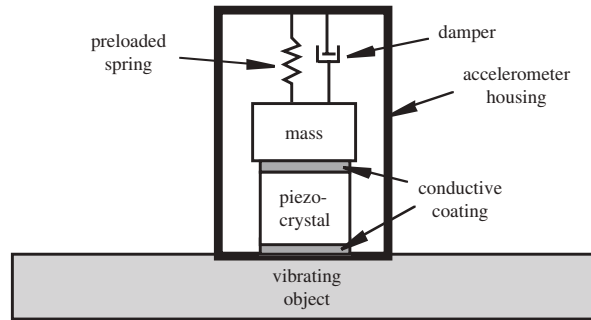
If we design the vibrometer so that $H_d(\omega)$ is nearly 1 over a large frequency range, then the input displacement amplitude is given directly by the relative displacement amplitude:

$$X_i = X_r \quad (9.78)$$

As can be seen in Figure 9.47, the largest frequency range resulting in a unity amplitude ratio occurs when the damping ratio ζ is 0.707 and the natural frequency ω_n is as small as possible (so ω/ω_n is large). We can make the natural frequency small by choosing a large seismic mass and a small spring constant. This explains the large size of seismographs used to measure motion due to an earthquake.

9.5.1 Piezoelectric Accelerometer

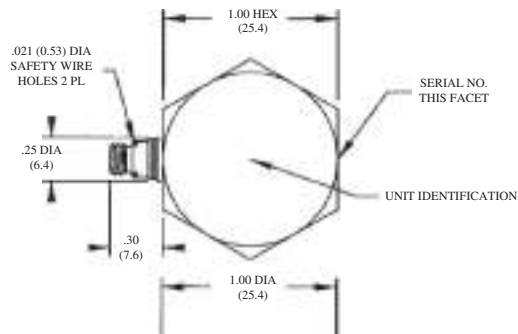
The highest quality accelerometers are constructed using a **piezoelectric crystal**, a material whose deformation results in charge polarization across the crystal. In a reciprocal manner, application of an electric field to a piezoelectric material results in deformation. As illustrated in Figure 9.48a, a piezoelectric accelerometer consists of a crystal in contact with a mass, supported in a housing by a spring. The purpose for the preload spring is to help keep the mass in contact with the crystal and to keep the crystal in compression, which can help prolong its life. The crystal itself also has stiffness that contributes to the overall stiffness of the system. Figure 9.48b shows a commercially available piezoelectric accelerometer.



(a) schematic illustration



Source: Endevco, San Juan Capistrano, CA



(b) actual device

Figure 9.48 Piezoelectric accelerometer construction.

Source: Endevco, San Juan Capistrano, CA

In addition to the natural damping properties inherent in the crystal, additional damping is sometimes incorporated (e.g., by filling the housing with oil). When the supporting object experiences acceleration, relative displacement occurs between the case and the mass due to the inertia of the mass. The resulting strain in the piezoelectric crystal causes a displacement charge between the crystal conductive coatings as a result of the piezoelectric effect. Note that an accelerometer using a piezoelectric crystal requires no external power supply. Also, it is important to recognize that the accelerometer measures acceleration only in the direction in which it is mounted (i.e., along the axis of the spring, mass, and crystal).

A piezoelectric material produces a large output for its size. Naturally occurring piezoelectric materials are Rochelle salt, tourmaline, and quartz. Some crystalline materials can be artificially polarized to take on piezoelectric characteristics by heating and then slowly cooling them in a strong electric field. Such materials are barium titanate, lead zirconate (PZT), lead titanate, and lead metaniobate. These ferroelectric ceramics are more often used in accelerometers because the sensitivity can be controlled during manufacturing.

A simple equivalent circuit for a piezoelectric crystal is shown in Figure 9.49, implying that the crystal is effectively a capacitor and a charge source that generates a charge q across the capacitor plates proportional to the deformation of the crystal. Representing the accelerometer by a Thevenin equivalent circuit (see Figure 9.50), the open circuit voltage V is equal to the charge, typically in the picocoulomb range, divided by the capacitance, typically in the picofarad range:

$$V = \frac{q}{C_p} \quad (9.79)$$

The sensitivity of the accelerometer is the ratio of the charge output to the acceleration of the housing expressed in pC/g, (rms pC)/g, or (peak pC)/g, where g is the acceleration due to gravity. The output of the accelerometer is attached to a **charge amplifier**, which converts the displacement charge on the crystal to a voltage that can be measured. Most accelerometers are calibrated in millivolts per g for a specified charge amplifier.

In general, piezoelectric accelerometers cannot measure constant or slowly changing accelerations, because the crystals can measure a change in force only by sensing a change in strain. But they are excellent for dynamic measurements such as vibration and impacts. The response at low frequencies is further limited by the low-frequency cutoff of the charge amplifier, which may be on the order of a few hertz. The response at high frequencies is a function of the mechanical characteristics of

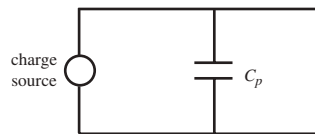


Figure 9.49 Equivalent circuit for piezoelectric crystal.

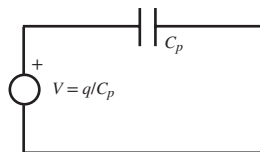


Figure 9.50 Thevenin equivalent of piezoelectric crystal.

the accelerometer. The dynamic range of an accelerometer ranges from a few hertz to a fraction of the resonant frequency, which is given by

$$f_n = \frac{1}{2\pi} \sqrt{\frac{k}{m}} \tag{9.80}$$

usually in the kHz range. A typical frequency response curve for a piezoelectric accelerometer is shown in Figure 9.51. Piezoelectric accelerometers are also more rugged and can operate over a much larger temperature range than other types of accelerometers (e.g., IC accelerometers using MEMS technology described in Section 9.7).



Lab Exercise

Lab 14 Vibration measurement with an accelerometer



Video Demo

9.14 Accelerometer bearing signature analysis experiment



Internet Link

9.10 Sample bearing signature analysis result for a good bearing

9.11 Sample bearing signature analysis result for a bad bearing

■ CLASS DISCUSSION ITEM 9.14
Amplitude Anomaly in Accelerometer Frequency Response

In Figure 9.53, why does the output amplitude have a positive dB value close to 10,000 Hz? What is causing this physically, and how does it affect measurement accuracy?

Lab Exercise 14 explores how to use an accelerometer to monitor vibrations from rotating equipment. The health of bearings in a system can be determined by monitoring the spectrum of the vibration signal. This is called bearing signature analysis. Video Demo 9.14 shows a demonstration of the experiment, and Internet Links 9.10 and 9.11 point to some example results. Scratches and wear in roller bearings create more high-frequency content in the vibration spectrum.

■ CLASS DISCUSSION ITEM 9.15
Piezoelectric Sound

How does a piezoelectric microphone work? How about a piezoelectric buzzer?

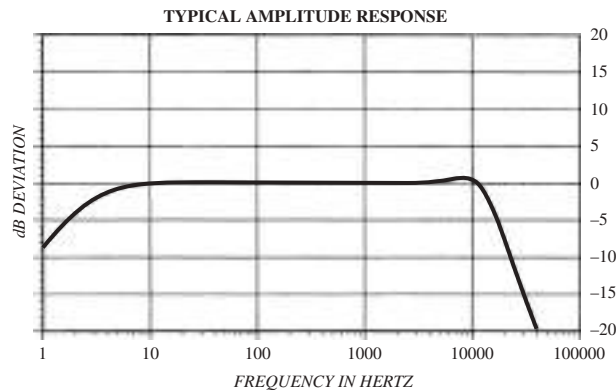


Figure 9.51 Piezoelectric accelerometer frequency response.
Source: Endevco, San Juan Capistrano, CA

9.6 PRESSURE AND FLOW MEASUREMENT

Most techniques for measuring pressure involve sensing a displacement or deflection and relating it to pressure through calibration or theoretical relations. One type of pressure sensor is a manometer, which measures a static pressure or pressure difference by detecting fluid displacements in a gravitational field. Another type is the elastic diaphragm, bellows, or tube where deflection of an elastic member is measured and related to pressure. Another type is the piezoelectric pressure transducer that can measure dynamic pressures when the piezoelectric crystal deforms in response to the applied pressure. References that cover these and other techniques are included in the bibliography at the end of the chapter. Internet Link 9.12 is also an excellent resource.

There are also many techniques for measuring gas and liquid flow rates. A pitot tube measures the difference between total and static pressure of a moving fluid. Venturi and orifice meters are based on measuring pressure drops across obstructions to flow. Turbine flow meters detect the rate of flow by measuring the rate of rotation of an impeller in the flow. Coriolis flow meters measure mass flow rate through a U-tube in rotational vibration. Hot-wire anemometers sense the resistance changes in a hot current-carrying wire. The temperature and resistance of the wire depend on the amount of heat transferred to the moving fluid. The heat transfer coefficient is a function of the flow rate. Laser doppler velocimeters (LDVs) sense the frequency shift of laser light scattered from particles suspended in a moving fluid. Most fluid mechanics textbooks present the theoretical foundation of a variety of flow measurement techniques. References that cover these and other techniques are included in the bibliography at the end of the chapter. Internet Link 9.13 is also an excellent resource.



Internet Link

9.12 Pressure measurement techniques and devices

9.13 Flow measurement techniques and devices

9.7 SEMICONDUCTOR SENSORS AND MICROELECTROMECHANICAL DEVICES

The advent of wide-scale semiconductor electronic design and manufacturing changed more than the way we process electronic signals. Many of the techniques developed for producing integrated circuits have been adapted for the design of a new class of semiconductor sensors and actuators called **microelectromechanical (MEM)** devices. In 1980, the first MEM sensor was developed using integrated circuit technology to etch silicon and produce a device that responded to acceleration. It consisted of a tiny silicon cantilever with an integral semiconductor strain gage. Acceleration deflected the cantilever (due to its inertia), and the strain gage sensed the magnitude of acceleration. The strain gage and the bar were etched from a single piece of silicon using the processing methods developed earlier to modify silicon for semiconductor electronics. MEM accelerometers are now used in automobiles to control airbag systems. Other common successful applications of MEM sensors include pressure sensors for automobile tire pressure monitoring systems (TPMS), and accelerometers and gyros for detecting orientation and motion of video game and TV controllers and portable electronic devices (e.g., smart phones and cameras).



Video Demo

5.3 Chip manufacturing process

5.4 How a CPU is made

ICs are made by a series of processes consisting of photoresist lithographic layering, light exposure, controlled chemical etching, vapor deposition, and doping (see Video Demos 5.3 and 5.4). The chemical etching process is important in that tiny mechanical devices can be created by a technique known as micromachining. Using carefully designed masks and timed immersion in chemical baths, microminiature versions of accelerometers, static electric motors, and hydraulic or gas-driven motors can be formed.

Semiconductor sensor designs are based on different electromagnetic properties of doped silicon and gallium arsenide and the variety of ways that semiconductors function in different physical environments. The following list summarizes some of the semiconductor properties that are the basis for different classes of semiconductor MEMs:

- Capacitance changes between fixed and flexural silicon elements can be used to detect orientation, inclination, or acceleration (e.g., in MEMS IC accelerometers).
- The piezoresistive characteristic of doped silicon, the coupling between resistance change and deformation, is the basis for semiconductor strain gages and pressure sensors.
- The magnetic characteristics of doped silicon, principally the Hall effect, are the basis of semiconductor magnetic transistors where the collector current can be modulated by an external magnetic field.
- Electromagnetic waves and nuclear radiation induce electrical effects in semiconductors, forming the basis of light color sensors and other radiation detectors.
- The thermal properties of semiconductors are the basis for thermistors, thermal conductivity sensors, humidity sensors, and temperature sensor ICs.

Surface acoustic wave (SAW) devices are an important class of MEM sensors. A SAW device consists of a flat piezoelectric substrate with metallic patterns lithographically deposited on the surface. These patterns form interdigital transducers (IDTs) and reflection coupler gratings as shown in Figure 9.52. An input signal applied to an interdigital transducer excites a deformation in the piezoelectric substrate generating an acoustic wave that propagates on the surface. Conversely, a SAW wave can induce a voltage in an IDT resulting in an output signal.

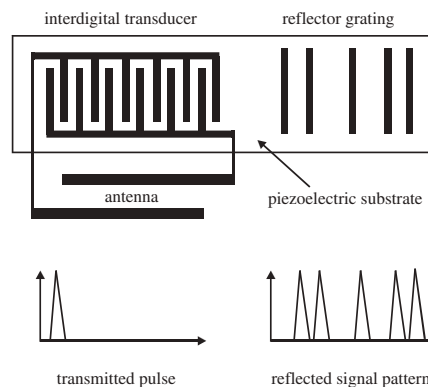


Figure 9.52 Surface acoustic wave transponder device.

Figure 9.52 illustrates a common application of a SAW device: a wireless identification system. A transmitter sends out a pulse that is received by the passive SAW device via an antenna. The resulting SAW wave is reflected as a pattern of pulses unique to the spacings within the reflector grating. The pulses are retransmitted through the same antenna back to a receiver allowing identification of the SAW device. This device is commonly used in automatic highway toll booths to identify vehicles as they pass under a transceiver.

Other applications of SAW devices include delay lines, frequency filters, and a variety of sensors. Their function depends on the substrate SAW propagation and resonance and the patterns and spacings of IDTs and reflector gratings.

With the development of so many different semiconductor sensors, engineers have now begun to integrate sensors and signal processing circuits together in a hybrid circuit that contains transducers, signal processing circuits, A/D converters, programmable memory, interface circuits, and a microprocessor. The complete system, packaged on a single IC, is called a **microelectromechanical system (MEMS)** or a **micromasurement system (MMS)**. MEMS IC sensors provide advantages over traditional discrete measurement systems because they are accurate, have a small size, and have a desirable output (e.g., digital, or a linearized and amplified voltage) suitable to directly interfacing to other devices. Distributed micromasurement systems will be used more and more in future mechatronic system design.

QUESTIONS AND EXERCISES

Section 9.2 Position and Speed Measurement

- 9.1. Draw schematics for each switch in Figure 9.3.
- 9.2. Show how an SPDT switch can be wired, with a 5 V supply and resistor(s), to provide a digital signal that is low when the switch is open and high when it is closed.
- 9.3. Show how a NO pushbutton switch can be wired, with a 5 V supply and resistor(s), to provide a negative logic (active low) reset signal to a microprocessor. The signal should be low only while the button is held down.
- 9.4. Draw a schematic for a DPDT switch and show how it can be wired to switch two separate circuits on and off.
- 9.5. Document a complete and thorough answer to Class Discussion Item 9.1.
- 9.6. Document a complete and thorough answer to Class Discussion Item 9.2.
- 9.7. Document a complete and thorough answer to Class Discussion Item 9.3.
- 9.8. You are using a poorly constructed 4-bit natural binary-coded absolute encoder and observe that, as the encoder rotates through the single step from code 3 to code 4, the encoder outputs several different and erroneous values. If misalignment between the photosensors and the code disk is the problem, what possible codes could result during the code 3-to-4 transition?
- 9.9. Document a complete and thorough answer to Class Discussion Item 9.4.
- 9.10. What is the angular resolution of a two-channel incremental encoder with a 2X quadrature decoder circuit if the code disk track has 1000 radial lines?
- 9.11. Write a PicBasic program to perform the functionality in Figure 9.16.
- 9.12. Document a complete and thorough answer to Class Discussion Item 9.5.

Section 9.3 Stress and Strain Measurement

- 9.13. Derive Equation 9.9 for a circular conductor instead of a rectangular conductor.
- 9.14. A new experimental strain gage is mounted on a 0.25 inch diameter steel bar in the axial direction. The gage has a measured resistance of $120\ \Omega$, and when the bar is loaded with 500 lb in tension, the gage resistance increases by $0.01\ \Omega$. What is the gage factor of the gage?
- 9.15. Document a complete and thorough answer to Class Discussion Item 9.8.
- 9.16. A steel bar with modulus of elasticity 200 GPa and diameter 10 mm is loaded in tension with an axial load of 50 kN. If a strain gage of gage factor 2.115 and resistance $120\ \Omega$ is mounted on the bar in the axial direction, what is the change in resistance of the gage from the unloaded state to the strained state? If the strain gage is placed in one branch of a Wheatstone bridge (R_1) with the other three legs having the same base resistance ($R_2 = R_3 = R_4 = 120\ \Omega$), what is the output voltage of the bridge (V_{out}) in the strained state, as a function of the excitation voltage? What is the stress in the bar?
- 9.17. Document a complete and thorough answer to Class Discussion Item 9.10.
- 9.18. Draw a schematic diagram illustrating the wiring of a Wheatstone bridge circuit that takes advantage of both three-wire lead connections and dummy gage temperature compensation.
- 9.19. A strain gage bridge used in a load cell dissipates energy. Why? Compare the power dissipated in a bridge circuit with equal resistance arms for gages of $350\ \Omega$ and $120\ \Omega$ when the excitation voltage is 10 V. What strategies can one employ if heating becomes a problem? Do these strategies have any deficiencies?
- 9.20. Even when we use three-wire connections to a strain gage to reduce the effects of leadwire resistance changes with temperature, we can have a phenomenon called leadwire desensitization. If the magnitude of the leadwire resistance exceeds 0.1% of the nominal gage resistance, significant error can result. Assuming a 22AWG leadwire ($0.050\ \Omega/\text{m}$) and a standard $120\ \Omega$ gage, how long can the leads be before there is leadwire desensitization?

Section 9.4 Temperature Measurement

- 9.21. Find the approximate sensitivity (in $\text{mV}/^\circ\text{C}$) of a J-type thermocouple by evaluating or plotting its polynomial function.
- 9.22. Find the approximate sensitivity (in $\text{mV}/^\circ\text{C}$) of a T-type thermocouple by evaluating or plotting its polynomial function.
- 9.23. If a J-type thermocouple is used in a standard two-junction thermocouple configuration (see Figure 9.40) with a 0°C reference temperature, what voltage would result for an input temperature of 200°C ?
- 9.24. If a J-type thermocouple is used in a standard two-junction thermocouple configuration (see Figure 9.40) with a 100°C reference temperature, what measurement temperature would correspond to a measured voltage of 30 mV?
- 9.25. Solve Question 9.24 if the reference temperature were 11°C instead of 100°C with everything else the same.
- 9.26. Using a J-type thermocouple with a fixed 0°C reference, how much would the voltage reading change if the measurement temperature changes from 10°C to 120°C ?

Section 9.5 Vibration and Acceleration Measurement

- 9.27.** Derive Equation 9.67.
- 9.28.** An accelerometer is designed with a seismic mass of 50 g, a spring constant of 5000 N/m, and a damping constant of 30 Ns/m. If the accelerometer is mounted to an object experiencing displacement $x_{in}(t) = 5 \sin(100t)$ mm, find each of the following:
- the actual acceleration amplitude of the object.
 - the amplitude of the steady state relative displacement between the seismic mass and the housing of the accelerometer.
 - the acceleration amplitude, as measured by the accelerometer.
 - an expression for the steady state relative displacement of the seismic mass relative to the housing as a function of time $[x_r(t)]$.
- 9.29.** A spring-mass-damper vibrometer is designed with a seismic mass of 1 kg, a coil spring of spring constant 2 N/m, and a dashpot with damping constant 2 Ns/m. Determine an expression for the steady state displacement of the seismic mass $x_{out}(t)$ given an object input displacement of $x_{in}(t) = 10 \sin(1.25t)$ mm.

BIBLIOGRAPHY

- Beckwith, T., Marangoni, R., and Lienhard, J., *Mechanical Measurements*, 6th Edition, Pearson, New York, 2006.
- Burns, G., Scroger, M., and Strouse, G., "Temperature-Electromotive Force Reference Functions and Tables for the Letter-Designated Thermocouple Types Based on the ITS-90," NIST Monograph 175, April 1993.
- Complete Temperature Measurement Handbook and Encyclopedia*, vol. 28, Omega Engineering, Stamford, CT, 1992.
- Dally, J. and Riley, W., *Experimental Stress Analysis*, 3rd Edition, McGraw-Hill, New York, 1991.
- Doebelin, E., *Measurement Systems Application and Design*, 4th Edition, McGraw-Hill, New York, 1990.
- Figliola, R., and Beasley, D., *Theory and Design for Mechanical Measurements*, 5th Edition, John Wiley, New York, 2010.
- Gardner, J., *Microsensors: Principles and Applications*, John Wiley, New York, 1994.
- Hauptmann, P., *Sensors, Principles and Applications*, Carl Hanser Verlag, 1991.
- Holman, J., *Experimental Methods for Engineers*, 8th Edition, McGraw-Hill, New York, 2011.
- Janna, W., *Introduction to Fluid Mechanics*, Brooks/Cole Engineering Division, Monterey, CA, 1983.
- Kovacs, G., *Micromachined Transducers Sourcebook*, WCB/McGraw-Hill, New York, 1998.
- Measurements Group Education Division, "Strain Gage Based Transducers: Their Design and Construction," Measurements Group, Raleigh, NC, 1988.
- Measurements Group Education Division, "Student Manual for Strain Gage Technology," Measurements Group, Raleigh, NC, 1991.
- Miu, D., *Mechatronics: Electromechanics and Contramechanics*, Springer-Verlag, New York, 1993.

Pallas-Areny, R. and Webster, J., *Sensors and Signal Conditioning*, 2nd Edition, John Wiley, New York, 2000.

Proceedings of the Sixth UK Mechatronics Forum International Conference, C5—Novel Sensors and Actuators session, Skovde, Sweden, 1998.

Sze, S., *Semiconductor Sensors*, John Wiley, New York, 1994.

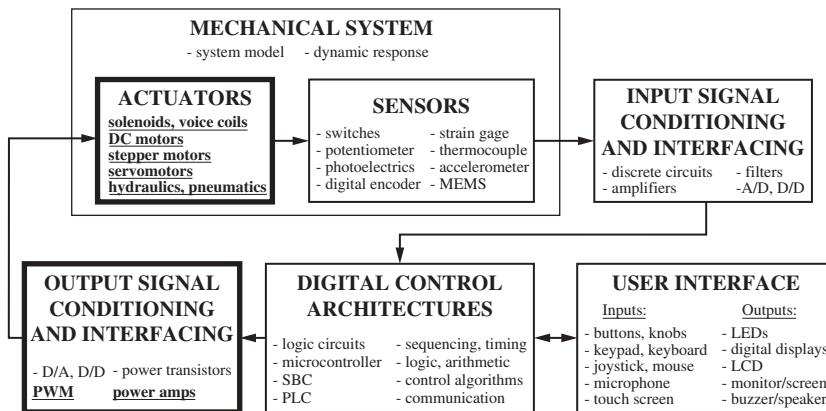
Walton, J., *Engineering Design: From Art to Practice*, pp. 117–119, West Publishing, St. Paul, MN, 1991.

White, F., *Fluid Mechanics*, 7th Edition, McGraw-Hill, New York, 2010.

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Actuators

This chapter describes various actuators important in mechatronic system design. ■



CHAPTER OBJECTIVES

After you read, discuss, study, and apply ideas in this chapter, you will:

1. Be able to identify different classes of actuators, including solenoids, DC motors, AC motors, hydraulics, and pneumatics
2. Understand the differences among series, shunt, compound, permanent magnet, and stepper DC motors
3. Understand how to design electronics to control a stepper motor

4. Be able to select a motor for a mechatronics application
5. Be able to identify and describe the components used in hydraulic and pneumatic systems

10.1 INTRODUCTION

Most mechatronic systems involve motion or action of some sort. This motion or action can be applied to anything from a single atom to a large articulated structure. It is created by a force or torque that results in acceleration and displacement. **Actuators** are the devices used to produce this motion or action.

Up to this point in the book, we have focused on electronic components and sensors and associated signals and signal processing, all of which are required to produce a specific mechanical action or action sequence. Sensor input measures how well a mechatronic system produces its action, open loop or feedback control helps regulate the specific action, and much of the electronics we learned about is required to manipulate and communicate this information. Actuators produce physical changes such as linear and angular displacement. They also modulate the rate and power associated with these changes. An important aspect of mechatronic system design is selecting the appropriate type of actuator. This chapter covers some of the most important actuators: solenoids, electric motors, hydraulic cylinders and rotary motors, and pneumatic cylinders. Putting it poetically, this chapter is “where the rubber meets the road.” Internet Link 10.1 provides links to vendors and online resources for various commercially available actuators and support equipment.



Internet Link

10.1 Actuator
online resources
and vendors

10.2 ELECTROMAGNETIC PRINCIPLES

Many actuators rely on electromagnetic forces to create their action. When a current-carrying conductor is moved in a magnetic field, a force is produced in a direction perpendicular to the current and magnetic field directions. **Lorentz’s force law**, which relates force on a conductor to the current in the conductor and the external magnetic field, in vector form is

$$\vec{F} = \vec{I} \times \vec{B} \quad (10.1)$$

where $\vec{F}$ is the force vector (per unit length of conductor), $\vec{I}$ is the current vector, and $\vec{B}$ is the magnetic field vector. Figure 10.1 illustrates the relationship among these vectors and indicates the **right-hand rule** analogy, which states that if your right-hand index finger points in the direction of the current and your middle finger is aligned with the field direction, then your extended thumb (perpendicular to the index and middle fingers) will point in the direction of the force. Another way to apply the right-hand rule is to align your extended fingers in the direction of the $\vec{I}$ vector and orient your palm so you can curl (flex) your fingers toward the direction of the $\vec{B}$ vector. Your hand will then be positioned such that your extended thumb points in the direction of $\vec{F}$.

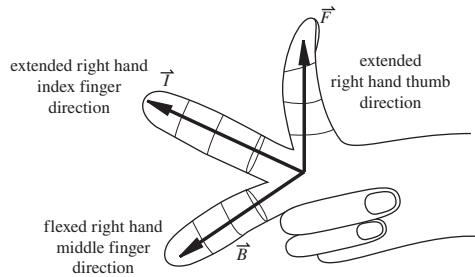


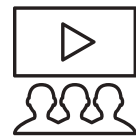
Figure 10.1 Right-hand rule for magnetic force.

Another electromagnetic effect important to actuator design is field intensification within a coil. Recall that, when discussing inductors in Chapter 2, we stated that the magnetic flux through a coil is proportional to the current through the coil and the number of windings. The proportionality constant is a function of the permeability of the material within the coil. The permeability of a material characterizes how easily magnetic flux penetrates the material. Iron has a permeability a few hundred times that of air; therefore, a coil wound around an iron core can produce a magnetic flux a few hundred times that of the same coil with no core. Most electromagnetic devices we will present use iron cores of one form or another to enhance magnetic flux. Cores are usually laminated (made up of insulated layers of iron stacked parallel to the coil-axis direction) to reduce the eddy currents induced when the cores experience changing magnetic fields. Eddy currents, which are a result of Faraday's law of induction, result in inefficiencies and undesirable core heating.

10.3 SOLENOIDS AND RELAYS

As illustrated in Figure 10.2, a **solenoid** consists of a coil and a movable iron core called the **armature**. When the coil is energized with current, the core moves to increase the flux linkage by closing the air gap between the cores. The movable core is usually spring-loaded to allow the core to retract when the current is switched off. The electromagnetic force generated is approximately proportional to the square of the current and inversely proportional to the square of the width of the air gap. Solenoids are inexpensive, and their use is limited primarily to on-off applications such as latching, locking, and triggering. They are frequently used in home appliances (e.g., washing machine valves), automobiles (e.g., door latches and the starter solenoid), pinball machines (e.g., plungers and bumpers), and factory automation. Video Demos 10.1 through 10.3 show examples of interesting student projects using solenoids in creative ways.

An electromechanical **relay** is a solenoid used to make or break mechanical contact between electrical leads. A small voltage input to the solenoid controls a potentially large current through the relay contacts. Applications include power switches and electromechanical control elements. A relay performs a function similar to a power transistor switch circuit but has the capability to switch much larger currents.



Video Demo

- 10.1** Magic piano
- 10.2** Automated melodica
- 10.3** LED fountain system

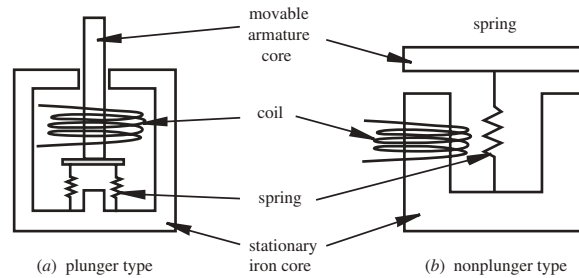


Figure 10.2 Solenoids.

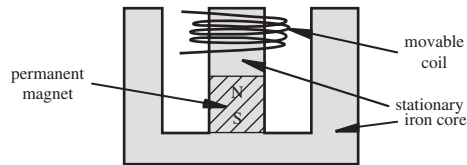


Figure 10.3 Voice coil.



Video Demo

10.4 Relay and transistor switching circuit comparison

10.5 Computer hard-drive with voice coil

10.6 Computer hard-drive track seeking demonstration

10.7 Computer hard-drive super-slow-motion video of track finding

Relays, because they create a mechanical connection and don't require voltage biasing, can be used to switch either DC or AC power. Also, the input circuit of a relay is electrically isolated from the output circuit, unlike the common-emitter transistor circuit, where there is a common ground between the input and output. Because the relay is electrically isolated, noise, induced voltages, and ground faults occurring in the output circuit have minimal impact on the input circuit. One disadvantage of relays is that they have slower switching times than transistors. And because they contain contacts and mechanical components, they wear out much faster. Video Demo 10.4 demonstrates how relays and transistors respond to different switching speeds.

As illustrated in Figure 10.3, a **voice coil** consists of a coil that moves in a magnetic field produced by a permanent magnet and intensified by an iron core. Figure 10.4 shows the coil and iron core of a commercially available voice coil, which can be used as either a sensor or an actuator. When used as an actuator, the force on the coil is directly proportional to the current in the coil. The coil is usually attached to a movable load such as the diaphragm of an audio speaker, the spool of a hydraulic proportional valve, or the read-write head of a computer disk drive. The linear response, small mass of the moving coil, and bidirectional capability make voice coils more attractive than solenoids for high-performance control applications.

Video Demos 10.5 and 10.6 show how a computer disk drive functions, where a voice coil is used to provide the pivoting motion of the read-write head. Video Demo 10.7 shows a super-slow-motion clip, filmed with a special high-speed camera, which dramatically demonstrates the accuracy and speed of the voice coil motion. The read-write head comes to a complete stop on one track before moving to another. In real-time (e.g., in Video Demo 10.6), this motion is a total blur.

■ CLASS DISCUSSION ITEM 10.1

Examples of Solenoids, Voice Coils, and Relays

Make a list of common household and automobile devices that contain solenoids, voice coils, and relays. Describe why you think the particular component was selected for each of the devices you cite.



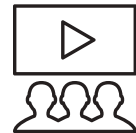
Figure 10.4 Photograph of a voice coil iron core and coil.

©David Alciatore

10.4 ELECTRIC MOTORS

Electric motors are by far the most ubiquitous of the actuators, occurring in virtually all electromechanical systems. Electric motors can be classified either by function or by electrical configuration. In the functional classification, motors are given names suggesting how the motor is to be used. Examples of functional classifications include torque, gear, servo, instrument servo, and stepping. However, it is usually necessary to know something about the electrical design of the motor to make judgments about its application for delivering power and controlling position. Figure 10.5 provides a configuration classification of electrical motors found in mechatronics applications. The differences are due to motor winding and rotor designs, resulting in a large variety of operating characteristics. The price-performance ratio of electric motors continues to improve, making them important additions to all sorts of mechatronic systems from appliances to automobiles. AC induction motors are particularly important in industrial and large consumer appliance applications. In fact, the AC induction motor is sometimes called the workhorse of industry. Video Demos 10.8 through 10.11 show some examples and describe how induction motors function. And for more information, see Internet Link 10.2.

Figure 10.6 illustrates the construction and components of a typical electric motor. The stationary outer housing, called the **stator**, supports radial magnetized poles. These poles consist of either permanent magnets or wire coils, called **field**



Video Demo

10.8 AC induction motor (single phase)

10.9 AC induction motor with a soft start for a water pump

10.10 AC induction motor variable frequency drive for a building air handler unit

10.11 How induction motors work



Internet Link

10.2 AC Induction motor

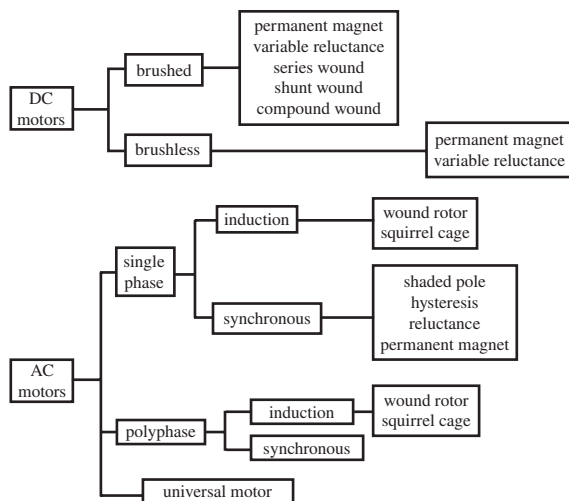


Figure 10.5 Configuration classification of electric motors.

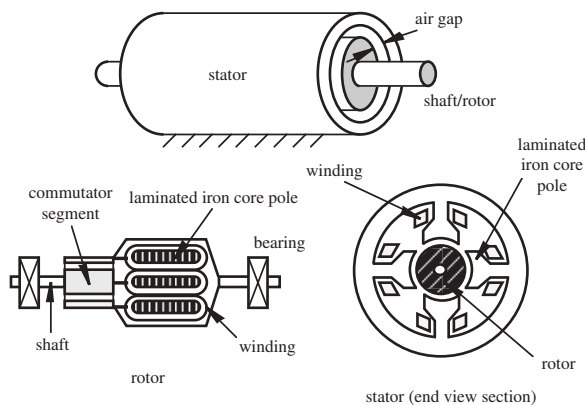


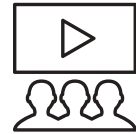
Figure 10.6 Motor construction and terminology.

coils, wrapped around laminated iron cores. The purpose of the stator poles is to provide radial magnetic fields. The iron core intensifies the magnetic field inside the coil due to its permeability. The purpose for laminating the core is to reduce the effects of eddy currents, which are induced in a conducting material (see Class Discussion Item 10.2). The **rotor** is the part of the motor that rotates. It consists of a rotating shaft supported by bearings, conducting coils usually referred to as the **armature** windings, and an iron core that intensifies the fields created by the windings. There is a small **air gap** between the rotor and the stator where the magnetic fields interact. In many **DC motors**, the rotor also includes a **commutator** that delivers and controls the direction of current through the armature windings. For motors with a commutator, **brushes** provide stationary electrical contact to the moving commutator conducting segments. Brushes in early motors consisted of bristles of copper

wire flexed against the commutator, hence the term brush; but now they are usually made of graphite, which provides a larger contact area and is self-lubricating. The brushes are usually spring-loaded to ensure continual contact with the commutator. The advantage of a brushed motor is its simplicity since no sensors or control electronics are required. However, the brushes do create frictional drag, slightly reducing how much torque can be delivered to the load, and the electrical resistance between the brushes and the commutator result in some energy loss and heating. Also, there is a limit to the maximum speed the motor can run while allowing the brushes and commutator to function properly. And in the case of graphite, dust is created as the brushes wear. And with prolonged use, maintenance is required to replace worn-down brushes. Video Demo 10.12 shows a small, brushed, permanent-magnet DC motor disassembled so you can see the various components and how they function. This particular motor simply has brass tabs serving as the “brushes.”

A **brushless** DC motor has permanent magnets on the rotor and a rotating field in the stator. The permanent magnets on the rotor eliminate the need for a commutator. Instead, the DC currents in the stator coils are switched in response to proximity sensors (often Hall Effect sensors) that are triggered as the shaft rotates. Video Demos 10.13 and 10.14 show two examples of brushless DC motors, and Video Demo 10.15 provides an excellent explanation and animation demonstrating how brushless motors work. One advantage of a brushless motor is that it does not require maintenance to replace worn brushes. Also, there is no frictional drag associated with brushes. Therefore, they usually run more efficiently and more quietly than brushed motors. Also, because there are no rotor windings or iron core, the rotor inertia is much smaller, sometimes making control easier with faster response. There are also no rotor heat dissipation problems, because there are no rotor windings and hence no I^2R heating. Another advantage of not having brushes is that there is no arcing associated with mechanical commutation. Therefore, brushless motors create less EMI and are more suitable in environments where explosive gases might be present. One disadvantage of brushless motors is that they are more complex than brushed motors and can cost more due to the sensors and control circuitry required.

Figure 10.7 shows examples of commercially available assembled motors. In the top figure, the motor on the left is an AC induction motor with a gearhead speed reduction unit attached. The motor on the right is a two-phase stepper motor. Motors come in standard sizes with standard mounting brackets, and they usually include nameplates listing some of the motor’s specifications. The bottom figure shows the internal construction of a permanent-magnet-rotor stepper motor. Video Demo 10.16 shows other examples of commercially available regular DC motors and stepper motors.



Video Demo

10.12 DC motor components

10.13 Brushless DC motor from a computer fan

10.14 Brushless DC motor gear pump

10.15 How brushless motors work

10.16 DC and stepper motor examples

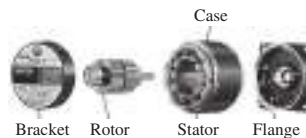
■ CLASS DISCUSSION ITEM 10.2

Eddy Currents

Describe the causes of eddy currents that are induced in a conducting material experiencing a changing magnetic field. The iron core in a motor rotor is usually laminated. Explain why. What is the best orientation for the laminations?



(a) AC induction and stepper motor



(b) exploded view of stepper motor with a permanent magnet rotor

Figure 10.7 Examples of commercial motors. (Courtesy of Oriental Motor, Torrance, CA)

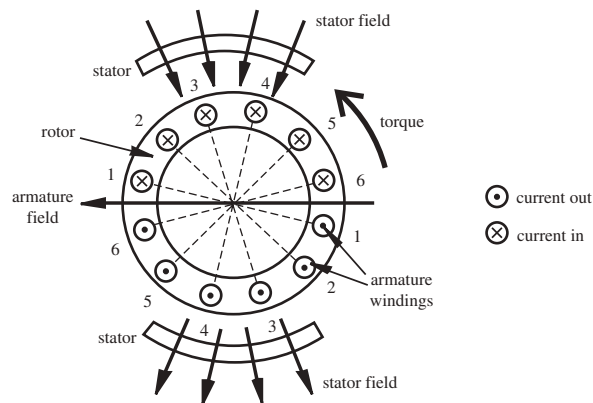


Figure 10.8 Electric motor field-current interaction.

Torque is produced by an electric motor through the interaction of either stator fields and armature currents or stator fields and armature fields. We illustrate both principles starting with the first. Figure 10.8 illustrates a DC motor with six armature windings. The direction of current flow in the windings is illustrated in the figure. As a result of Equation 10.1, the interaction of the fixed stator field and the currents in the armature windings produce a torque in the counterclockwise direction. You can verify this torque direction by applying the right-hand rule to the armature current

and stator field directions. To maintain the torque as the rotor rotates, the spatial arrangement of the armature currents relative to the stator field must remain fixed. A commutator accomplishes this by switching the currents in the armature windings in the correct sequence as the rotor turns.

Figure 10.9 illustrates an example commutator. It consists of a ring of alternating conductive and insulating materials connected to the rotor windings. Current is directed through the windings via the brushes, which slide on the surface of the commutator as it rotates. In the position shown, the current flows through windings *A*, *B*, and *C* in the clockwise direction and through *F*, *E*, and *D* in the counterclockwise direction.

When the rotor turns clockwise one sixth of a full rotation from the position shown, the currents in windings *C* and *F* switch directions. As the brushes slide over the rotating commutator, this process continues in sequence. With appropriate winding configurations, the commutator maintains a consistent spatial arrangement of the currents relative to the fixed stator fields. This continually maintains the torque in the desired direction.

Another method by which electric motors can create torque is through the interaction of stator and rotor magnetic fields. The torque is produced by the fact that like field poles attract and unlike poles repel. Figure 10.10 illustrates this principle of operation with a simple two-pole DC motor. The stator poles generate fixed magnetic fields with permanent magnets or coils carrying DC current. The winding in the rotor is commutated to cause changes in direction of its magnetic field. The interaction of the changing rotor field and the fixed stator fields produce a torque on the shaft, causing rotation. With the rotor in position *i*, the right brush contacts commutator segment *A* and the left brush contacts segment *B*, creating a current in the rotor winding, resulting in the magnetic poles as shown. The rotor magnetic poles oppose the stator magnetic poles, creating a torque causing clockwise motion of the rotor. In position *ii*, the stator poles both oppose and attract the rotor poles to enhance the clockwise rotation. Between positions *iii* and *v* the commutator contacts switch, changing the direction of the rotor current and hence the direction of the magnetic field. In position *iv*, both brushes temporarily lose contact with the commutator, and

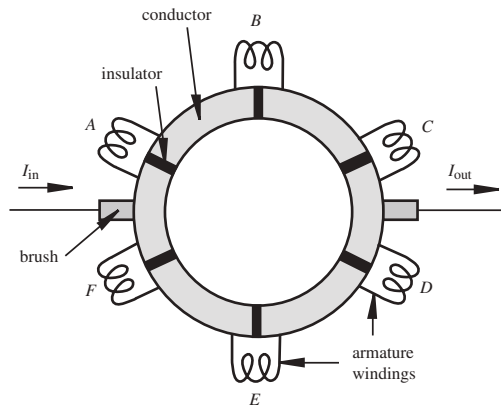


Figure 10.9 Electric motor six-winding commutator.

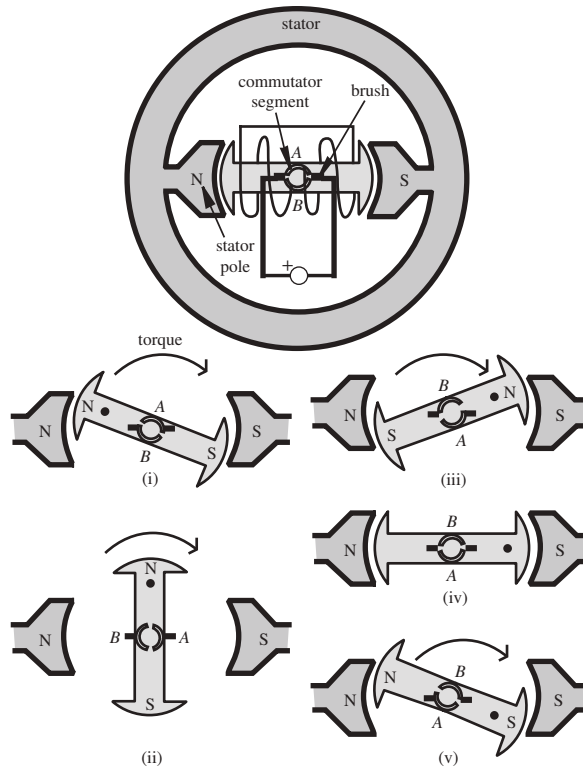


Figure 10.10 Electric motor field-field interaction.

the rotor temporarily experiences no torque, but the rotor continues to move due to its momentum. In position *v*, the reversed magnetic field in the rotor again opposes the stator field, continuing the clockwise torque and motion.

■ CLASS DISCUSSION ITEM 10.3

Field-Field Interaction in a Motor

Does the armature field in Figure 10.8 have any effect on the torque produced by the motor?



Video Demo

10.12 DC motor components

A problem with the simple two-pole design illustrated in Figure 10.10 is that starting would not occur if the motor happens to be in position *iv*, where the brushes are located over the commutator gaps. This problem can be avoided by designing the motor with more poles and more commutator segments with overlapping switching. This allows the brushes to always contact two active segments, even while switching (see Video Demo 10.12 and Class Discussion Item 10.4). Obviously, we would prefer to have a motor be “self starting” regardless of the position it happens to be in when power is applied.

Other problems not discussed with these simple models are a back electromotive force (emf) and induction. As the rotor windings cut through the stator magnetic field, a **back emf** is induced opposing the voltage applied to the rotor. Also, when the commutator switches the direction of current, a voltage is induced to oppose the change in current direction.

The principles of operation of **AC motors** are similar regarding interaction of the magnetic fields, but commutation is not required. This is because the magnetic field rotates around the stator as a result of the AC voltages and the arrangement of the coils around the stator housing. The rotor windings of **asynchronous** AC motors have no external voltage applied; rather, voltages are induced in the rotor windings due to the rotating fields around the stator. The rotor rotates at slower speeds than the rotating stator fields (this is called **slip**), making the induction possible, hence the term asynchronous. Because of this action, asynchronous motors are sometimes referred to as **induction machines**. With **synchronous** AC motors, the rotor windings are energized but through **slip rings** instead of a commutator. Brushes provide constant uninterrupted contact with the slip rings, causing fields to rotate around the rotor windings at the same rate as the fields rotate around the stator. Due to the interaction of these fields, the rotor rotates at the same speed as the stator fields, hence the term synchronous.

■ CLASS DISCUSSION ITEM 10.4

Dissection of Radio Shack Motor

Purchase an inexpensive 1.5–3 V DC motor (e.g., Radio Shack Catalog No. 273-223) and disassemble it. Identify the brushes, the commutator segments, the armature windings, the laminated rotor poles, and the stator permanent magnets. Sketch the magnetic field produced by the stator permanent magnets. For different commutator positions, determine the direction of current flow (and the resulting field direction) in the armature windings. Determine the direction of torque produced by the field-field and field-current interactions. Which effect do you think is stronger in this motor?

Internet Link 10.3 provides excellent illustrations and animations showing the fundamentals of how various motors, generators, and transformers function.

10.5 DC MOTORS

Direct current (DC) motors are used in a large number of mechatronic designs because of the torque-speed characteristics achievable with different electrical configurations. DC motor speeds can be smoothly controlled and in most cases are reversible. Since DC motors have a high ratio of torque to rotor inertia, they can respond quickly. Also, **dynamic braking**, where motor-generated energy is fed to a resistor dissipater, and **regenerative braking**, where motor-generated energy is fed back to the DC power supply, can be implemented in applications where quick stops and high efficiency are desired.



Internet Link

10.3 Electric motor illustrations and animations

Figure 10.11 illustrates a typical **torque-speed curve** that displays the torques a motor can provide at different speeds at rated voltage. For a given torque provided by the motor, the **current-torque curve** can be used to determine the amount of current required when rated voltage is applied. As a general rule of thumb, motors deliver large torques at low speeds, and large torques imply large motor currents. The **starting torque** or **stall torque** T_s is the maximum torque the motor can produce, at zero speed, associated with starting or overloading the motor. The **no-load speed** $\omega_{\max}$ is the maximum sustained speed the motor can attain. This speed can be reached only when no load or torque is applied to the motor (i.e., only when it is free running).

Based on how the stator magnetic fields are created, DC motors are classified into four categories: permanent magnet, shunt wound, series wound, and compound wound. The electrical schematics, torque-speed curves, and current-torque curves for each configuration are illustrated in Figures 10.12 through 10.15. In the figures, V is the DC voltage supply, I_A is the current in the rotor (armature) windings, I_F is the current in the stator (field) windings, and I_L is the total load current delivered by the DC supply.

The stator fields in **permanent magnet (PM) motors** (see Figure 10.12) are provided by permanent magnets, which require no external power source and therefore produce no I^2R heating (although, the armature coils on the rotor do require power and suffer from I^2R heating). A PM motor is lighter and smaller than other, equivalent DC motors because the field strength of permanent magnets is high. PM motors are easily reversed by switching the direction of the applied voltage, because the current and field change direction only in the rotor. The PM motor is ideal in control applications because of the linearity of its torque-speed relation. The design of a controller is always easier when the actuator is linear since the system analysis is greatly simplified. When a motor is used in a position or speed control application with sensor feedback to a controller, it is referred to as a **servomotor**. PM motors are used only in low-power applications since their rated power is usually limited to 5 hp (3728 W) or less, with fractional horsepower ratings being more common. PM DC motors can be brushed, brushless, or stepper motors.

Shunt motors (see Figure 10.13) have armature and field windings connected in parallel, which are powered by the same supply. The total load current is the sum of the armature and field currents. Shunt motors exhibit nearly constant speed over a large range of loading, have starting torques about 1.5 times the rated operating torque, have the lowest starting torque of any of the DC motors, and can be economically converted to allow adjustable speed by placing a potentiometer in series with the field windings.

Series motors (see Figure 10.14) have armature and field windings connected in series so the armature and field currents are equal. Series motors exhibit very high starting torques, highly variable speed depending on load, and very high speed when the load is small. In fact, large series motors can fail catastrophically when they are suddenly unloaded (e.g., in a belt drive application when the belt fails) due to dynamic forces at high speeds. This is called **run-away**. As long as the motor remains loaded, this poses no problem. The torque-speed curve for a series motor is hyperbolic in

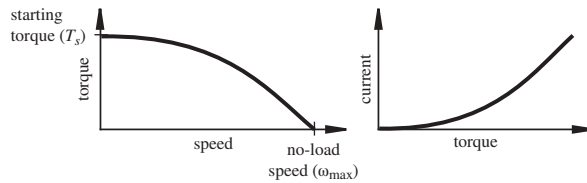


Figure 10.11 Motor torque-speed curve.

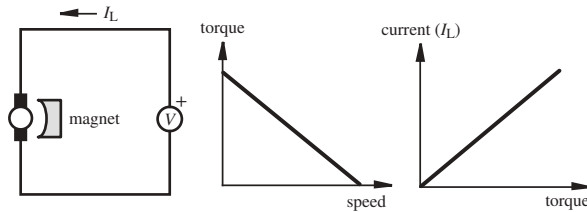


Figure 10.12 DC permanent magnet motor schematic and torque-speed curve.

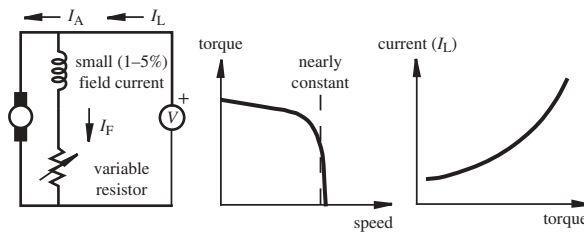


Figure 10.13 DC shunt motor schematic and torque-speed curve.

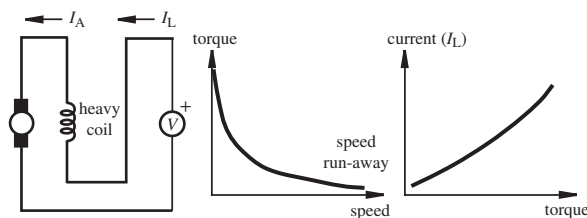


Figure 10.14 DC series motor schematic and torque-speed curve.

shape, implying an inverse relationship between torque and speed and nearly constant power over a wide range. A special type of series motor is called a **universal motor**. It can actually run on either DC or AC power, hence the name. Universal motors are commonly used in portable power tools and home appliances. For more information and examples, see Internet Link 10.4 and Video Demo 10.17.

Compound motors (see Figure 10.15) include both shunt and series field windings, resulting in combined characteristics of both shunt and series motors. Part



Internet Link

10.4 Universal motor



Video Demo

10.17 How universal motors work

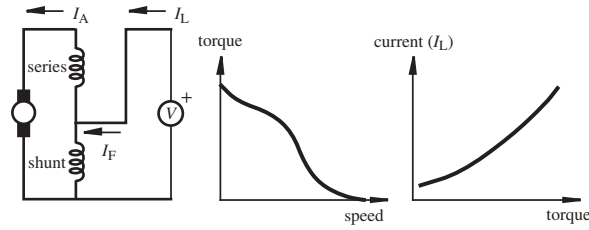


Figure 10.15 DC compound motor schematic and torque-speed curve.

of the load current passes through both the armature and series windings, and the remaining load current passes through the shunt windings only. The maximum speed of a compound motor is limited, unlike a series motor, but its speed regulation is not as good as with a shunt motor. The torque produced by compound motors is somewhat lower than that of series motors of similar size.

Note that, unlike the permanent magnet motor, when voltage polarity for a shunt, series, or compound DC motor is changed, the direction of rotation does not change (i.e., these motors are not reversible). The reason for this is that the polarity of both the stator and rotor changes because the field and armature windings are excited by the same source. Video Demo 10.18 provides excellent explanations and animations demonstrating how various types of DC motors operate.



Video Demo

10.18 How DC motors work

10.5.1 DC Motor Electrical Equations

As illustrated in Figure 10.16, the impedance of a DC motor's armature can be modeled as a resistance R in series with an inductance L . However, as the conducting armature begins to rotate in the magnetic field produced by the stator, a voltage called the **back emf** V_{emf} is induced in the armature windings opposing the applied voltage. The back emf is proportional to the speed of the motor ω in rad/sec:

$$V_{\text{emf}} = k_e \omega \quad (10.2)$$

where the proportionality constant k_e is called the **electrical constant** of the motor.

If the voltage applied to the armature is V_{in} , and the current through the armature is I_{in} , the electrical equation for the motor is

$$V_{\text{in}} = L \frac{dI_{\text{in}}}{dt} + RI_{\text{in}} + k_e \omega \quad (10.3)$$

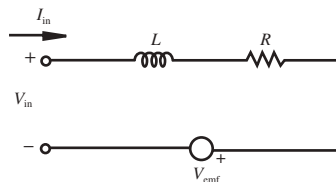


Figure 10.16 Motor armature equivalent circuit.

10.5.2 Permanent Magnet DC Motor Dynamic Equations

Since the permanent magnet (PM) DC motor is so important and is the easiest to understand and analyze, we look at its governing equations in more detail. Due to the interaction between the stator field and the armature current, the torque generated by a PM DC motor is directly proportional to armature current:

$$T = k_t I_{\text{in}} \quad (10.4)$$

where k_t is defined as the **torque constant** of the motor. A PM motor's electrical constant k_e and torque constant k_t are very important parameters, and they are often reported in manufacturer specifications. When the dynamics of a motor and its load are considered, the generated motor torque T is given by

$$T = (J_a + J_L) \frac{d\omega}{dt} + T_f + T_L \quad (10.5)$$

where J_a and J_L are the polar moments of inertia of the armature and the attached load, T_f is the frictional torque opposing armature rotation (including drag created by air resistance), and T_L is the torque dissipated by the load.

When voltage is applied to a PM DC motor, the rotor accelerates until a steady state operating condition is attained. At steady state, Equation 10.3 becomes

$$V_{\text{in}} = RI_{\text{in}} + k_e \omega \quad (10.6)$$

Note that, at steady state, from Equation 10.5, the motor torque balances the friction and load torques.

By solving for I_{in} in Equation 10.4 and substituting into Equation 10.6, we get

$$V_{\text{in}} = \left(\frac{R}{k_t} \right) T + k_e \omega \quad (10.7)$$

and by solving for the motor torque in this equation, we get

$$T = \left(\frac{k_t}{R} \right) V_{\text{in}} - \left(\frac{k_e k_t}{R} \right) \omega \quad (10.8)$$

This equation predicts the linear torque-speed relation for a PM DC motor with a fixed applied voltage.

Figure 10.17 shows the linear torque-speed curve and the power-speed curve for a permanent magnet DC motor with a fixed supply voltage V_{in} . The linear relation in Equation 10.8 can also be expressed in terms of the starting torque T_s and the no-load speed ω_{max} as

$$T(\omega) = T_s \left(1 - \frac{\omega}{\omega_{\text{max}}} \right) \quad (10.9)$$

The no-load speed is the steady-state speed at which the motor will run if there is no load torque ($T_L = 0$). At this speed, the motor torque balances the friction torque (i.e., $T = T_f$).

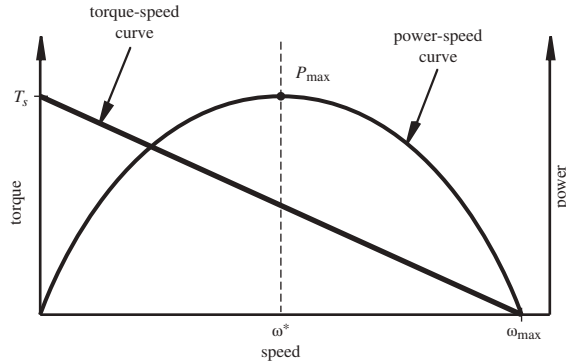


Figure 10.17 Permanent magnet DC motor characteristics.

By comparing Equations 10.8 and 10.9, you can see that the stall torque and no-load speed are related to the motor parameters according to

$$T_s = \left(\frac{k_t}{R} \right) V_{in} \quad (10.10)$$

and

$$\omega_{max} = \frac{T_s R}{k_e k_t} \quad (10.11)$$

Using Equation 10.9, the power delivered by the motor at different speeds can be expressed as

$$P(\omega) = T\omega = \omega T_s \left(1 - \frac{\omega}{\omega_{max}} \right) \quad (10.12)$$

The maximum power output of the motor occurs at the speed where

$$\frac{dP}{d\omega} = T_s \left(1 - \frac{2\omega}{\omega_{max}} \right) = 0 \quad (10.13)$$

Solving for the speed gives

$$\omega^* = \frac{1}{2} \omega_{max} \quad (10.14)$$

Therefore, the best speed to run a permanent magnet motor to achieve maximum power output is half the no-load speed.

In addition to the electrical and torque constants, manufacturers often specify the armature resistance R . Using Equations 10.4 and 10.10, the **stall current** I_s can be found in terms of the armature resistance and supply voltage:

$$I_s = \frac{V_{in}}{R} \quad (10.15)$$

This equation for current is valid only when the motor rotor is not turning; otherwise, the rotor current is affected by the back emf induced in the rotor windings. The stall current is the maximum current through the motor for a given supply voltage.

10.5.3 Electronic Control of a Permanent Magnet DC Motor

The simplest form of motor control is open loop control, where one simply sets the drive voltage value, and the motor characteristics and load determine the operating speed and torque. But most interesting problems require some sort of automatic control, where the voltage is automatically varied to produce a desired motion. This is called **closed-loop** or **feedback control**, and it requires an output speed and/or torque sensor to feed back output values to continuously compare the actual output to a desired value, called the **set point**. The controller then actively changes the motor output to move closer to the set point. Electronic speed controllers are of two types: linear amplifiers and pulse width modulators. Pulse width modulation controllers have the advantage that they either drive bipolar power transistors rapidly between cutoff and saturation or they turn FETs on and off. In either case, power dissipation is small. Servo amplifiers using linear power amplification are satisfactory but produce a lot of heat, because they function in the transistor linear region. You will find commercial servo controllers using linear amplifiers, but because of lower power requirements, ease of design, smaller size, and lower cost, we focus on the switched amplifier designs, which are generally called **pulse-width modulation (PWM)** amplifiers.

The principle of a PWM amplifier is shown in Figure 10.18. A DC power supply voltage is rapidly switched at a fixed frequency f between two values (e.g., ON and OFF). This frequency is often in excess of 1 kHz. The high value is held during a variable pulse width t within the fixed period T where

$$T = \frac{1}{f} \quad (10.16)$$

The resulting asymmetric waveform has a **duty cycle** defined as the ratio between the ON time and the period of the waveform, usually specified as a percentage:

$$\text{duty cycle} = \frac{t}{T} 100\% \quad (10.17)$$

As the duty cycle is changed (by the controller), the average current through the motor changes, causing changes in speed and torque at the output. It is primarily the duty cycle, and not the value of the power supply voltage, that is used to control the speed of the motor. Section 10.7 covers how PWM signals are used to control standard radio-controlled (RC) servomotors. Lab Exercise 11 explores how to use a microcontroller to generate a PWM signal to vary the speed of a DC motor. The end result of the exercise is demonstrated in Video Demo 7.5.

The block diagram of a PWM speed feedback control system for a DC motor is shown in Figure 10.19. A voltage tachometer produces an output linearly related to the motor speed. This is compared to the desired speed set point (another voltage



Video Demo

7.5 Pulse-width-modulation speed control of a DC motor, with keypad input



Lab Exercise

Lab 11 Pulse-width-modulation motor speed control with a PIC

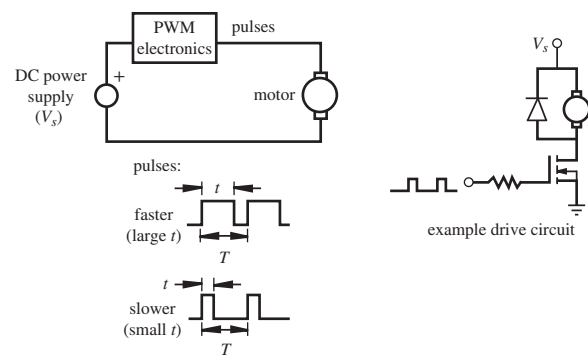


Figure 10.18 Pulse width modulation of a DC motor.

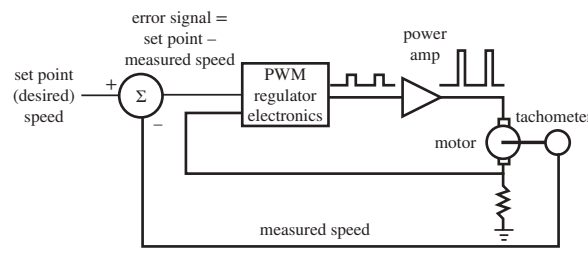


Figure 10.19 PWM velocity feedback control.

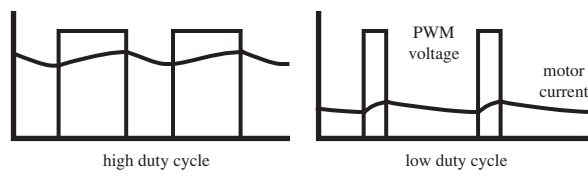


Figure 10.20 PWM voltage and motor current.

that can be manually set or computer controlled). The error and the motor current are sensed by a pulse-width-modulation regulator that produces a width-modulated square wave as an output. This signal is amplified to a level appropriate to drive the motor.

In a PWM motor controller, the armature voltage switches rapidly, and the current through the motor is affected by the motor inductance and resistance. Since the switching speed is high, the resulting current through the motor has a small fluctuation around an average value, as illustrated in Figure 10.20. As the duty cycle grows larger, the average current grows larger and the motor speed increases.

10.5.4 Bidirectional DC Motor Control

To be able to reverse the direction of rotation of a DC motor, the applied voltage polarity across the motor and the resulting current direction must be flipped. This can be done with a circuit called an **H-bridge** illustrated in Figure 10.21. The “H” in the name comes from the configuration of the circuit, where the motor (M) is in the horizontal portion of the “H” and the four switches (Q_1 through Q_4) are in each of the four vertical legs of the “H.” Q_1 through Q_4 can be manual switches, relays, or transistors, and they must be turned on in pairs to send current through the motor in the desired direction. If switches Q_1 and Q_3 are ON and Q_2 and Q_4 are OFF, current flows through the motor from left to right (see the bold curved arrow in the figure), causing the motor to rotate in the forward direction. And if switches Q_2 and Q_4 are ON and Q_1 and Q_3 are OFF, current flows from right to left (see the dashed curved arrow in the figure), causing the motor to rotate in the reverse direction.

Figure 10.22 shows how an H-bridge can be constructed with pnp and npn BJT transistors. MOSFETs can also be used instead of BJT transistors (see Design Example 10.1). The top two transistors (Q_1 and Q_2) in Figure 10.22 are pnp

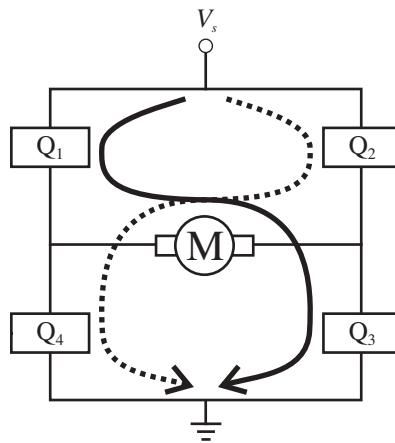


Figure 10.21 H-bridge current-direction control.

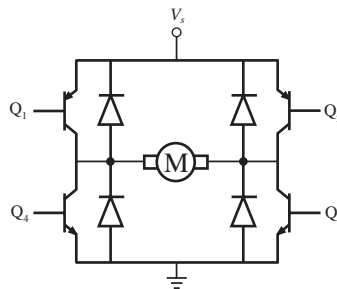


Figure 10.22 BJT H-bridge with flyback protection.

transistors, which are switched on with a low signal at the base (see Section 3.4.1). The bottom two transistors are npn transistors, which are switched on with a high signal at the base. To create the forward current in Figure 10.21, set Q_1 low (ON) and Q_3 high (ON), and set Q_2 high (OFF) and Q_4 low (OFF). And to create reverse current, set Q_1 high (OFF) and Q_3 low (OFF), and set Q_2 low (ON) and Q_4 high (ON). The four diodes create flyback protection in both directions (see Section 3.3.1 and Class Discussion Item 10.5). With a transistor H-bridge, PWM speed control (per Section 10.5.3) can be easily implemented by cycling the transistors on and off with the desired duty cycle.

■ CLASS DISCUSSION ITEM 10.5

H-bridge Flyback Protection

The four diodes in Figure 10.22 provide flyback protection (see Section 3.3.1) when the motor is switched off. Consider the case when current is flowing in the forward direction with transistors Q_1 and Q_3 both ON. If the diodes were not there, what would happen when the transistors are both switched off? With the diodes included, what is different? How does the motor current path change when the transistors are switched off?

Figure 10.23 shows how an H-bridge can be constructed with relays instead of transistors. Here, two double-pole, double-throw (DPDT) relays are being used. Refer to Section 9.3.1 for an introduction to switch terminology, which also applies to relays. And for more information about how relays work and why they are used, see Section 10.3. An alternative to the DPDT design in Figure 10.23 is to use four SPST relays instead, one for each switch (Q_1 through Q_4) in Figure 10.21, but the two DPDT approach is less expensive and requires less space. In Figure 10.23, the two relays are shown in their nonenergized states, with the pole contacts in the normally-closed (NC) throw positions. In this state, no voltage is applied to the motor, and it does not turn. When current is sent through the coil of a DPDT relay, both throw contacts switch over from the NC positions to the normally-open (NO) positions. When the relay on the left is energized (and the one on the right is not), voltage is applied to the left side of the motor and the right side of the motor is grounded, so current flows from left to the right and the motor turns forward. When the relay on the right is energized (and the one of the left is not), voltage is applied to the right side of the motor and the left side of the motor is grounded, so current flows from right to the left and the motor turns in the reverse direction. The signals “forward” and “reverse” are used to control the motor. The transistors are used to provide ample current through the relay coil to switch the relay. With small relays that don’t require much tripping current, digital signals (e.g., microcontroller outputs) might provide enough current to switch the relay (without the transistor assist). If not, the transistors will boost the current to the required level. The diodes across the relay coils are used

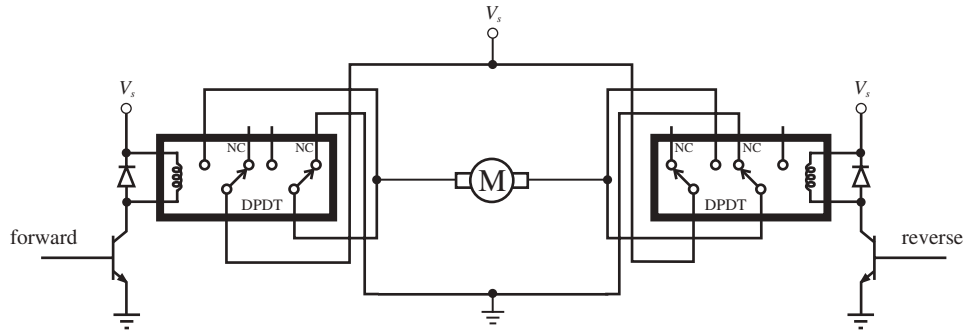


Figure 10.23 DPDT relay H-bridge.

to provide flyback protection for the transistors. The flyback protection shown in Figure 10.22 can also be applied to relay H-bridge designs.

Relays offer a simple solution and the advantage of electrical isolation between the control circuits (attached to the relay coils) and the motor circuit (which can involve significant noise and current spikes) if separate power supplies and grounds are used for the coil and motor circuits. However, relays have the disadvantage of not being able to switch very fast, so PWM speed control is not really an option. Also, because relays are mechanical devices, they make clicking sounds, and they can wear out and fail after many switching cycles. However, for applications where you need only reversibility and not PWM speed control, and where clicking sounds and long-term reliability are not concerns, relays can be a good option.

Instead of constructing your own H-bridge using discrete relay or transistor components, a better option might be to use a commercially available H-bridge provided as single-package unit that is carefully designed, inexpensive, and easy to use, and includes additional circuitry for a simplified interface and additional features. Design Example 10.1 and Threaded Design Example C.5 show examples using commercially available H-bridges. Electronics and hobby robotics vendors offer H-bridges in a variety of sizes, packages, and power ratings (see Internet Links 2.4 and 10.10).



Internet Link

2.4 Electronic component online resources and vendors

10.10 Hobby robotics online vendors

H-Bridge Drive for a DC Motor

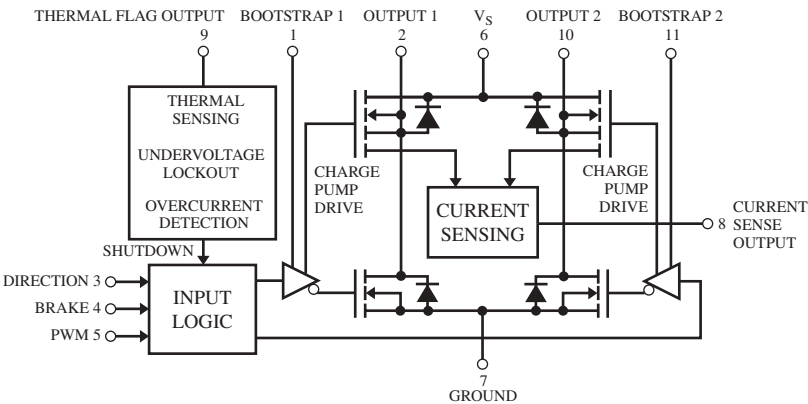
Although it is possible to design and build a drive circuit for a servomotor with discrete control and power components, several integrated circuit designs are available that save enormously on time and money in mechatronic design. In this design, we utilize a monolithic H-bridge from National Semiconductor's line of motion control ICs, which can be conveniently adapted for driving DC motors. Consider the LMD15200, a 3 A, 55 V H-bridge specifically designed to drive DC and stepper motors. It allows for current direction control, and also offers features for overcurrent and overtemperature detection, pulse width modulation, and dynamic braking. The functional diagram follows.

(continued)

DESIGN EXAMPLE 10.1

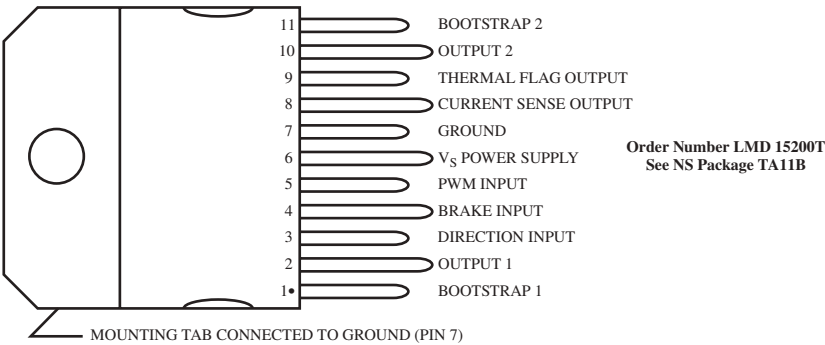
(concluded)

Functional Diagram



TL/H/10564-1

Function Diagram and Ordering Information



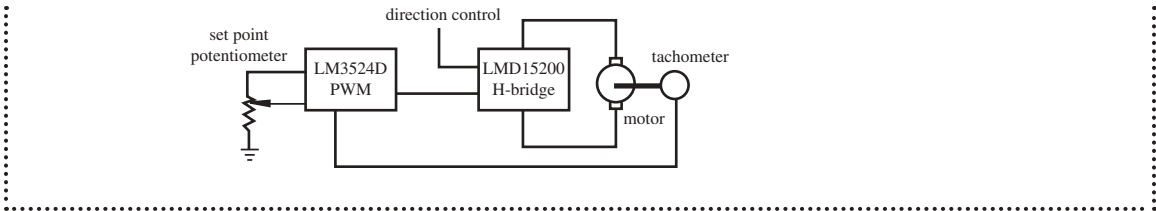
TL/H/10568-2

Top View

Source: National Semiconductor Inc., Santa Clara, CA

This design uses power MOSFETs with flyback protection diodes that suppress large reverse transients across the transistors. The motor poles are connected between Output 1 and Output 2. The voltage supply can be up to 55 V. External digital signals control direction, braking, and pulse width modulation. A thermal sensor shuts down the outputs when the device temperature exceeds 170°C.

The complete block diagram for our speed controller design is shown in the next figure. The speed set point is controlled with a potentiometer or input voltage value. A tachometer is added to the motor as the sensor to provide a measure of the motor speed. The National Semiconductor pulse width modulation IC LM3524D is conveniently used here to drive the H-bridge motor controller input.

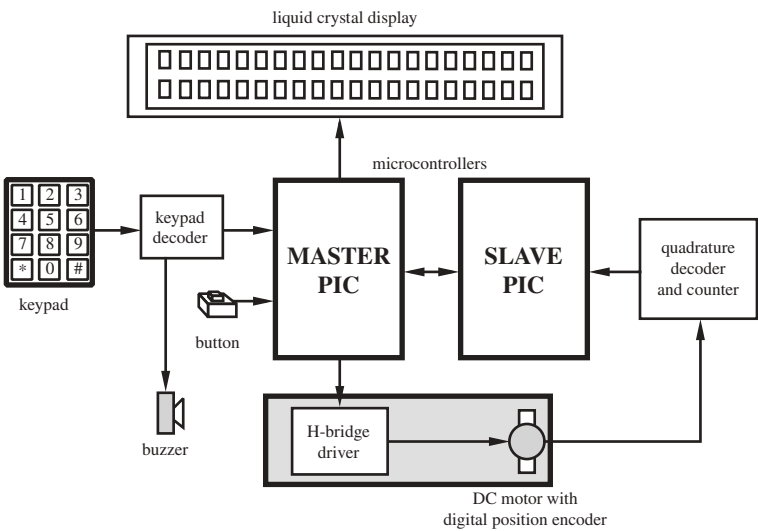


THREADED DESIGN EXAMPLE

DC motor position and speed controller—H-bridge driver and PWM speed control

C.5

The figure below shows the functional diagram for Threaded Design Example C (see Section 1.3 and Video Demo 1.8), with the portion described here highlighted.



Video Demo

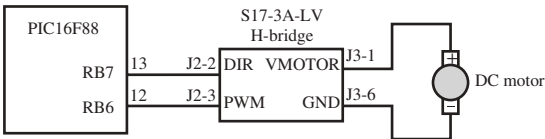
1.8 DC motor position and speed controller

The complete circuit required for this part of the design is shown below. A commercially available S17-3A-LV H-bridge was selected because of its ample current capacity and compatibility with the selected motor. It also exhibits a near linear relationship between PWM duty cycle and motor speed over a fairly large range. Details about the H-bridge and motor can be found at Internet Link 10.4. The two inputs to the H-bridge are a direction line to indicate whether the motor turns clockwise or counterclockwise, and a PWM line to control the speed of the motor via an appropriate duty cycle.



Internet Link

10.4 S17-3A-LV H-bridge



(continued)

(concluded)

The code used to rotate the motor at a desired speed is presented below. The subroutine *pwm_periods* calculates the pulse segment widths to create a duty cycle proportional to the desired motor speed. The subroutine *pwm_pulse* is called continuously by *run_motor* to keep the motor rotating at the selected speed. The comments in the code explain some of the details involved with the solution.

```
' Define I/O pin names
motor_dir Var PORTB.7      ' motor H-bridge direction line
motor_pwm Var PORTB.6      ' motor H-bridge pulse-width-modulation line

' Declare Variables
motor_speed Var BYTE       ' motor speed as percentage of maximum (0 to 100)
motion_dir Var BIT         ' motor direction (1:CW/Forward 0:CCW/Reverse)
on_time Var WORD           ' PWM ON pulse width
off_time Var WORD          ' PWM OFF pulse width
pwm_cycles Var BYTE        ' # of PWM pulses sent during the position control loop

' Define constants
pwm_period Con 50          ' period of each motor PWM signal cycle (in microsec)
                          ' (50 microsec corresponds to 20kHz)

' Initialize I/O and variables
TRISB.6 = 0                ' configure H-bridge DIR pin as an output
TRISB.7 = 0                ' configure H-bridge PWM pin as an output
motion_dir = CW            ' starting motor direction: CW (forward)
motor_speed = 50           ' starting motor speed = 50% duty cycle
Low motor_pwm              ' make sure the motor is off to begin with

' Subroutine to run the motor at the desired speed and direction until the
'   stop button is pressed. The duty cycle of the PWM signal is the
'   motor_speed percentage
run_motor:
  ' Set the motor direction
  motor_dir = motion_dir

  ' Output the PWM signal
  Gosub pwm_periods        ' calculate the on and off pulse widths
  While (stop_button == 0) ' until the stop button is pressed
    Gosub pwm_pulse ' send out a full PWM pulse
  Wend

Return

' Subroutine to calculate the PWM on and off pulse widths based on the desired
' motor speed (motor_speed)
pwm_periods:
  ' Be careful to avoid integer arithmetic and
  '   WORD overflow [max=65535] problems
  If (pwm_period >= 655) Then
    on_time = pwm_period/100 * motor_speed
    off_time = pwm_period/100 * (100-motor_speed)
```

```

Else
    on_time = pwm_period * motor_speed / 100
    off_time = pwm_period * (100-motor_speed) / 100
Endif
Return

' Subroutine to output a full PWM pulse based on the data from pwm_periods
pwm_pulse:
    ' Send the ON pulse
    High motor_pwm
    Pauseus on_time

    ' Send the OFF pulse
    Low motor_pwm
    Pauseus off_time
Return

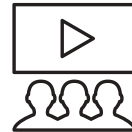
```

10.6 STEPPER MOTORS

A special type of DC motor, known as a **stepper motor**, is a permanent magnet or variable reluctance DC motor that has the following performance characteristics: it can rotate in both directions, move in precise angular increments, sustain a holding torque at zero speed, and be controlled with digital circuits. It moves in accurate angular increments, known as **steps**, in response to digital pulses sent to an electric drive circuit. The number and rate of the pulses control the position and speed of the motor shaft. Generally, stepper motors are manufactured with steps per revolution of 12, 24, 72, 144, 180, and 200, resulting in shaft increments of 30°, 15°, 5°, 2.5°, 2°, and 1.8° per step. Special **micro-stepping** circuitry can be designed to allow many more steps per revolution, often 10,000 steps/rev or more.

Stepper motors are either **bipolar**, requiring two power sources or a switchable polarity power source, or **unipolar**, requiring only one power source. They are powered by DC sources and require digital circuitry to produce coil energizing sequences for rotation of the motor. Feedback is not always required for control, but the use of an encoder or other position sensor can ensure accuracy when exact position control is critical. The advantage of operating without feedback (i.e., in open-loop mode) is that a closed-loop control system is not required. Generally, stepper motors produce less than 1 hp (746 W) and are therefore used only in low-power position control applications. Video Demos 9.2 and 10.19 show interesting student project examples of stepper motor applications.

A commercial stepper motor has a large number of poles that define a large number of equilibrium positions of the rotor. In the case of a permanent magnet stepper motor, the stator consists of wound poles, and the rotor poles are permanent magnets. Exciting different stator winding combinations moves and holds the rotor in different positions. The **variable reluctance** stepper motor has a ferromagnetic rotor rather than a permanent magnet rotor. Motion and holding result from the attraction of stator and rotor poles to positions with minimum magnetic reluctance (magnetic field resistance) that allow for maximum magnetic flux. A variable reluctance motor



Video Demo

9.2 Automated laboratory rat exercise machine with IR sensor and stepper motor

10.19 Multifunction slot machine

has the advantage of a lower rotor inertia and therefore a faster dynamic response. The permanent magnet stepper motor has the advantage of a small residual holding torque, called the **detent torque**, even when the stator is not energized.

To understand how the rotor moves in an incremental fashion, consider a simple design consisting of four stator poles and a permanent magnet rotor as illustrated in Figure 10.24. In step 0, the rotor is in equilibrium, because opposite poles on the stator and rotor are adjacent to and attract each other. Unless the magnet polarities of the stator poles are changed, the rotor remains in this position and can withstand an opposing torque up to a value called the **holding torque**. When the stator polarities are changed as shown (step 0 to step 1), a torque is applied to the rotor, causing it to move 90° in the clockwise direction to a new equilibrium position shown as step 1. When the stator polarities are again changed as shown (step 1 to step 2), the rotor experiences a torque driving it to step 2. By successively changing the stator polarities in this manner, the rotor can move to successive equilibrium positions in the clockwise direction. The sequencing of the pole excitations is the means by which the direction of rotation occurs. Counterclockwise motion can be achieved by applying the polarity sequence in the opposite direction. The motor torque is directly related to the magnetic field strength of the poles and the rotor.

The dynamic response of the rotor and attached load must be carefully considered in applications that involve starting or stopping quickly, changing or ramping speeds quickly, or driving large or changing loads. Due to the inertia of the rotor and attached load, rotation can exceed the desired number of steps. Also, as illustrated in Figure 10.25, a stepper motor driving a typical mechanical system through one step will exhibit an underdamped response. If damping is increased in the system, for example, with mechanical, frictional, or viscous damping, the response can be modified to reduce oscillation, as shown in the figure. Note, however, that even with an ideal choice for damping, the motor requires time to totally settle into a given position, and this settling time varies with the step size and the amount of damping. It is also important to note that the torque required from the motor increases with added damping. Video Demo 10.20 shows an example of a typical underdamped second-order system response of a stepper motor with a fairly large step size. It also shows how the response changes as the step rate increases. Video Demo 10.21 shows



Video Demo

10.20 Stepper motor step response and acceleration through resonance

10.21 High-speed video of medium speed response

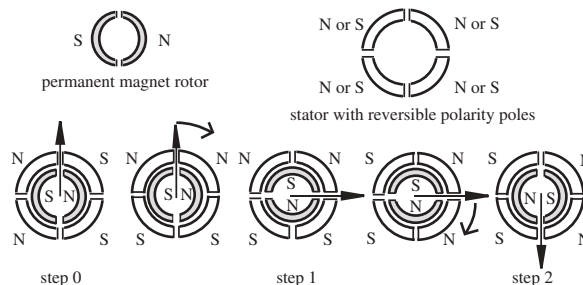


Figure 10.24 Stepper motor step sequence.

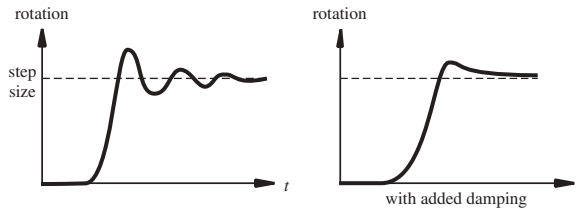


Figure 10.25 Dynamic response of a single step.

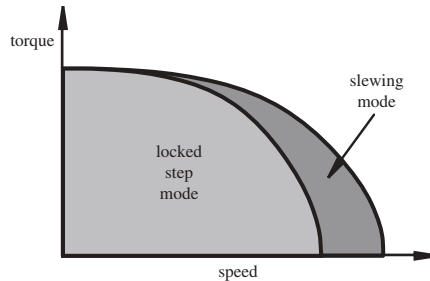


Figure 10.26 Stepper motor torque-speed curves.

slow-motion footage of the motor turning at a medium speed to show how the step response effects are less pronounced at higher step rates.

The torque-speed characteristics for a stepper motor are usually divided into two regions as illustrated in Figure 10.26. In the **locked step mode**, the rotor decelerates and may even come to rest between each step. Within this region, the motor can be instantaneously started, stopped, or reversed without losing step integrity. In the **slewing mode**, the speed is too fast to allow instantaneous starting, stopping, or reversing. The rotor must be gradually accelerated to enter this mode and gradually decelerated to leave the mode. While in slewing mode, the rotor is in synch with the stator field rotation and does not settle between steps. The curve between the regions in the figure indicates the maximum torques that the stepper can provide at different speeds without slewing. The curve bordering the outside of the slewing mode region represents the absolute maximum torques the stepper can provide at different speeds.

Figure 10.27 illustrates a unipolar stepper motor field coil schematic with external power transistors that must be switched on and off to produce the controlled sequence of stator polarities to cause rotation. The schematic in Figure 10.27 shows six wires connected to the motor. Because the second and fifth wires are usually connected externally as shown, manufacturers sometimes connect them inside the motor, in which case the motor only has five external wires. The wires are usually color coded by the manufacturers to help the user make a correspondence to the schematic. Figure 10.27 includes a common color scheme used for a six-wire unipolar stepper motor: yellow (coil 1), red (1/2 common), orange (coil 2), black (coil 3), green (3/4 common), brown (coil 4). Another common six-wire color scheme is

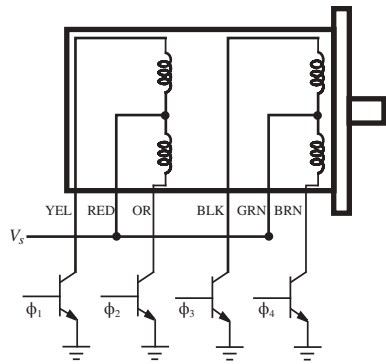


Figure 10.27 Standard unipolar stepper motor field coil schematic.



Internet Link

10.5 How to identify the different wires of a stepper motor

green (coil 1), white (1/2 common), blue (coil 2), red (coil 3), white (3/4 common), black (coil 4). A common color scheme for a five-wire unipolar stepper is red (coil 1), green (coil 2), black (common), brown (coil 3), white (coil 4). If you come across a motor for which you have no documentation and the color scheme is unknown, there is a testing procedure you can follow to determine the wire identities (e.g., see Internet Link 10.5 , being aware that the coils are numbered differently in the linked web page. Coils 3-2-1-4 in the web page correspond to coils 1-2-3-4 or ϕ_1 - ϕ_2 - ϕ_3 - ϕ_4 here).

Figure 10.28 illustrates the construction of and stepping sequence for a four-phase unipolar stepper motor. It consists of a two-pole permanent magnet rotor and a four-pole stator, with each pole wound by two complementary windings (e.g., ϕ_1 and ϕ_2 wound in opposite directions on the top left pole). Table 10.1 lists the phase sequence required to step the motor in full steps, where two of the four phases are energized (ON) and each stator pole is polarized. Table 10.2 lists the phase sequence for half-stepping, where between each full step only one phase is energized (ON) and

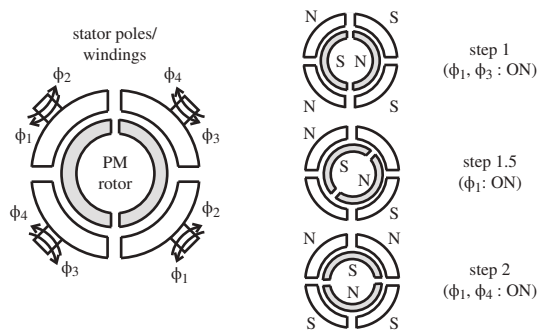


Figure 10.28 Example of a unipolar stepper motor.

Table 10.1 Unipolar full-step phase sequence

	Step	ϕ_1	ϕ_2	ϕ_3	ϕ_4
CW	1	ON	OFF	ON	OFF
↓	2	ON	OFF	OFF	ON
CCW	3	OFF	ON	OFF	ON
↑	4	OFF	ON	ON	OFF

Table 10.2 Unipolar half-step phase sequence

	Step	ϕ_1	ϕ_2	ϕ_3	ϕ_4
CW	1	ON	OFF	ON	OFF
↓	1.5	ON	OFF	OFF	OFF
	2	ON	OFF	OFF	ON
	2.5	OFF	OFF	OFF	ON
CCW	3	OFF	ON	OFF	ON
↑	3.5	OFF	ON	OFF	OFF
	4	OFF	ON	ON	OFF
	4.5	OFF	OFF	ON	OFF

only two stator poles are polarized. The resolution or number of steps of the motor is twice as large in the half-step mode (8 steps/rev at 45°) than in the full-step mode (4 steps/rev at 90°), but the holding torque and drive torque change between two values on alternate cycles in half-step mode. Another technique for increasing the number of steps is called **micro-stepping**, where the phase currents are controlled by fractional amounts, rather than just ON and OFF, resulting in more magnetic equilibrium positions between the poles. In effect, discretized sine waves are applied to the phases instead of square waves. The most common commercially available stepper motors have 200 steps/rev in full-step mode and are sometimes referred to as 1.8° ($360^\circ/200$) steppers. In micro-stepping mode, 10,000 or more steps per revolution can be achieved.

Figure 10.29 illustrates a bipolar stepper motor schematic with external power transistors that must be switched on and off in ordered combinations to produce the controlled sequence of stator polarities to cause rotation. There are four wires connected to the motor, which easily distinguishes it from a unipolar stepper, which has either five or six wires. The wires are usually color coded by the manufacturer to help make a correspondence to the schematic. Figure 10.29 includes a common color scheme used for a bipolar stepper motor: red (+) and grey (−) for the coil A, and yellow (+) and black (−) for coil B.

Table 10.3 lists the phase sequence required to step a bipolar stepper motor in full steps. Note that the table is the same as for a unipolar stepper (see Table 10.1), but here sets of two transistors are switched together for each ON or OFF state

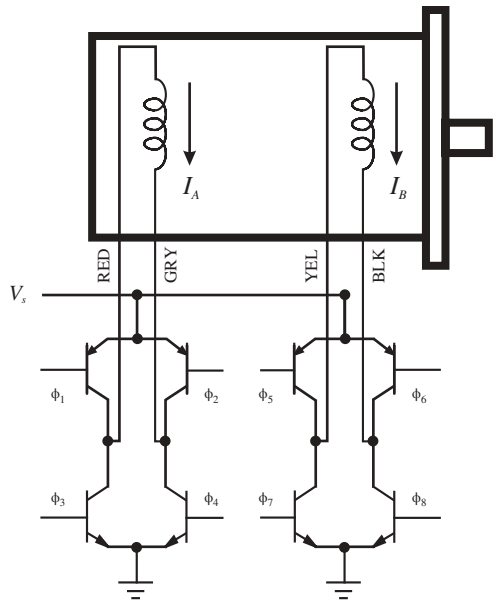


Figure 10.29 Standard bipolar stepper motor field coil schematic.

Table 10.3 Bipolar full-step phase sequence

	Step	ϕ_1 and ϕ_4	ϕ_2 and ϕ_3	ϕ_5 and ϕ_8	ϕ_6 and ϕ_7
CW	1	ON	OFF	ON	OFF
↓	2	ON	OFF	OFF	ON
CCW	3	OFF	ON	OFF	ON
↑	4	OFF	ON	ON	OFF

instead of just one with the unipolar sequence. The configuration of transistors is called an H-bridge configuration (see Section 10.5.4). By switching the transistors in pairs, the current direction can be reversed. For example, in step 1, transistors 1 and 4 are ON and transistors 2 and 3 are OFF. This applies power to coil A in the forward direction, creating a positive current ($I_A > 0$). Likewise, transistors 5 and 8 are ON and 6 and 7 are OFF in step 1, creating a positive current in coil B ($I_B > 0$). In step 2, transistors 5 and 8 are OFF and 6 and 7 are ON, reversing the direction of the current in coil B ($I_B < 0$). Table 10.4 lists the phase sequence for half-stepping. As with the unipolar motor, only half of the holding torque is available in the half-step positions, because only one coil is energized.

Figure 10.30 illustrates the structure, pole geometry, and coil connections of an actual stepper motor in more detail. This particular stepper motor can be wired as a four-phase unipolar motor or a two-phase bipolar motor. Figure 10.31 shows the 50-tooth split rotor with one side having north polarity and the other having south

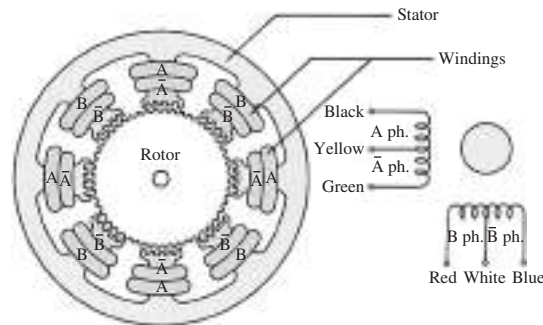


Figure 10.30 Typical stepper motor rotor and stator configuration.

Source: Oriental Motor, Torrance, CA



Figure 10.31 Actual stepper motor rotor.

Source: Oriental Motor, Torrance, CA

Table 10.4 Bipolar half-step phase sequence

	Step	ϕ_1 and ϕ_4	ϕ_2 and ϕ_3	ϕ_5 and ϕ_8	ϕ_6 and ϕ_7
CW	1	ON	OFF	ON	OFF
↓	1.5	ON	OFF	OFF	OFF
	2	ON	OFF	OFF	ON
	2.5	OFF	OFF	OFF	ON
CCW	3	OFF	ON	OFF	OFF
↑	3.5	OFF	ON	OFF	OFF
	4	OFF	ON	ON	OFF
	4.5	OFF	OFF	ON	OFF

polarity, creating a large number of effective poles. This type of stepper motor is sometimes called a **hybrid synchronous stepper** because it has a combination of the features of both a PM stepper (with the PMs on the rotor) and a variable-reluctance stepper (with the multiple tooth-like projections on both the PM rotor and the stator poles). Video Demo 10.22 provides an excellent explanation and demonstration of how these types of stepper motors provide the small step sizes that they do.

See Internet Link 10.6 for links to many resources and manufacturers for various stepper motor products.



Internet Link

10.6 Stepper motor online resource



Video Demo

10.22 Stepper motors and how to use them

10.6.1 Stepper Motor Drive Circuits

A drive circuit for properly phasing the signals applied to the poles of the unipolar stepper motor for rotation in full-step mode is easily and economically produced using the components illustrated in Figure 10.32. A similar drive circuit can be purchased as a single monolithic IC (e.g., Paladin's PDN1200, Signetics' SAA1027, or Allegro Microsystems' UCN 5804B). The discrete circuit includes 7414 Schmitt trigger buffers, a 74191 up-down counter, and 7486 Exclusive OR gates. The Schmitt triggers (see Section 6.12.2) produce well-defined control signals with sharp rise and fall times, even in the presence of noise or fluctuations on the direction (CW/CCW), initialization (RESET), and single-step (STEP) input lines. The up-down counter and the XOR gates in turn create four properly phased motor drive signals. These four digital signals ($\phi_1, \phi_2, \phi_3, \phi_4$) are coupled to the bases of power transistors that sequentially energize the respective motor coils connected to the DC motor supply, resulting in shaft rotation. Each square-wave pulse received at the STEP input causes the motor to rotate a full step in the direction determined by the CW/CCW input.

The timing diagram for the two least significant output bits B_0 and B_1 of the counter and the phase control signals is shown in Figure 10.33. Compare the signals

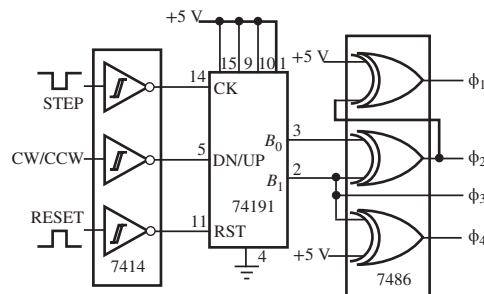


Figure 10.32 Unipolar stepper motor full-step drive circuit.

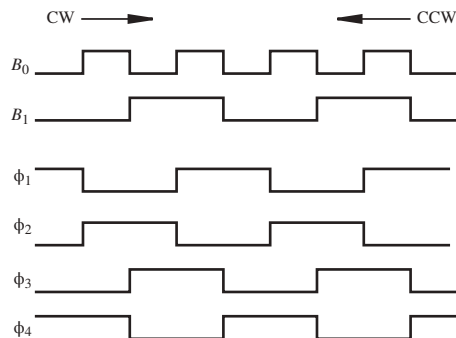


Figure 10.33 Timing diagram for full-step unipolar stepper motor drive circuit.

to the sequence in Table 10.1. They are in agreement. Boolean expressions that produce the four desired phased outputs from the two counter bits can be represented in both AND-OR-NOT and XOR forms:

$$\begin{aligned}\phi_1 &= \overline{\phi_2} = \phi_2 \oplus 1 \\ \phi_2 &= (B_0 \cdot \overline{B_1}) + (\overline{B_0} \cdot B_1) = B_0 \oplus B_1 \\ \phi_3 &= B_1 \\ \phi_4 &= \overline{B_1} = B_1 \oplus 1\end{aligned}\quad (10.18)$$

These expressions can be verified (Class Discussion Item 10.6) by checking the signal values at different times in the timing diagram shown in Figure 10.33. The purpose for representing the Boolean expressions in XOR form is to allow the logic to be executed using a single IC (the quad XOR 7486); otherwise, three ICs would be required for the AND, OR, and NOT representation.

■ CLASS DISCUSSION ITEM 10.6

Stepper Motor Logic

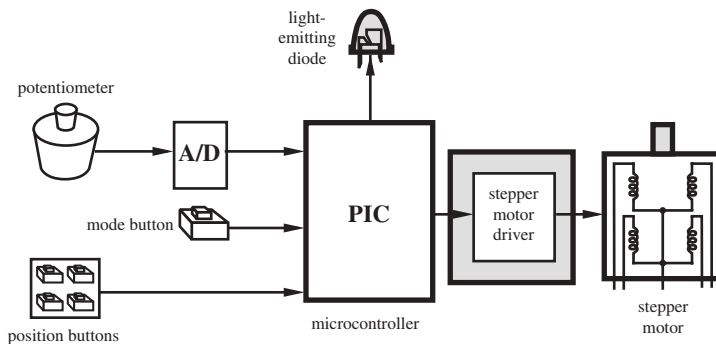
Construct a truth table for the timing diagram in Figure 10.33 and verify that Equations 10.18 are correct. Also, show that the sum-of-product and product-of-sum results for ϕ_2 are equivalent.

THREADED DESIGN EXAMPLE

Stepper motor position and speed controller—Stepper motor driver

B.3

The figure below shows the functional diagram for Threaded Design Example B (see Section 1.3 and Video Demo 1.7), with the portion described here highlighted.


Video Demo

1.7 Stepper motor position and speed controller


```

Else
    motor_dir = CCW
    delta = motor_pos - new_motor_pos
EndIf

' Determine the required number of steps (given 7.5 degrees per step)
num_steps = 10 * delta / 75

' Step the motor the appropriate number of steps
Gosub move_steps

' Update the current motor position
motor_pos = new_motor_pos
Return

' Subroutine to move the motor a given number of steps (indicated by num_steps)
move_steps:
    For i = 1 to num_steps
        Gosub step_motor
    Next
Return

' Subroutine to step the motor a single step (7.5 degrees) in the motor_dir direction
step_motor:
    Pulsout motor_step, 100 * step_period ' (100 * 10 microsec = 1 millisec)
    Pause step_period
    ' Equivalent code:
    ' High motor_step
    ' Pause step_period
    ' Low motor_step
    ' Pause step_period
Return

```

10.7 RC SERVOMOTORS

For small-scale projects requiring accurate and simple position or speed control, hobby **RC servomotors** are a good choice. An example is shown in Figure 10.34. The “RC” comes from the fact that these types of motors were originally developed for “radio control” or “remote control” model airplanes, cars, and boats, where the motors needed to be small and light and be able to move to and hold a range of positions for throttles, control surfaces, steering linkages, and rudders.

An RC servo includes several components inside: a small DC motor, a gear reducer to increase torque and reduce speed, a potentiometer to measure shaft position, and a circuit to perform closed-loop control (see Section 11.3) of motor position. RC servos have three colored leads for power (red), ground (black or brown), and control (white, orange, or yellow). The supply voltage is usually at or close to 5 V. The control lead is used to indicate the desired or commanded position using a form of **pulse-width**



Figure 10.34 Typical RC servomotor.

©David Alciatore

modulation (PWM). The width of a digital pulse on the control lead directly indicates the desired position based on the values shown in Table 10.5. The duty cycle of the signal is defined as the percentage of time the signal is on vs. off. Based on Figure 10.35, the duty cycle is $\Delta t/T \cdot 100\%$, where Δt is the pulse width and T is the total period of the pulse cycle, which is usually 20 ms. The angular position changes linearly with pulse width for values between those shown in Table 10.5. RC servomotor PWM is very different from PWM speed control of a DC motor (see Section 10.5.3), where the duty cycle is used to control motor speed by effectively changing the average voltage to the motor. Both Arduino and PIC microcontroller code examples for controlling RC servos can be found under “Servomotor Control” in Table 7.6 in Section 7.7.

Table 10.5 RC servomotor positions

pulse width (ms)	duty cycle	angular position
1	5%	−90°
1.25	6.25%	−45°
1.5	7.5%	0°
1.75	8.75%	45°
2	10%	90°

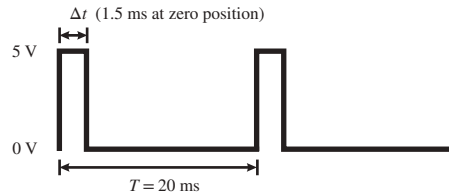


Figure 10.35 RC servo PWM.

An RC servo is designed to move to and hold a desired position. The larger the error between the current position and the commanded position, the faster the motor will move to reduce the error. This is called proportional control (for more info, see Section 11.3.3). The range of motion of an RC servo is usually 180°, but larger ranges are also available. Regardless of the range of motion, the 1.5 ms pulse width always corresponds to the center of the range of motion (0°). During motion to a new position, the PWM pulses must be sent continuously. Since the pulse cycle is 20 ms, the pulses are usually sent at a frequency of 50 Hz ($1 / [20 \text{ ms}]$). Once the motor reaches a commanded position, the pulses no longer need to be sent unless externally forces or torques are large enough to move the output shaft, in which case the pulses must continue to be sent to hold the position.

RC servos are inexpensive, widely available, easy to control, and do not require large voltages, all of which makes them popular choices for mechatronics hobbyists and students building small-scale projects requiring position control. They are available in hobby stores and from online small-scale-robotics suppliers (see Internet Link 10.10) in a variety of sizes and torque ratings, and they include mounting-brackets that are standard from one manufacturer to the next. They also usually come with an assortment of mounting hardware that can be attached to the output shaft and used to connect to components you want to move. The output arm shown in Figure 10.34 contains many mounting holes that pins, hooks, wires, or strings can be easily attached to create motion of connected components.

Continuous-rotation RC servos are also available, where pulse width controls the speed of the motor rather than position. A pulse width of 1.5 ms (the “zero position”) creates no motion, a pulse width less than 1.5 ms causes clockwise (CW) motion, and a pulse width greater than 1.5 ms causes counterclockwise (CCW) motion. The motor speed is proportional to the how different the pulse width is from the zero-position pulse width. A continuous-rotation servo often includes a trim pot that can be adjusted to fine-tune the zero “position” since it might not always be exactly at 1.5 ms (until it is adjusted with the trim pot).

Video Demo 10.23 does an excellent job summarizing and demonstrating all of the concepts in this section.

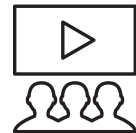
10.8 SELECTING A MOTOR

When selecting a motor for a specific mechatronics application, the designer must consider many factors and specifications, including speed range, torque-speed variations, reversibility, operating duty cycle, starting torque, and power required. These and other factors are described here in a list of questions that a designer must consider



Internet Link

10.10 Hobby robotics online vendors



Video Demo

10.23 Servos and how to use them

when selecting and sizing a motor in consultation with a motor manufacturer. As we will see, the torque-speed curve provides important information, helping to answer many questions about a motor's performance. Recall that the torque-speed curve displays the torques the motor can deliver at different speeds at rated voltage. Figure 10.36 shows an example of a torque-speed curve for a stepper motor, and Figure 10.37 shows an example of a torque-speed curve for a servomotor. These figures are examples from motor manufacturer specification sheets.

Some of the salient questions a designer may need to consider when choosing a motor for an application include the following:

- *Will the motor start and will it accelerate fast enough?* The torque at zero speed, called the **starting torque**, is the torque the motor can deliver when

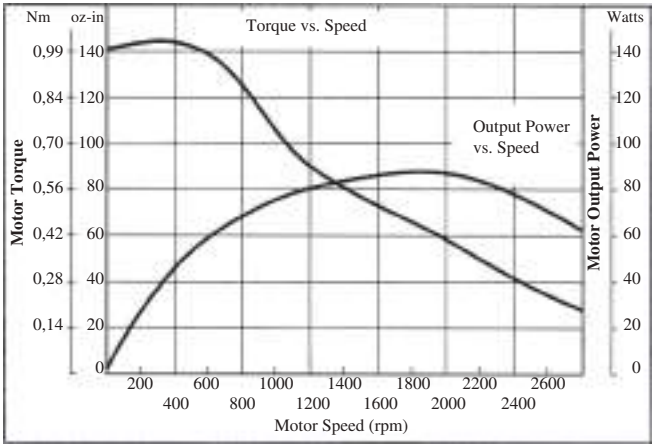


Figure 10.36 Typical stepper motor performance curves.
Source: Aerotech, Pittsburgh, PA

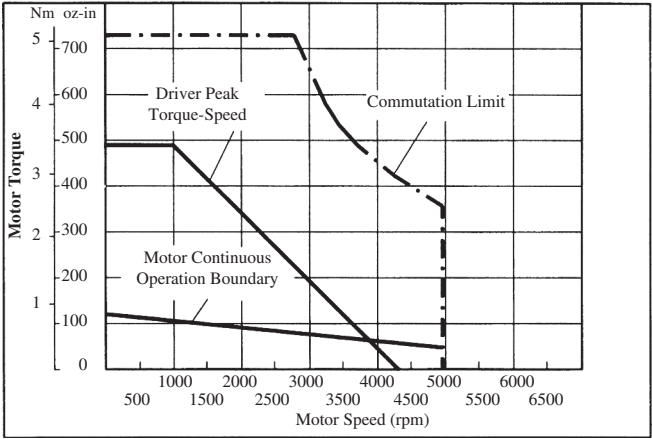


Figure 10.37 Typical servomotor performance curves.
Source: Aerotech, Pittsburgh, PA

rotation begins. For the system to be self-starting, the motor must generate torque sufficient to overcome friction and any load torques.

The acceleration of the motor and load at any instant is given by

$$\alpha = (T_{\text{motor}} - T_{\text{load}})/J \quad (10.19)$$

where α is the angular acceleration in rad/sec^2 , T_{motor} is the torque produced by the motor, T_{load} is the torque dissipated by the load, and J is the total polar moment of inertia of the motor rotor and the load. The difference between motor and load torques determines the acceleration of the system. When the motor torque is equal to the load torque, the system is at a steady state operating speed.

- *What is the maximum speed the motor can produce?* The zero torque point on the torque-speed curve determines the maximum speed a motor can reach. Note that the motor cannot deliver any torque to the load at this speed. When the motor is loaded, the maximum no-load speed cannot be achieved.
- *What is the operating duty cycle?* When a motor is not operated continuously, one must consider the operating cycle of the system. The **duty cycle** is defined as the ratio of the time the motor is on with respect to the total elapsed time. If a load requires a low duty cycle, a lower-power motor may be selected that can operate above rated levels but still perform adequately without overheating during repeated on-off cycles.
- *How much power does the load require?* The power rating is a very important specification for a motor. Knowing the power requirements of the load, a designer should choose a motor with adequate power based on the duty cycle.
- *What power source is available?* Whether the motor is AC or DC might be a critical decision. Also, if battery power is to be used, the battery characteristics must match the load requirements.
- *What is the load inertia?* As Equation 10.19 implies, for fast dynamic response, it is desirable to have low motor rotor and load inertia J . When the load inertia is large, the only way to achieve high acceleration is to size the motor so it can produce much larger torques than the load requires under steady state conditions.
- *Is the load to be driven at constant speed?* The simplest method to achieve constant speed is to select an AC synchronous motor or a DC shunt motor which runs at a relatively constant speed over a significant range of load torques. Stepper motors and servomotors can also be driven at constant and accurate speeds, but these alternatives can involve more cost and might not be available in larger sizes (e.g., as required in industrial applications).
- *Is accurate position or speed control required?* In the cases of angular positioning at discrete locations and incremental motion, a stepper motor is a good choice. A stepper motor is easily rotated to and held at discrete positions. It also can rotate at a wide range of speeds by controlling the step rate. The stepper motor can be operated with open-loop control, where no sensor feedback is required. However, if you attempt to drive a stepper motor at too fast a step rate or if the load torque is too large, the stepper motor may slip and not execute the number of steps

expected. Therefore, a feedback sensor such as an encoder might be included with a stepper motor to check if the motor has achieved the desired motion.

For some complex motion requirements, where precise position or speed profiles are required (e.g., in automation applications where machines need to perform prescribed programmed motion), a servomotor may be the best choice. A **servomotor** is a DC, AC, or brushless DC motor combined with a position sensing device (e.g., a digital encoder). The servomotor is driven by a programmable controller that processes the sensor input and generates amplified voltages and currents to the motor to achieve specified motion profiles. This is called **closed-loop control**, since it includes sensor feedback. A servomotor is typically more expensive than a stepper motor, but it can have a much faster and smoother response. Video Demo 10.24 shows the typical components in a commercial servomotor system, and Internet Link 10.7 provides links to resources and vendors of motion control products.



Video Demo

10.24 Servomotor system

10.25 Sign language machine

10.26 Automatic sensing prosthetic

For small-scale robotics and hobby projects, an RC servo is a good option. An RC servo is a small DC motor with an integral potentiometer (to sense shaft angle) and feedback electronics to provide position control directed by a PWM input signal. For more information, see Section 10.7. Video Demos 10.25 and 10.26 show interesting examples of student projects utilizing RC servos.

- *Is a transmission or gearbox required?* Often loads require low speeds and large torques. Since motors usually have better performance at high speed and low torque, a speed-reducing transmission (gear box or belt drive) is often needed to match the motor output to the load requirements. The term **gear motor** is used to refer to a motor-gearbox assembly sold as a single package.

When a transmission is used, the effective inertia of the load is

$$J_{\text{eff}} = J_{\text{load}} \left(\frac{\omega_{\text{load}}}{\omega_{\text{motor}}} \right)^2 \quad (10.20)$$

where J_{eff} is the effective polar moment of inertia of the load as seen by the motor. The sum of this inertia and the motor rotor inertia can be used in Equation 10.19 (i.e., $J = J_{\text{motor}} + J_{\text{eff}}$) to calculate acceleration. The speed ratio in Equation 10.20 is called the **gear ratio** of the transmission. It is often specified as a ratio of two numbers, where one or both numbers are integers (which is always the case when using meshing gears, which have integer numbers of teeth). So a gear ratio is sometimes written $N : M$, which can be read as: N to M gear reduction. This means N turns of the motor are required to create M turns of the load, so for an $N : M$ gear ratio, the speeds are related by

$$\omega_{\text{load}} = (M/N)\omega_{\text{motor}} \quad (10.21)$$

- *Is the motor torque-speed curve well matched to the load?* If the load has a well-defined torque-speed relation, called a **load line**, it is wise to select a motor with a similar torque-speed characteristic. If this is the case, the motor torque can match the load torque over a large range of speeds, and the speed can be controlled easily by making small changes in voltage to the motor.



Internet Link

10.7 Motor and motion controller online resources and vendors

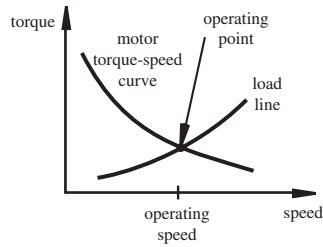


Figure 10.38 Motor operating speed.

- *For a given motor torque-speed curve and load line, what will the operating speed be?* As Figure 10.38 illustrates, for a given motor torque-speed curve and a well-defined load line, the system settles at a fixed speed operating point. Furthermore, the operating point is self-regulating. At lower speeds, the motor torque exceeds the load torque and the system accelerates toward the operating point, but at higher speeds, the load torque exceeds the motor torque, reducing the speed toward the operating point. The operating speed can be actively changed by adjusting the voltage supplied to the motor, which in turn changes the torque-speed characteristic of the motor.
- *Is it necessary to reverse the motor?* Some motors are not reversible due to their construction and control electronics, and care must be exercised when selecting a motor for an application that requires rotation in two directions.
- *Are there any size and weight restrictions?* Motors can be large and heavy, and designers need to be aware of this early in the design phase.

It can be very difficult to size motors for small-scale applications or hobby-scale projects because friction in moving parts is often a big factor, and it is very difficult to predict or model the amount of friction in bearings, on rubbing surfaces, at rolling contacts, and in joints that are slightly misaligned and/or flex. In larger precision-engineered systems, friction can often be ignored, and you can size based on the acceleration and load requirements. But for small-scale projects, sometimes trial and error will be required, or you can simply select a motor that is safely oversized for your needs. Fortunately, small-scale motors are not very expensive.

■ CLASS DISCUSSION ITEM 10.7

Motor Sizing

Why is it important not to oversize a motor for a particular application?

■ CLASS DISCUSSION ITEM 10.8

Examples of Electric Motors

Make a list of the different types of electric motors found in household devices and automobiles. Describe the reasons why you think the particular type of motor is used for each example you cite.

10.9 HYDRAULICS

Hydraulic systems are designed to move large loads by controlling a high-pressure fluid in distribution lines and pistons with mechanical or electromechanical valves. A hydraulic system, illustrated in Figure 10.39, consists of a pump to deliver high-pressure fluid, a pressure regulator to limit the pressure in the system, valves to control flow rates and pressures, a distribution system composed of hoses or pipes, and linear or rotary actuators. The infrastructure, which consists of the elements contained in the dashed box in the figure, is typically used to power many hydraulic valve-actuator subsystems.

A hydraulic **pump** is usually driven by an electric motor (e.g., a large AC induction motor) or an internal combustion engine. Typical fluid pressures generated by pumps used in heavy equipment (e.g., construction equipment and large industrial machines) are in the 1000 psi (6.89 MPa) to 3000 psi (20.7 MPa) range. The hydraulic fluid is selected to have the following characteristics: good lubrication to prevent wear in moving components (e.g., between pistons and cylinders), corrosion resistance, and incompressibility to provide rapid response. Most hydraulic pumps act by **positive displacement**, which means they deliver a fixed volume of fluid with each cycle or rotation of the pump. The three main types of positive displacement pumps used in hydraulic systems are gear pumps, vane pumps, and piston pumps. An example of a **gear pump**, which displaces the fluid around a housing between teeth of meshing gears, is shown in Figure 10.40. Note that the meshing teeth provide a seal, and the

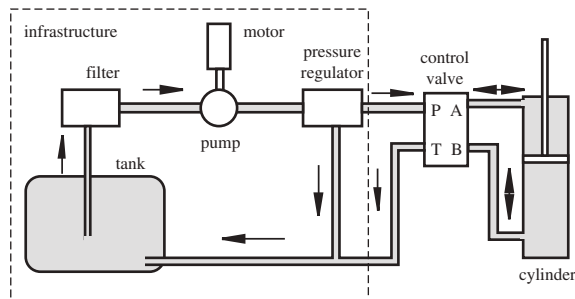


Figure 10.39 Hydraulic system components.

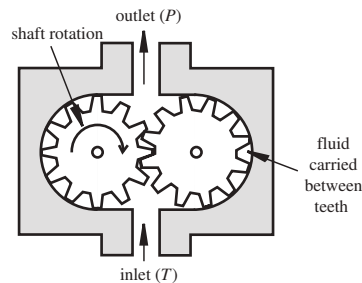


Figure 10.40 Gear pump.

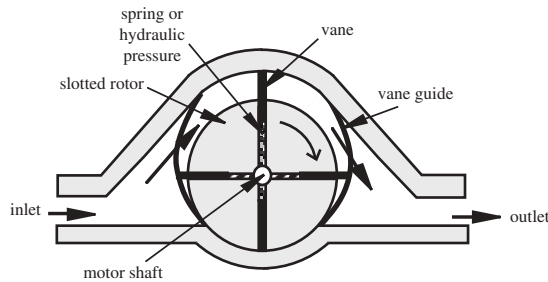


Figure 10.41 Vane pump.

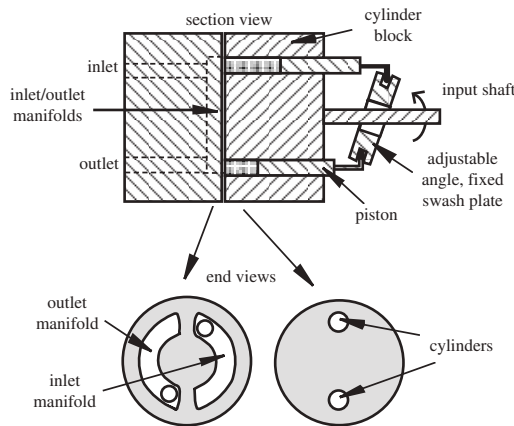


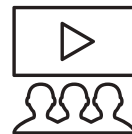
Figure 10.42 Swash plate piston pump.

fluid is displaced from the inlet to the outlet along the nonmeshing side of the gears. Video Demos 10.27 and 10.28 show and describe various types of gear pumps.

Figure 10.41 illustrates a **vane pump**, which displaces the fluid between vanes guided in rotor slots riding against the housing and vane guide. The vane guide supports the vanes from one side of the housing to the next and is constructed to allow the fluid to pass. The output displacement can be varied (with a constant motor speed) by moving the shaft vertically relative to the housing.

Figure 10.42 illustrates a **piston pump**. The cylinder block is rotated by the input shaft, and the piston ends are driven in and out as they ride in the fixed **swash plate** slot, which is angled with respect to the axis of the shaft. A piston draws fluid from an inlet manifold over half the swash plate and expels fluid into the outlet manifold during the other half. The displacement of the pump can be changed simply by changing the angle of the fixed swash plate. Table 10.6 lists and compares the general characteristics of the different pump types.

Since positive displacement hydraulic pumps provide a fixed volumetric flow rate, it is necessary to include a pressure relief valve, called a **pressure regulator**,



Video Demo

10.27 Gear pumps

10.28 Hydraulic gear pumps

Table 10.6 Comparison of pump characteristics

Pump type	Displacement	Typical pressure (psi)	Cost
Gear	Fixed	2000	Low
Vane	Variable	3000	Medium
Piston	Variable	6000	High

to prevent the pressure from exceeding design limits. The simplest pressure regulator is the spring-ball arrangement illustrated in Figure 10.43. When the pressure force exceeds the spring force, fluid is vented back to the tank, preventing a further increase in pressure. The threshold pressure, or **cracking pressure**, is usually adjusted by changing the spring’s compressed length and therefore its resisting force.

10.9.1 Hydraulic Valves

There are two types of hydraulic valves: the **infinite position valve** that allows any position between open and closed to modulate flow or pressure, and the **finite position valve** that has discrete positions, usually just open and closed, each providing a different pressure and flow condition. Inlet and outlet connections to a valve are called **ports**. Finite position valves are commonly described by an *x/y* designation, where *x* is the number of ports and *y* is the number of positions. As an example, a 4/3 valve, with 4 ports and 3 positions, is illustrated in schematic form in Figure 10.44. In position 1, system pressure is vented to tank; in position 2, output port A is pressurized and port B is vented to tank; and in position 3, output port B is pressurized and port A is vented to tank. As illustrated in Figure 10.45, this particular valve is useful in controlling a double-acting hydraulic cylinder where ports A and B connect to opposite ends of the cylinder, applying or venting pressure on opposite sides of the

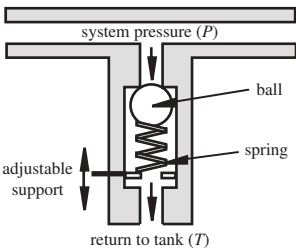


Figure 10.43 Pressure regulator.

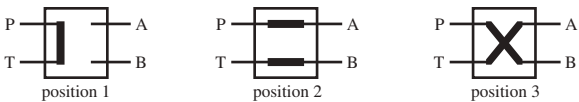


Figure 10.44 4/3 valve schematic.

piston. In position 1, the cylinder does not move, because the pressure is vented to the tank. In position 2, the cylinder moves to the right, since pressure is applied to the left side of the piston. In position 3, the cylinder moves to the left, because pressure is applied to the right side of the piston.

Common types of finite position valves are check valves, poppet valves, spool valves, and rotary valves. Figure 10.46 illustrates check and poppet valves. The **check valve** allows flow in one direction only. The **poppet valve** is a check valve that can be forced open to allow reverse flow.

As illustrated in Figure 10.47, a **spool valve** consists of a cylindrical spool with multiple lobes moving within a cylindrical casing containing multiple ports. The spool can be moved back and forth to align spaces between the spool lobes with input and output ports in the housing to direct high-pressure flow to different conduits in the system. The spool is balanced in each position because the static pressure is the same on opposing internal faces of the lobes. Therefore, no force is required to hold a position. In the left position, port A is pressurized, and port B is vented to the tank; and in the right position, port B is pressurized and port A is vented. To move the spool between positions, an axial force is required, from an actuator or manual control lever, to overcome the hydrodynamic forces associated with changing the momentum of the flow.

In the design of a spool valve where large hydrodynamic forces occur, a **pilot valve** is added, as shown in Figure 10.48. The pilot valve operates at a lower pressure, called **pilot pressure**, and at much lower flow rates and therefore requires less force to actuate. The pilot valve directs pilot pressure to one side of the main spool, and the force generated by the pressure acting over the main spool lobe face is large enough to actuate the main valve. The effect of the pilot valve is to amplify the force provided by the solenoid or mechanical lever acting on the pilot spool. In the figure, the pilot spool is in the full left position, causing pilot pressure to be applied to the left side of the main spool and venting fluid from the right side of the main spool to tank, thus driving the main spool to the full right position. This applies main

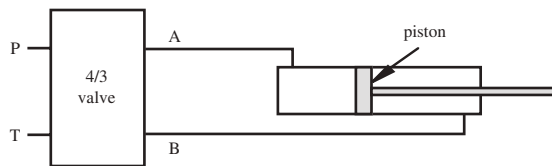


Figure 10.45 Double-acting hydraulic cylinder.

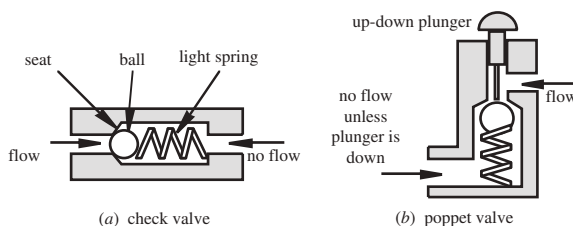


Figure 10.46 Check and poppet valves.

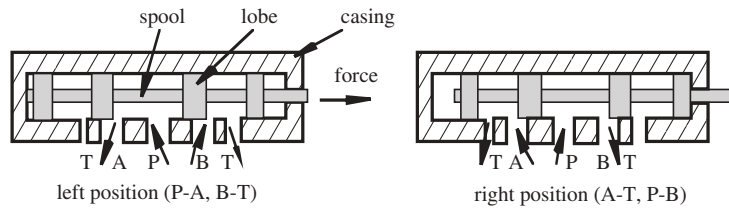


Figure 10.47 Spool valve.

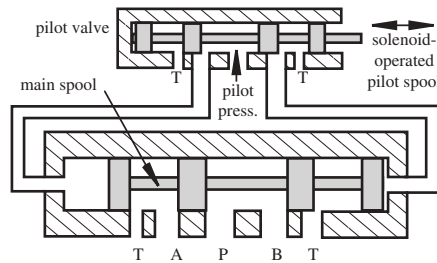


Figure 10.48 Pilot-operated spool valve.



Video Demo

10.29 Pilot valve hydraulic amplifier cut-away

pressure to port B and vents port A. Video Demo 10.29 illustrates how a pilot valve can be used to create an amplified hydraulic force.

The discussion of spool valves so far has been limited to operation between two positions only: on and off. Continuous operation can be achieved by using a **proportional valve**, one whose spool moves a distance proportional to a mechanical or electrical input (e.g., a lever or an adjustable-current solenoid), thus changing the rate of flow and varying the speed and force of the actuator. When the spool position is controlled by electrical solenoids, the proportional valve is called an **electrohydraulic valve**. These valves may be used in open-loop control situations with no feedback, but they often include sensors to monitor spool position or actuator output. Proportional valves equipped with sensor and control circuitry are often called **servo valves**. Electrohydraulic valves are often pilot operated where the solenoids drive the pilot spool, which in turn controls the position of the primary spool. The pilot spool can be driven by a single solenoid with a spring return or a set of opposing solenoids. The solenoid currents, and therefore displacements, can be controlled by amplifiers linked to analog or digital controllers.

10.9.2 Hydraulic Actuators

The most common hydraulic actuator is a simple **cylinder** with a piston driven by a pressurized fluid. As illustrated in Figure 10.49, a cylinder can be **single acting**, where it is driven to and held in one position by pressure and returned to the other position by a spring or by the weight of the load, or **double acting**, where pressure is used to drive the piston in both directions. As illustrated in Figure 10.50, the linear actuator can be very versatile in achieving a variety of motions. Cylinder motion in

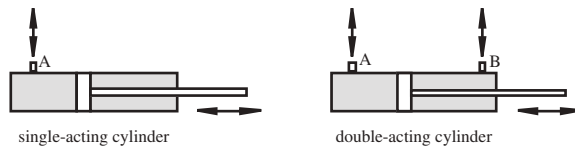


Figure 10.49 Single-acting and double-acting cylinders.

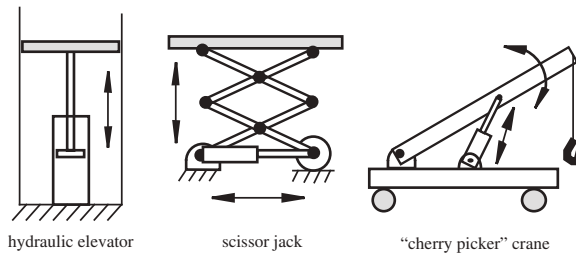


Figure 10.50 Example mechanisms driven by a hydraulic cylinder.

the hydraulic elevator drives the elevator directly. The scissor jack converts small linear motion in the horizontal direction to larger linear motion in the vertical direction. Linear motion of the cylinder in the crane results in rotary motion of its pivoted boom.

Rotary motion can also be achieved with hydraulic systems directly with a rotary actuator. One type of rotary actuator, called a **gear motor**, is simply a gear pump (see Figure 10.40) driven in reverse where pressure is applied, resulting in rotation of a shaft.

■ CLASS DISCUSSION ITEM 10.9

Force Generated by a Double-Acting Cylinder

For a given system pressure, is the force generated by a double-acting cylinder different depending on the direction of actuation? How is the force determined for each direction of motion?

Hydraulic systems have the advantage of generating extremely large forces from very compact actuators. They also can provide precise control at low speeds and have built-in travel limits defined by the cylinder stroke. The drawbacks of hydraulic systems include the need for a large infrastructure (high-pressure pump, tank, and distribution lines); potential for fluid leaks, which are undesirable in a clean environment; possible hazards associated with high pressures (e.g., a ruptured line); noisy operation; vibration; and maintenance requirements. Because of these disadvantages, electric motor drives are often the preferred choice. However, in large systems, which require extremely large forces, hydraulics often provide the only alternative. For more information, Internet Link 10.8 provides links to online resources and manufacturers of hydraulic components and systems.



Internet Link

10.8 *Hydraulic Valves.org*
(valve, pump, motor, cylinder manufactures and information)

10.10 PNEUMATICS

Pneumatic systems are similar to hydraulic systems, but they use compressed air as the working fluid rather than hydraulic liquid. The components in a pneumatic system are illustrated in Figure 10.51. A compressor is used to provide pressurized air, usually on the order of 70 to 150 psi (482 kPa to 1.03 MPa), which is much lower than hydraulic system pressures. As a result of the lower operating pressures, pneumatic actuators generate much lower forces than hydraulic actuators.

After the inlet air is compressed, excess moisture and heat are removed from the air with an air treatment unit (see Figure 10.51). Unlike hydraulic pumps, which provide positive displacement of fluid at high pressure on demand, compressors cannot provide high volume of pressurized air responsively; therefore, a large volume of high-pressure compressed air is stored in a reservoir or tank. The working pressure delivered to the system can be controlled by a pressure regulator to be much lower than the reservoir pressure. The reservoir is equipped with a pressure-sensitive switch that activates the compressor when the pressure starts to fall below the desired level. Control valves and actuators act in much the same way as in hydraulic systems, but instead of returning fluid to a tank, the air is simply returned (exhausted) to the atmosphere. Pneumatic systems are open systems, always processing new air, and hydraulic systems are closed systems, always recirculating the same oil. This eliminates the need for a network of return lines in pneumatic systems. Another advantage of pneumatic systems is that air is “cleaner” than oil, although air does not have the self-lubricating features of hydraulic oil.

When sources of compressed air are readily available, as they often are in engineering-related facilities, pneumatic actuators may be a good choice. Double-acting or single-acting pneumatic cylinders are ideal for providing low-force linear motion between two well-defined endpoints. Since air is compressible, pneumatic cylinders are not typically used for applications requiring accurate motion between the endpoints, especially in the presence of a varying load. Video Demo 10.30 demonstrates various types of pneumatic cylinders, and Video Demo 10.31 shows an interesting example of an apparatus driven by a pneumatic system. A good overview of pneumatic system components and industrial applications can be found in Video Demo 10.32.



Video Demo

10.30 Pneumatic cylinders of various types and sizes

10.31 Pneumatic biomechanics exercise apparatus overview

10.32 Overview of pneumatic system components and applications

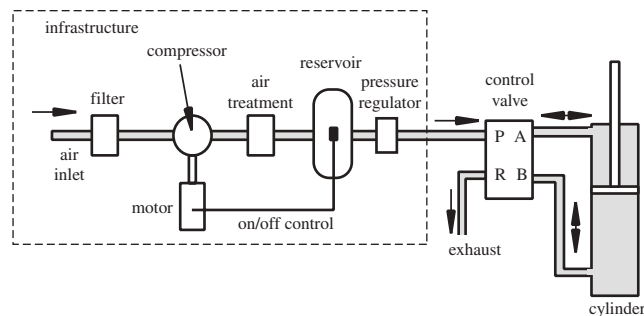


Figure 10.51 Pneumatic system components.

Another advantage of pneumatic systems is the possibility of replacing the infrastructure with a high-pressure storage tank and regulator. The tank serves a function analogous to a battery in an electrical system. This makes possible light, mobile pneumatic systems (e.g., a pneumatically actuated walking robot). In these applications, the capacity of the tank limits the range or operating time of the system.

QUESTIONS AND EXERCISES

Section 10.3 Solenoids and Relays

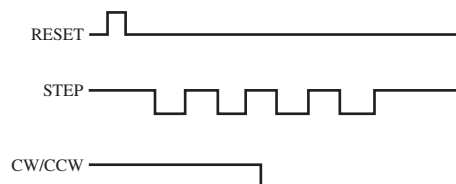
- 10.1.** A solenoid can be modeled as an inductor in series with a resistor. Design a circuit to use a digital output to control a 24 V solenoid.

Section 10.5 DC Motors

- 10.2.** Why can the presence of electric motors or solenoids affect the function of nearby electronic circuits?
- 10.3.** If you know the stall torque and no-load speed of a PM DC motor, what is the maximum power the motor can deliver?
- 10.4.** If a manufacturer's specifications for a PM DC motor are as follows, what are the motor's no-load speed, stall current, starting torque, and maximum power for an applied voltage of 10 V?
- Torque constant = 0.12 N.m/A
 - Electrical constant = 12 V/1000 RPM
 - Armature resistance = 1.5 Ω
- 10.5.** Recognizing that the H-bridge IC in Design Example 10.1 includes a current sense output, draw the block diagram for torque control of a brushed DC motor using the IC discussed. (Hint: The current sense output pin from the H-bridge yields 377 mA of current for each amp that is output to the motor. Convert this output to a voltage and use it as the input to a PWM chip like the LM3524D. Include a torque adjust potentiometer on the LM3524D.)

Section 10.6 Stepper Motors

- 10.6.** For the full-step drive circuit in Figure 10.32, complete the following timing diagram by adding signals B_0 , B_1 , ϕ_1 , ϕ_2 , ϕ_3 , and ϕ_4 . Using Table 10.1, verify that the intended motion results.



- 10.7.** Document a complete and thorough answer to Class Discussion Item 10.6.

- 10.8.** A unipolar stepper motor full-step drive circuit is available as a single component from some manufacturers. Explore the Internet to find a stepper motor driver, show a labeled pin-out diagram, and indicate how to connect it to a stepper motor properly.
- 10.9.** A designer wishes to use a stepper motor coupled to a gearbox to drive an indexed conveyor belt to achieve a linear resolution of 1 mm and a maximum speed of 10 cm/sec. The gearbox is a speed reducer with a gear ratio of 3 to 1, and the conveyor is driven by a 10-cm diameter drum attached to the output shaft of the gearbox. What is the minimum resolution required for the stepper motor? Also, what step rate would be required to achieve the maximum speed at this resolution?

Section 10.8 Selecting a Motor

- 10.10.** For each of the following applications, what is a good choice for the type of electric motor used? Justify your choice.
- robot arm joint
 - ceiling fan
 - electric trolley
 - circular saw
 - NC milling machine
 - electric crane
 - disk drive head actuator
 - disk drive motor
 - windshield wiper motor
 - industrial conveyor motor
 - washing machine
 - clothes dryer
- 10.11.** A permanent magnet DC motor is coupled to a load through a gearbox. If the polar moments of inertia of the rotor and load are J_r and J_l , the gearbox has a $N:M$ reduction (where $N > M$) from the motor to the load, the motor has a starting torque T_s and a no-load speed $\omega_{\max}$, and the load torque is proportional to its speed ($T_l = k\omega$),
- What is the maximum acceleration that the motor can produce on the load?
 - What is the steady state speed of the motor and the load?
 - How long will it take for the system to reach 95% of its steady state speed?

Section 10.9 Hydraulics

- 10.12.** Document a complete and thorough answer to Class Discussion Item 10.9.
- 10.13.** What is the maximum force a 1-inch inner diameter single-acting hydraulic cylinder can generate with a fluid pressure of 1000 psi?
- 10.14.** If a machine requires that a 1-cm inner diameter single-acting hydraulic cylinder produce 2000 N of force, what is the minimum required system pressure in MPa?

Section 10.10 Pneumatics

- 10.15.** You are designing a pneumatic system that requires the use of a pneumatic valve. On the Internet, find the specifications for a pneumatic valve capable of handling 100 psi, and draw a schematic showing how you would interface it to a digital system.
- 10.16.** You are designing a pneumatic actuator using a dual-acting cylinder to produce a force of 100 pounds using a 2000-psi scuba tank as a pressure source. Specify the elements required in the system in block diagram form. Be as specific as possible about component specifications.

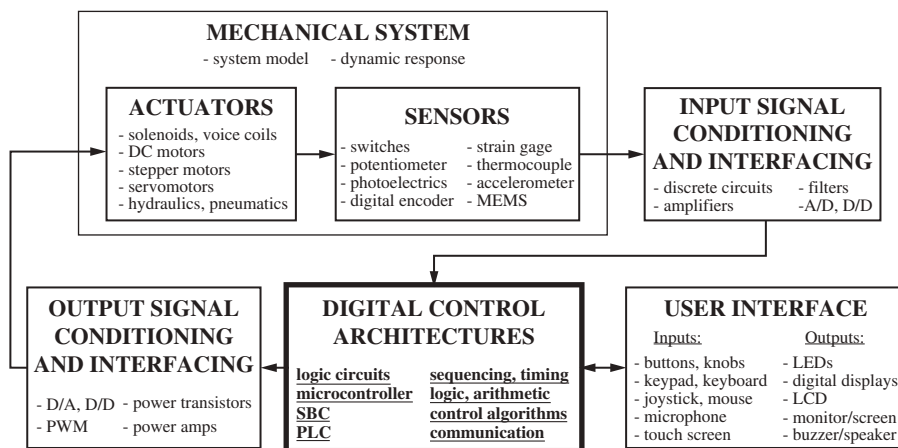
BIBLIOGRAPHY

- Kenjo, T., *Electric Motors and Their Controls*, Oxford Science Publications, Oxford, England, 1994.
- Khol, R., editor, “Electrical & Electronics Referral Issue,” *Machine Design*, v. 57, n. 12, May 30, 1985.
- McPherson, G., *An Introduction to Electrical Machines and Transformers*, 2nd Edition, John Wiley, New York, 1990.
- National Semiconductor Corporation, “National Power ICs Databook,” 2900 Semiconductor Drive, P.O. Box 58090, Santa Clara, CA 95052.
- Norton, R. L., *Design of Machinery*, 3rd ed., McGraw-Hill, New York, 2003.
- Shultz, G. P., *Transformers and Motors*, Macmillan, Carmel, IN, 1989.
- Westbrook, M. H., and Turner, J. D., *Automotive Sensors*, Institute of Physics Publishing, Philadelphia, 1994.
- Williamson, L., “What You Always Wanted to Know About Solenoids,” *Hydraulics and Pneumatics*, September, 1980.

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Mechatronic Systems— Control Architectures and Case Studies

This chapter provides a summary of mechatronic system digital control architectures, introduces the concepts of PID control, and presents three case studies of mechatronic system design. ■



CHAPTER OBJECTIVES

After you read, discuss, study, and apply ideas in this chapter, you will:

1. Know why many engineering designs today can be classified as mechatronic systems
2. Be aware of the various types of control architectures possible in mechatronic system design

3. Understand the basic principles of feedback control systems
4. Appreciate the variety of designs that can result from limited specifications of a mechatronic system
5. Understand the basics of programmable logic controller (PLC) programming using ladder logic
6. Recognize that many aerospace, automotive, and factory-automation systems, and consumer products, are mechatronic systems

11.1 INTRODUCTION

In the previous chapters of this book, we developed the foundations for the integration of mechanical devices, sensors, and signal and power electronics into mechatronic systems. As we progressed through the chapters, we included increasingly challenging mechatronic design examples to help you connect the theory and analysis with actual applications to expand your knowledge and design skills. To obtain completeness in the integration of mechanical devices, sensors, and signal and power electronics into the most advanced mechatronic systems, we must include microprocessor-based control systems. Chapter 7 presented the basics of microcontroller programming and interfacing. Here, we briefly introduce other control architectures also useful in mechatronic system design. Then we present three case studies of complete mechatronic systems: a myoelectrically controlled robotic arm, an articulated walking machine for movement in unusual environments, and a coin counter. These projects have been used as mechatronic projects in coursework at Colorado State University. To provide a final perspective, we list examples of mechatronic systems in many industries.

11.2 CONTROL ARCHITECTURES

Many mechatronic systems have multiple inputs and outputs related by deterministic relationships that result in some form of control of the outputs. A designer can choose from a wide spectrum of control architectures, ranging from simple open-loop control to complex feedback control. Implementation of the control can be as simple as using a single op amp or as complicated as programming massively parallel microprocessors. Here, we describe a hierarchy of basic control approaches you may consider in the design of a mechatronic system.

11.2.1 Analog Circuits

Many simple mechatronic designs require a specific actuator output based on an analog input signal. In some cases, analog signal processing circuits consisting of op amps and transistors can be employed to effect the desired control. Op amps can be used to perform comparisons and mathematical operations such as analog addition, subtraction, integration, and differentiation. They can also be used in amplifiers for

linear control of actuators. Analog controllers are often simple to design and easy to implement and can sometimes be less expensive than microprocessor-based systems.

11.2.2 Digital Circuits

If the input signals are digital or can be converted to a finite set of states, then combinational or sequential logic controllers may be easy to implement in mechatronic design. The simplest designs use a few digital chips to create a digital controller. To generate complex Boolean functions on a single IC, specialized digital devices such as **programmable array logic (PAL)** controllers and **programmable logic arrays (PLAs)** can be used to reduce design complexity. PALs and PLAs contain many gates and a gridwork of conductors that can be custom connected using a programming device. Once programmed, the ICs implement the designed Boolean function between the inputs and outputs. PALs and PLAs may offer an alternative to complex sequential and combinational logic circuits that require many ICs.

Another type of programmable logic-gate-based device is the **field-programmable gate array (FPGA)**. Like PALs and PLAs, an FPGA contains a large number of reconfigurable gates that can be programmed to create a wide range of logic functions. FPGAs are different from PALs and PLAs because they also can include memory, I/O ports, arithmetic functions, and other functionality found in microcontrollers. Furthermore, FPGAs are usually programmed with a high-level software language (e.g., VHDL) that allows for fairly sophisticated functionality. Video Demo 11.1 shows an example of an FPGA development system used to control a simple device.

Sometimes, it may be economically feasible to design an **application-specific integrated circuit (ASIC)** that provides unique functionality on a single IC. Logic functions, memory, computation, signal processing, and other digital and analog features can be custom built onto a single ASIC. Design and setup for manufacturing can be expensive, but in high-volume manufacturing applications an ASIC solution can be cheaper in the long run. ASICs are also attractive because the integrated solution will usually be smaller in size and consume less power than alternatives.

11.2.3 Programmable Logic Controller

Programmable logic controllers (PLCs) are specialized industrial devices for easily interfacing to and controlling analog and digital devices. They are designed with a small instruction set suitable for industrial control applications. They are usually programmed with **ladder logic**, which is a graphical method of laying out the connectivity and logic between system inputs (e.g., switches, sensors, user inputs, etc.) and outputs (e.g., motors, valves, pumps, lights, etc.). PLCs are designed with industrial control and industrial environments specifically in mind, and they are commonly used for factory automation. Therefore, in addition to being flexible and easy to program, they are robust and relatively immune to external interference. They are also designed to handle harsh environments (e.g., dirt, dust, vibration, power fluctuations, temperature extremes, etc.) typical in some factory settings.

The symbols, notation, and basic constructs used to define and create ladder logic diagrams are shown in Figure 11.1. Programming a PLC is a simple matter of constructing a diagram like this by interactively dragging and dropping components



Video Demo

11.1 Table tennis assistant controlled by an FPGA

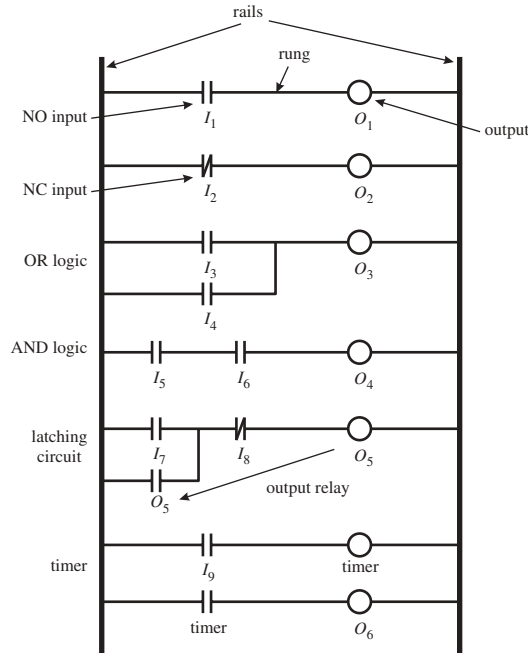


Figure 11.1 Ladder logic symbols and basic functions.

in a graphical user interface provided by the manufacturers. Referring to the figure, the **rails** on the ladder represent power (on the left) and ground (on the right), and the **rungs** represent current-flow paths (from left to right) to output devices. An **input** is typically a switch or proximity sensor that is represented by a **normally open (NO)** or **normally closed (NC)** relay symbol. Inputs can be arranged in series and parallel configurations in a rung to represent various logic functions. An **output** is included on the right side of a rung, and it is energized when the input relays on the left side of the rung result in a closed circuit. An output can be a motor, heater, lamp, solenoid, or other controlled device. An output state can also be used as an input relay to control other rungs in the ladder. Special features such as timers and counters are also available to create sequencing, stopping, and restarting of a series of events.

In Figure 11.1 output O_1 is energized only while NO input I_1 is closed. I_2 is an NC input, and output O_2 is off when I_2 is open. Output O_3 is energized only while NO input I_3 is closed **or** NO input I_4 is closed. Output O_4 is energized only while NO input I_5 is closed **and** NO input I_6 is closed. The O_5 rung is called a **latching circuit**. It is triggered (i.e., O_5 is energized) when NO input I_7 is closed. Also, once triggered, the output remains energized, even if input I_7 returns to the open state, until NC input I_8 opens. This is accomplished by using the output signal as an additional input (called an **output relay**) OR'd with the trigger input I_7 . The term *latch* is used because the output's ON state is maintained (stored) until it is reset by a second input (I_8). The last two rungs show how a timer is used. When NO input I_9 closes, a timer is started. When the timer reaches a preprogrammed period, the timer input closes, energizing output O_6 .



Video Demo

11.2 Program-mable logic controller with ladder logic

11.3 PLC infant formula machine



Internet Link

11.1 Program-mable logic controller online resources and manufacturers

11.2 PLC tutorial



Internet Link

7.1 Microcontroller online resources and manufacturers

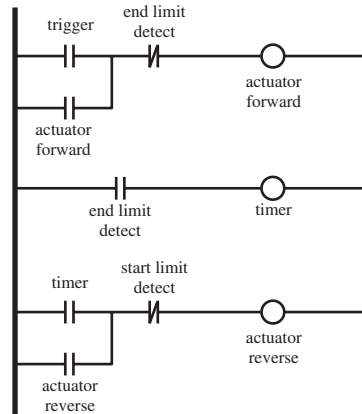


Figure 11.2 Ladder logic motor control cycle example.

Figure 11.2 shows an example ladder logic diagram for a common assembly-line control system where a motor or double-acting pneumatic or hydraulic cylinder is actuated back and forth based on a trigger event (e.g., a widget being detected by a proximity sensor next to a conveyor belt). Limit switches or sensors detect the desired ends of travel of the actuator in each direction. Here is the sequence of events: when the NO “trigger” input closes, the actuator is driven in the forward direction. The latching circuit maintains this forward motion until the NC “end limit detect” signal changes state. This opens the NC “end limit detect” input in the first rung and closes the NO “end limit detect” input in the second rung, which starts the timer. When the timer reaches its preset time, the third rung is triggered and the actuator reverses until the NC “start limit detect” signal is detected. In summary, when triggered, the actuator moves forward until the end of travel is detected, then the system pauses before returning the actuator back to the start position.

Video Demo 11.2 shows an example PLC development system and demonstrates how ladder logic can be used to create a fluid-level control system, and Video Demo 11.3 shows an interesting student project example using a PLC. Internet Link 11.1 provides links to various online resources for, and manufacturers of, PLC products, and Internet Link 11.2 provides an excellent set of tutorials on various PLC topics.

11.2.4 Microcontrollers and DSPs

The **microcontroller**, which is a microcomputer on a single IC, provides a small, flexible control platform that can be easily embedded in a mechatronic system. The microcontroller can be programmed to perform a wide range of control tasks. Designing with microcontrollers usually requires knowledge of a high-level programming language (e.g., C or Basic) or assembly language and experience in interfacing digital and analog devices. See Chapter 7 for background information and examples. Internet Link 7.1 provides links to various online resources for, and manufacturers of, microcontrollers.

Another type of single-IC microcomputer device is a **digital signal processor (DSP)**. A DSP can have functionality similar to that of a microcontroller, but DSPs are usually better suited to high-speed floating point calculations used in signal processing. DSPs are useful in communication, audio/video, and control applications where fast calculations and cycle times are required for digital filtering, weighted sums, encoding, decoding, and spectral analysis. Internet Link 11.3 provides links to various DSP online resources and manufacturers.

11.2.5 Single-Board Computer

When an application requires more features or resources than can be found on a typical microcontroller and size is not a major concern, a **single-board computer** offers a good alternative. Most single-board computers have enough RAM and offer compilers to support programming in a high-level language such as C. Single-board computers are also easily interfaced to a personal computer and can often run stand-alone with their own operating system (e.g., as with Raspberry Pi boards). This is useful in the testing and debugging stages of design development and for downloading software into the single-board computer's memory.

We use the term **minicontroller** to refer to another class of device that falls between a microcontroller and a single-board computer. Examples are the Handyboard, Basic Stamp, and Arduino prototyping boards (see Section 7.7). These boards contain microcontrollers and other peripheral components that make it easier to interface to external components. Internet Link 11.4 provides links to online resources for single-board computer and minicontroller products.

11.2.6 Personal Computer

In the case of large sophisticated mechatronic systems, a desktop or laptop **personal computer (PC)** may serve as an appropriate control platform. Also, for those not experienced with microcontrollers and single-board computers, the PC may be an attractive alternative. The PC can be easily interfaced to sensors and actuators using commercially available plug-in data acquisition cards or modules (see Section 8.4). These devices typically include software drivers that enable programming with standard high-level language compilers and development environments. Due to the ease and convenience of this approach, PC-controlled mechatronic systems are especially common in R&D testing and product development laboratories, where fast prototyping is required but where large-quantity production and miniaturization are not concerns.

11.3 INTRODUCTION TO CONTROL THEORY

In mechatronic system design, we often need to accurately control an output (e.g., the position or speed of a motor's shaft) with fast response. An impressive example of position control is shown in Video Demo 10.3, where the read-write head of a computer hard drive is controlled with amazing speed and accuracy (see Video Demo 10.4 for a super-slow-motion playback of the motion). For accurate control, we need to use feedback from sensors (e.g., an encoder or a tachometer). By subtracting a feedback signal from a desired input signal (called the **set point**



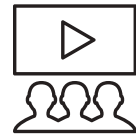
Internet Link

11.3 Digital signal processor resources and vendors



Internet Link

11.4 Single-board computer and minicontroller online resources and vendors



Video Demo

10.3 Computer hard-drive track seeking demonstration

10.4 Computer hard-drive super-slow-motion video of track finding

value), we have a measure of the error in the response. By continually changing the command signal to the system based on the error signal, we can improve the response of the system. This is called **feedback** or **closed-loop control**. The goal of this section is to introduce the basics of feedback control system design.

The theory and practice of control system design can be very complicated and may involve some mathematical techniques and software tools with which you might not be familiar. However, it is important for the reader to understand the approach to control system design, first to appreciate the value of its application and second to develop a desire to learn more about the field of controls (e.g., via follow-on coursework). In the subsections that follow, we explore the concepts of feedback control through a basic but important example of controlling the speed of a DC motor.

Before continuing, you may want to view Video Demos 11.4 and 11.5. They demonstrate two laboratory experiments that illustrate various control system topics. These examples might help you better relate to the material presented in this section. Video Demo 11.4 does a particularly good job of explaining some of the basic principles of proportional-integral-derivative (PID) control, which forms the basis of many control systems. Additional video demonstrations of control system concepts and applications can be found at Internet Links 1.4 and 11.7.

11.3.1 Armature-Controlled DC Motor

An important electromechanical device that is incorporated into many mechatronic systems is a permanent magnet or field-controlled DC motor. In mechatronic system applications, we might need to carefully control the output position, speed, or torque of the motor to match design specifications. This is a good example where feedback control is required. Our first problem, as in every mechatronic control system, is to model the motor. The mathematical model of a physical system is often referred to as the **plant**. This term originates from the early days of control theory development where a primary application was process control in chemical “plants.” With a model of the system, we can apply linear feedback analysis to the problem to help in selecting the design parameters for a controller that will reasonably track the desired output (specified input). We must create a good mathematical model of the motor (the system model) before we continue with controller design.

The basic equations governing the response of a DC motor were presented in Section 10.5, but we will take the analysis further here. A DC motor has an armature with inductance L and resistance R , such that when it rotates in a magnetic field, the armature will produce an output torque and angular velocity. Due to the motor construction, a back emf (voltage) proportional to angular velocity is caused by the armature coils moving through the stator magnetic fields. Figure 11.3 illustrates the salient elements in the system. The shaft of the armature transmits torque T to a load of inertia I_L and damping c . The motor armature also has inertia, and we will call the total moment of inertia of the armature and load I .

The model for the armature-controlled DC motor assumes that the motor produces a torque T proportional to the armature current i_a :

$$T(t) = k_i i_a(t) \quad (11.1)$$



Video Demo

11.4 PID control of the step response of a mechanical system

11.5 Inverted pendulum uprighting and balancing with linear cart motion



Internet Link

1.4 Robotics video demonstrations

11.7 Control system demonstrations

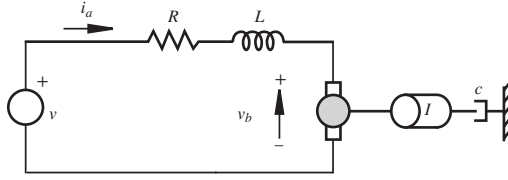


Figure 11.3 Armature-controlled DC motor.

and the back emf or voltage is proportional to the motor speed, ω :

$$v_b(t) = k_e \omega(t) \quad (11.2)$$

where k_t and k_e are parameters resulting from the motor's design that are provided by the motor manufacturer. If we draw a freebody diagram for the mechanical part of the system and apply Kirchhoff's voltage law to the electrical part, we can write two coupled differential equations that define the motor's electrical and mechanical properties:

$$v(t) = i_a R + L \frac{di_a}{dt} + k_e \omega \quad (11.3)$$

$$I \frac{d\omega}{dt} = T - c\omega = k_t i_a - c\omega \quad (11.4)$$

The coupling occurs through i_a and ω .

In advanced engineering systems analysis, Laplace transforms are commonly used to simplify the mathematics and help in the interpretation of the results. A mathematical transform converts an equation into a different form that may be easier to handle. The significant advantage of the Laplace transform is that an ordinary differential equation can be transformed into an algebraic equation. As was described in step 1 of the procedure in Section 4.10.2, the variables become functions of the complex variable s instead of time, and derivatives become powers of s . If we take the Laplace transform of the two differential equations 11.3 and 11.4, this converts them into algebraic expressions in the s domain, and we get

$$V(s) = (Ls + R)I_a(s) + k_e \Omega(s) \quad (11.5)$$

$$Is\Omega(s) = k_t I_a(s) - c\Omega(s) \quad (11.6)$$

Capital letters are used to indicate the Laplace transform of the appropriate time-domain function (e.g., $\Omega(s)$ is the Laplace transform of $\omega(t)$).

We can use the Laplace transform form of the system equations (Equations 11.5 and 11.6) to draw a **block diagram** for the motor that illustrates the signal flow in the system (see Figure 11.4). The terms in the equations are shown in the diagram so you can see how the diagram relates to the equations. As an aside, notice that the back emf (the $k_e \Omega(s)$ term) actually occurs in a negative feedback loop, which tends to stabilize the speed of the motor, although we are not explicitly designing this into the system.

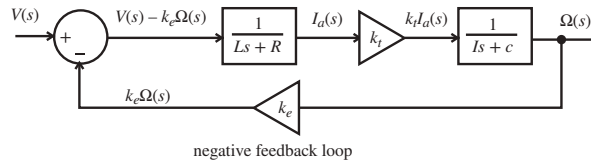


Figure 11.4 Block diagram for the DC motor system (plant).

An important step in controller design is expressing the input-output relationship of the plant, known as the **transfer function** of the system. Using Equations 11.5 and 11.6, we obtain

$$\frac{\Omega(s)}{V(s)} = \frac{k_t}{(Is + c)(Ls + R) + k_e k_t} = G(s) \quad (11.7)$$

This transfer function $G(s)$ relates the motor output speed $\Omega(s)$ to the input voltage $V(s)$. The polynomial in s in the denominator is known as the **characteristic equation**. The roots of this polynomial predict the type of response of the system. The characteristic equation for our motor system is second order, so your knowledge of second-order response will be helpful in understanding the angular velocity response to a step change in input voltage.

11.3.2 Open-Loop Response

In general, the transfer function can tell us a great deal about the response of the system. s is a complex variable, and the transfer function will have **poles** (values of s that make the denominator polynomial of the transfer function zero; i.e., the roots of the characteristic equation) that have extremely important consequences in interpreting the response of the DC motor. They have a profound effect on the motor response and stability; for example, whether any disturbance or input will cause unrestrained growth of the output. In fact, examining the location of the poles in the complex plane tells us whether the system is stable. They also determine whether or not the motor output oscillates when the input voltage command changes. This is where the software tool **Matlab** becomes a valuable asset in the analysis. We can use Matlab to find the poles easily and to determine the responses to various inputs, particularly the step response of the motor. The coefficients of the characteristic equation are determined by the motor parameters only, and they are of importance in determining the system response. We saw this in Chapter 4 where we distinguished among zero-, first-, second-, and higher-order systems and identified the characteristics of their responses. Therefore, knowing the order of the system, we can predict the pattern of the response.

Now let us calculate the response of the armature-controlled DC motor as an example. This is very easy to do by creating a **Simulink** model in Matlab, setting the parameters, applying a step input, and plotting the response. Excellent tutorials for learning how to use and apply Matlab and Simulink can be found at Internet Links 11.5 and 11.6. In the block diagram model shown in Figure 11.5, the electrical and mechanical transfer functions are shown separately and clearly labeled. A unit step input of voltage is applied, and the output angular velocity is plotted, as shown in Figure 11.6.



Internet Link

11.5 Matlab and Simulink tutorials and learning resources

11.6 Control tutorials for Matlab and Simulink

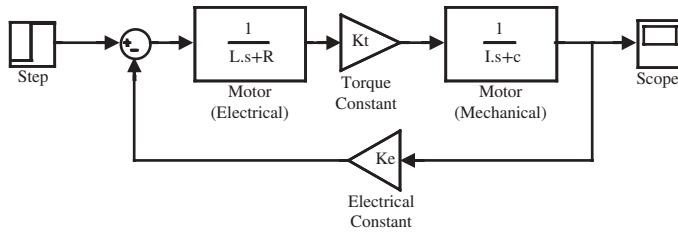


Figure 11.5 Simulink model block diagram.

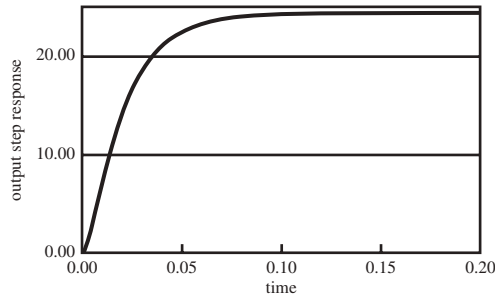


Figure 11.6 The angular velocity output for a step input voltage.

The output angular velocity takes time to respond to the step input, and asymptotically approach a final value due to the second-order nature of the characteristic equation. This response is what we call the open-loop response of the motor because no feedback has been added to the system (except for the existing internal back emf). It is our objective with a feedback controller to alter the response so that it meets design specifications such as faster rise time, some limited overshoot, and no oscillation.

11.3.3 Feedback Control of a DC Motor

In order to control the motor more effectively, we must add a sensor to monitor the output (in this case, a tachometer to measure speed), feed back the output and compare it to the desired speed input, and apply a control algorithm to the resulting error signal to improve the output response. Figure 11.7 shows a feedback control system in block diagram form. The input is the desired motor speed, and the output is the actual motor speed (e.g., as measured by a tachometer). The error signal is the difference between these two signals:

$$\text{error signal} = \text{input} - \text{output} \quad (11.8)$$

The controller changes its command signal (e.g., the motor voltage) to the system or plant (e.g., the motor) in response to the error signal.

There is art and engineering involved in designing a controller for a mechatronics system. The general steps for designing a controller include:

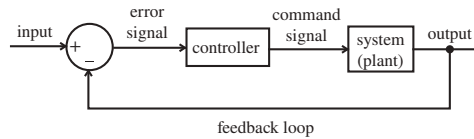


Figure 11.7 General feedback control system.

1. Choose a control action. We will describe that process in the example; however, generally, you start with a proportional control action, where the adjustment is made to the input in proportion to the size of the error signal. Then, integral and differential control actions, which are in proportion to the integral and derivative of the error signal, can be added to help better achieve the desired output specifications.
2. Check to see that the closed-loop system is stable by identifying the pole locations on the complex s -plane. Any poles on the right-hand side (with a positive real part) represent system instability.
3. Make sure the steady-state response meets design specifications.
4. Make sure the transient response meets design specifications.
5. Check the overall performance of the mechatronic system through testing with various inputs.

General controllers can take many forms but a majority of industrial applications use **PID** or proportional-integral-derivative controllers. The mathematical form of a PID controller, where the error signal is expressed as $e(t)$, is as follows:

$$\text{command signal} = K_p e(t) + K_d \frac{d}{dt} e(t) + K_i \int e(t) dt \quad (11.9)$$

where K_p is referred to as the proportional gain, K_d is the derivative gain, and K_i is the integral gain. Proportional control is the most intuitive because the control signal is proportional to the error. The larger the error is, the larger the corrective action will be. A large proportional gain creates a fast response, but it can lead to overshoot and oscillation, especially if the system has little damping. Derivative gain responds to the rate of change of the error signal. This allows the controller to limit overshoot by creating corrective action when the error changes too quickly. Derivative control action tends to dampen a system's response. Integral gain helps eliminate steady-state error by summing up errors over time. The longer the error stays on one side of the desired set point, the larger the corrective action becomes as a result of integral gain. Video Demo 11.4 describes and demonstrates the effect of each of the three control actions, as applied to position control of a DC servomotor system.

The choice of the gain parameters in a PID controller is a significant part of the design, and there are various analytical and empirical methods that can help one choose the gains. The control design can be specified in terms of important criteria such as settling time, overshoot, steady-state error, and rise time (see Figure 4.18 in Chapter 4 for more information). Please refer to a books on the subject of control (Ogata or Palm in the bibliography) if you want to explore some of the analytical methods for controller design.



Video Demo

11.4 PID control of the step response of a mechanical system

An alternative to model-based analytical design is to interactively adjust the PID gains via simulation, a process called controller tuning. We will illustrate this method with the example of speed control of an armature-controlled DC motor. The complete Simulink model, including the motor model along with a PID feedback controller, is shown in Figure 11.8. The input is a change in speed in the form of a step. The proportional, derivative, and integral gains of the PID controller are easily adjusted in the Simulink software, and the resulting output step response can be calculated and displayed almost instantaneously. This allows the user to test various gain combinations quickly during design iterations.

A good approach for varying the PID gains during design iterations in simulation is to first gradually increase the proportional gain (K_p) until the rise time is fast enough without too much overshoot and oscillation. Figure 11.9 shows the resulting step responses for various proportional gain values. With low gains, the response is slow, and there is significant steady-state error (i.e., the final value is not very close to the desired final speed of 1.0). With a large proportional gain, the response is fast, but there is significant overshoot and oscillation in the response.

After adjusting the proportional gain, derivative gain can be added to limit the overshoot and oscillation. Sometimes the proportional gain will need to be decreased as more derivative gain is added to limit the overall gain of the system. Figure 11.10 shows the resulting step responses for various derivative gain values. With a low gain, the overshoot and oscillation are still present. With very high derivative gain, there is no overshoot or oscillation, but the response is very sluggish.

For most systems, with just proportional and derivative gains, the output response will exhibit a steady-state error in the step response (i.e., the output doesn't quite reach the desired level). For the motor speed control example (see Figure 11.10), the

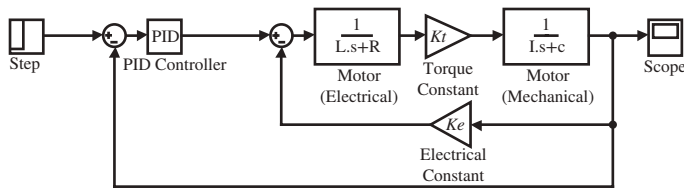


Figure 11.8 Simulink model of an example motor with a PID controller.

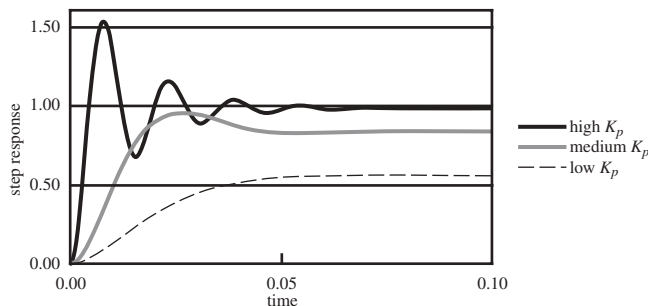


Figure 11.9 The effects of various proportional gains.

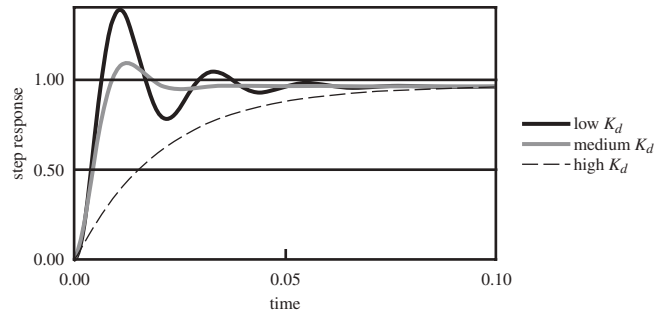


Figure 11.10 The effects of various derivative gains.

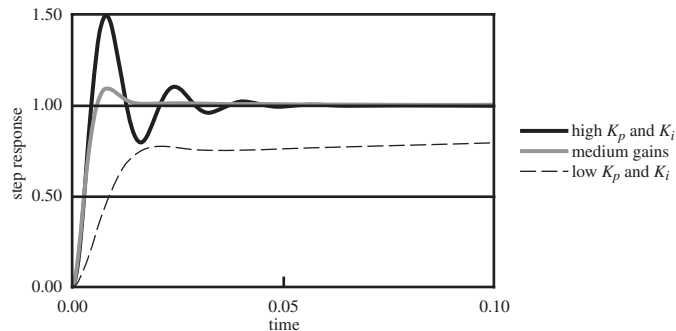


Figure 11.11 The effects of various integral gains.

reason for this is clear. The command signal to the motor (see Figure 11.7) must be nonzero to maintain a constant speed in steady state. Because the command signal is a function of the error signal, with just proportional control (note that the derivative term will be zero in steady state) there must be a nonzero error signal for the controller to output a command signal to the motor to keep it turning. Integral gain allows the controller to overcome this limitation and drive the error to zero. The integral term sums the error over time and adds a larger correction to the command signal the longer an error persists. Figure 11.11 shows the resulting step responses for various integral gain values. For a high gain, the error dissipates very quickly, but overshoot will be larger than if there was no integral gain. With a low integral gain, the error diminishes slowly, but it does eventually dissipate to zero. The medium gains curve exhibits a very good step response. There is very little overshoot and almost no oscillation, and the output settles quickly with no steady-state error.

11.3.4 Controller Empirical Design

In cases where it is difficult or impossible to model a system analytically, there are techniques to empirically design a controller by performing tests on an actual system. The procedure described in the previous section for simulation is one such approach, where the gains are adjusted iteratively. There are also software tools available that can perform system identification automatically, where a model can be approximated

by analyzing the system's response to various inputs. A controller can then be designed, possibly with the help of other software tools. Video Demo 8.8 shows a demonstration of how an example set of software tools can be used to develop a speed controller for a simple DC motor system. Video Demo 8.9 provides much more background and detailed demonstrations of the individual steps in the process.

A simple empirical method for tuning a PID controller that is sometimes used in industry is called the **Ziegler-Nichols (Z-N)** method (see Palm in the bibliography). The Z-N method is applied by observing the step response of the system under controlled conditions. From the observations, PID gains can then be selected to provide a fast system response with minimal overshoot and oscillation.

A PID controller expressed in the s domain can be written as

$$G_{\text{controller}}(s) = K_p + \frac{K_i}{s} + K_d s \quad (11.10)$$

where K_p , K_i , and K_d are the proportional, integral, and derivative gains. Using the Ziegler-Nichols method, the controller is usually expressed as

$$G_{\text{controller}}(s) = K_p \left(1 + \frac{1}{T_i s} + T_d s \right) \quad (11.11)$$

where T_i is called the reset time and T_d is the derivative time.

To apply the Z-N method, start by using proportional control action alone ($T_i = \text{infinity}$, $T_d = 0$) and increase K_p from zero until the observed output shows sustained (undamped) oscillation. The resulting period of the oscillations is observed and labeled P_{cr} , and the corresponding gain value is called the critical gain K_{cr} . Then K_p is reduced by a factor, and $K_i (T_i)$ and $K_d (T_d)$ are selected based on the proportions in Table 11.1. Ziegler and Nichols showed that these proportions result in a good system response for the selected type of controller. Note that K_p is lower for a PI controller than a P controller and higher for a PID controller because the I-component increases the order of the system and may destabilize it, and the D-component tends to stabilize the system, so K_p can be increased a little.

Often, the Z-N gains will serve only as a starting design, and you may need to tune the gains (i.e., tweak the K_p , K_i , and K_d parameters) to achieve your desired design specifications. This usually requires some trial and error.

11.3.5 Controller Implementation

In previous sections, everything was done in simulation, where the physical system was represented by a mathematical model. To implement a PID controller in an actual physical system, the model is replaced by actual hardware, and the controller must be built as an analog circuit or with a microprocessor-based system running



Video Demo

8.8 National Instruments DC motor demo

8.9 National Instruments LabVIEW DC motor controller design

Table 11.1 Ziegler-Nichols recommended gains

Controller	K_p	T_i	T_d
P	$0.5 K_{\text{cr}}$	Infinity	0
PI	$0.45 K_{\text{cr}}$	$P_{\text{cr}}/1.2$	0
PID	$0.6 K_{\text{cr}}$	$P_{\text{cr}}/2$	$0.125 P_{\text{cr}}$

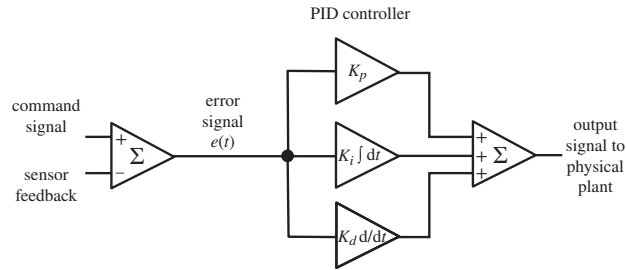


Figure 11.12 Analog PID controller constructed from op amp circuits.

digital software. In Chapter 5, we learned how to construct proportional gain, integrator, differentiator, summer, and difference circuits using operational amplifiers. These circuits can serve as the building blocks for an analog controller. Figure 11.12 shows how the various circuits can be combined, in schematic form, to create an analog PID controller. Each control action has a gain (K_p , K_i , or K_d) created by appropriate choices of component values in the op amp circuits.

An alternative to an op-amp-based analog controller is a digital controller created with software in a microprocessor-based system (e.g., a microcontroller). A digital control system is different from an analog controller because it requires a discrete amount of time to perform control updates. During each update cycle, the sensor signal is acquired, the controller output is calculated, and the controller signal is output. The time delay corresponding to the control loop cycle affects the response of the system. This effect must be accounted for in the mathematical model of the system to be able to predict system response accurately and to choose control parameters intelligently. The concept of the z -transform, where the continuous s -domain is transformed into a discrete representation, enables us to model and analyze such systems. Please refer to a book on modern control theory (see Ogata or Palm in the bibliography at the end of this chapter) if you want to learn more about this topic.

To implement a digital controller, the differentiation and integration must be discretized. If successive error signal samples are referred to as $e_1, e_2, e_3, \dots, e_{i-1}, e_i, e_{i+1}, \dots$, we can accumulate an approximation to the integral with the following equation:

$$I_i = I_{i-1} + \Delta t e_i \quad (11.12)$$

where $I_0 = 0$ and Δt is the cycle time of the control loop. The derivative can be approximated with a finite difference approximation. For example,

$$D_i = (e_i - e_{i-1})/\Delta t \quad (11.13)$$

Although, a digital filter usually needs to be applied to this calculation to minimize the undesirable effects of high-frequency noise in the position signal (see Class Discussion Item 11.1). Code for an example control loop cycle might look like the following:

```
error_previous = 0
integral = 0
```

```

control_loop:
    Gosub get_set_point_value      ' acquire set_point value
    Gosub get_sensor_value        ' acquire sensor_value

    error = sensor - set_point
    integral = integral + error*DT
    derivative = (error - error_previous)/DT

    output = KP*error + KI*integral + KD*derivative
    Gosub send_output_to_system    ' update command signal

    error_previous = error
Goto control_loop

```

The cycle time DT in the code can be determined using a microcontroller's built-in hardware timer feature, by measuring the elapsed time since the previous loop update; although, this would add a small amount of "overhead" to the loop cycle, which would slow the cycle time slightly (which might not be desirably in a high-performance application). An alternative is to measure the loop cycle time beforehand and then just hard-code the DT value in the final implementation. This measurement could be done using a microcontroller timer, starting the timer at the beginning of the loop and stopping it at the end. It could also be done manually (e.g., using a stop watch) by timing how long a large number of loop cycles takes to run and then dividing the total time by the number of cycles.

■ CLASS DISCUSSION ITEM 11.1

Derivative Filtering

As mentioned below Equation 11.13, derivative calculations often need to be filtered. One approach to doing this is to average a set of previous derivative calculations (i.e., use a running average). What is the effect of such an approach, and how can the example code be modified to achieve this?

11.3.6 Conclusion

This section presented a very brief overview of control theory. Although this topic cannot really be covered adequately in such a small amount of space, you have at least now a basic understanding of the main concepts. Anyone interested in pursuing this topic further needs references (and coursework) completely dedicated to this topic.

There are many software tools available to help with modeling, analysis, and controller design. Above, we used Matlab and Simulink for simulation and design. The LabVIEW software introduced in Chapter 8 also provides tools to help with these tasks. Video Demos 8.8 and 8.9 demonstrate the whole process of model-based controller design with LabVIEW. Many additional control systems video demonstrations can be found at Internet Link 11.7. Please review some or all of these videos to help improve your level of understanding of the application of control theory.



Video Demo

8.8 National Instruments DC motor demo

8.9 National Instruments LabVIEW DC motor controller design



Internet Link

11.7 Control system demonstrations

11.4 CASE STUDIES

Case studies of past project solutions are excellent learning resources. We can learn a lot from the best practices, design choices, and mistakes of others who have solved problems before us. In the required junior-level Mechatronics course in the Departments of Mechanical and Biomedical Engineering at Colorado State University, countless student groups have designed and constructed unique microcontroller-based mechatronic systems in fulfillment of the project requirement of the course. The guidelines for the project can be found at Internet Link 7.12. All student groups must include certain required elements (output displays, audio, user input, sensors, actuators, mechanisms, and microcontrollers), but the groups are free to choose their own project concept. This approach has resulted in an incredibly diverse and creative collection of projects over the years, all of which are excellent case studies. Since 2001, we have videotaped demonstrations and explanations of the best projects from each semester and put them online for others to enjoy and benefit from. The videos can be viewed at Internet Link 7.14. Some of the better project videos are also supplemented by complete microcontroller code and the student final reports. There is much to learn by viewing these videos and supporting resources. One requirement in the student final report is for them to summarize important “lessons learned,” listing problems they faced and how they solved them, along with advice to future students (i.e., things they wish they had known before and while they worked on the project). All of the most helpful student “lessons learned” are summarized in various categories at Internet Link 7.19. And many inexpensive project components used successfully by past students are listed at Internet Link 7.22. These are excellent resources for current and future students.

The remainder of this section presents three case studies of work done by past students in mechatronics-related courses and research projects. Since these projects were not done very recently, some of the design decisions and hardware choices might seem a little outdated, but the information and lessons are still instructional.

11.4.1 Myoelectrically Controlled Robotic Arm

This case study is an extension of Design Example 5.1, which dealt with myogenic control of a prosthetic limb. Here, more detail is presented, and the control is applied instead to a robotic arm. The problem is presented in steps according to the microcontroller-based system design procedure presented in Section 7.10. This case study is a good example of how to use PIC microcontrollers to interface to and communicate with an assortment of devices including analog circuits, desktop computers, and standard serial interfaces. Video Demo 11.6 demonstrates the finished product in action. You might want to view the video first so you can better relate to the information presented below.

1. Define the problem

The goal of this project is to design a system that uses myoelectric voltages from a person’s biceps as a control signal for a robotic arm. As shown in Figure 11.13, this project can be divided into three phases: data acquisition, classification, and actuation.

Myoelectric signals, or surface electromyograms (sEMG), are produced during muscle contraction when ions flow in and out of muscle cells. When a nerve sends the signal to initiate muscle contraction, an “action potential” of ions travels



Internet Link

7.12 PIC-based class design project description

7.14 PIC microcontroller student design projects

7.19 Lessons learned by past students

7.22 Project components used by past students



Video Demo

11.6 Robot controlled by an EMG biosignal

- Data Acquisition—*Measuring and digitizing the myoelectric signal*
- Classification—*Estimating the muscle force based on the myoelectric signal*
- Actuation—*Moving a robotic arm to a position corresponding to the estimated force*

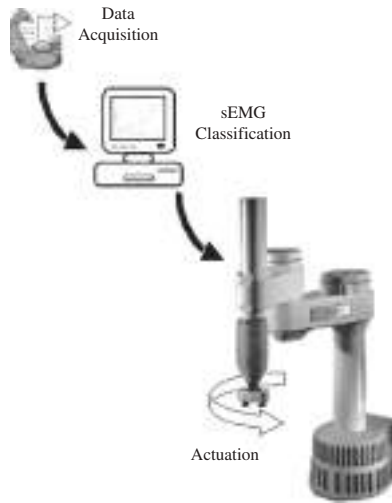


Figure 11.13 EMG robot project phases.

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along the length of the muscle. This ionic current can be transduced into electronic current with Ag-AgCl electrodes placed on the surface of the skin above the contracting muscle. Typically, the greater the contraction level, the higher the measured amplitude of the sEMG signal. However, even if a contraction level is constant, the sEMG signal can be quite irregular.

Typical sEMG signals have the following characteristics:

Amplitude	0–5 mV
Frequency range	0–500 Hz
Dominant frequency range	50–150 Hz

As can be seen, the sEMG signal is very small, in the millivolt range. In fact, electrical noise on the surface of the skin can be of greater magnitude than the signal of interest. There are three main frequency ranges in which noise may be present:

- a. 0–10 Hz: low-frequency motion artifacts (e.g., due to wire sway)
- b. 60 Hz: line noise (e.g., due to electrical equipment in the room)
- c. >500 Hz: high-frequency noise (e.g., due to random movement between the electrodes relative to the muscle)

2. Draw a functional diagram

Figure 11.14 shows a block diagram depicting the flow of information between the system's required components. Before digitizing the sEMG signal, it must be amplified to take full advantage of the input range of the A/D converter (see Chapter 8 for more details). However, we cannot simply pass the signal into an op amp; if we did, the noise would also be amplified, and it would be impossible to distinguish the sEMG from the noise. Consequently, we need to filter out the noise and amplify the signal prior to A/D conversion. This stage of data acquisition is called **signal conditioning**.

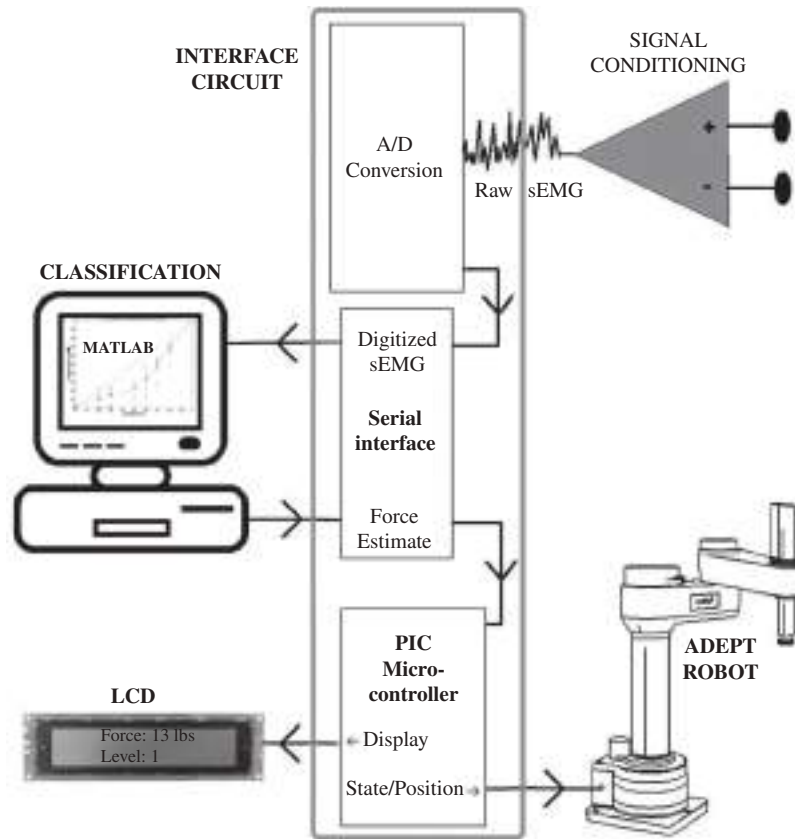


Figure 11.14 EMG robot system overview.

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After the signal is amplified and the noise is removed, it is ready for A/D conversion. The digitized signal is then sent to a PC where the muscle force is estimated based on analysis of the sEMG data. The estimated force is sent via an interface circuit to the robotic arm. Then the arm moves to a position that corresponds to the estimated force. For example, at rest the robotic arm will be at zero degrees; at the maximum contraction level the robotic arm will be at the maximum angle; and at intermediate contraction levels the robotic arm will be at corresponding angles in between. Although we could build a robotic arm from DC or stepper motors, this project used an AdeptOne-MV robotic arm. This type of robot is usually used for industrial purposes (e.g., assembly line work), but it also serves as a good laboratory model of a prosthetic arm.

3. Identify I/O requirements and 4. Select appropriate microcontroller models

Although a single microcontroller could probably be used with some creative programming, two microcontrollers are used to simplify the problem. One microcontroller is dedicated to performing the A/D conversion and sending the digitized

signal to a PC. Another microcontroller serves as the interface between the PC and the robotic arm. For the A/D microcontroller, the primary constraint is that it must have an analog input with a sampling rate over 1000 Hz (because the sampling theorem states that we must sample at least two times the highest frequency component of the signal, which is 500 Hz after it is filtered). A PIC16F819 was chosen, although any PIC with A/D capability would meet this criterion. The only salient difference between PICs with analog inputs is their resolution; some are 8 or 12 bit, but most are 10 bit (such as the 16F819). With a 20 MHz oscillator, the PIC can sample 10 bit values at about 50 kHz. Clearly, this is well above the 1 kHz required. However, the limiting factor in this process is not the sampling rate but the time required to transmit the digitized value to a PC. Because of the convenient functions provided in PicBasic for serial communication, this was chosen as the communications protocol. The fastest standard serial baud rate for the PIC is 38400 bits per second. Because each byte of data is limited to 8 bits, each 10 bit value is split up into 2 bytes (plus start and stop bits for each byte). Thus, each 10 bit value requires 20 bits of data to be sent (2 start bits + 2 stop bits + 2 bytes). Consequently, the PIC can only send digitized values at 1920 Hz (38,400 bits per sec / 20 bits). Sending data in a constant stream like this, however, can easily cause the data to be corrupted on the receiving end. If the clocks of the transmitter and receiver are slightly out of sync, then the receiver (i.e., the PC) may lose track of where the bytes of data start and stop. To obviate this problem, a small delay is incorporated in PicBasic before sending each value.

Every 100 msec the PC estimates the muscle force based on the previous 100 msec of data. Also, the estimated force is “binned.” For example, an estimated force between 0 and 5 lb would be assigned to bin 0, an estimated force between 5 and 10 lb would be assigned to bin 1, and so on. The bin number directly corresponds to a position of the robotic arm. Every 100 msec, the PC will send two bytes back out of the serial port: the estimated force and the bin number. A PIC16F876 was chosen as the microcontroller to interface the PC to the robotic arm and to display information on an LCD. The primary factor considered when choosing a PIC was the number of I/Os. One input is needed for the serial communication, six I/O are required for the LCD interface, five outputs are used to interface to the Adept robot, and one output is for a status LED. Although many PIC models can handle these 13 I/O, the 22 I/O 16F876 is used in case future upgrades are desired.

5. Identify necessary interface circuits

The **signal conditioning circuit** must amplify the small sEMG signal and filter out noise prior to digitization. An instrumentation amplifier is used as the primary amplification and noise reduction component. As described in Section 5.9, an instrumentation amplifier is essentially a difference amplifier buffered with op amps at each of its two inputs. The buffering op amps provide high input impedance, which improves the difference amplifier’s ability to reject noise (i.e., it has a high CMRR). The voltage difference that we will measure is the difference between two electrodes placed on the biceps. As a muscle action potential travels down the biceps, the first electrode will become positive relative to the more distal electrode; conversely, as the action potential continues down the biceps, the second electrode will then become more positive (which, of course, means the first electrode will be negative relative

to the second). In theory, ambient noise will reach the electrodes simultaneously and will not be amplified, because the voltage *difference* between the two electrodes, due to noise, will be zero.

To further eliminate noise, high-pass and low-pass filters are implemented. A high-pass filter of 10 Hz is desired to reduce motion artifacts and DC offsets. A low-pass filter of about 500 Hz is desired to reduce high-frequency noise. A low-pass filter is important prior to A/D conversion to prevent aliasing. Unfortunately, 60 Hz line noise is in the middle of the frequency range of the sEMG signal so it would not be a good idea to employ a notch filter to remove this frequency range. Hopefully, the instrumentation amplifier will sufficiently reject the line noise.

A 0–5 V input range is used on the A/D converter. To ensure that the sEMG amplitude is in this range, two more components are incorporated in the signal conditioning circuit: a full wave rectifier and an adjustable gain. The full wave rectifier approximates the absolute value of the signal. Because the sEMG signal is bipolar (i.e., it can be both positive and negative), passing it through a full-wave rectifier will guarantee that the signal is entirely positive. Finally, an adjustable gain is useful to account for differences in electrode size, geometry, and positioning, as well as differences among individuals—all of which affect the amplitude of the signal. By adjusting the gain of the signal conditioning circuit, we can attain a maximum amplitude of about 5 V (e.g. during maximum contraction levels).

One protocol that dictates how **serial communication** is executed is called **RS-232**. This protocol states, for example, that a logic 1 is between -3 V and -25 V, whereas a logic 0 is between $+3$ V and $+25$ V. Because a PIC cannot output negative voltage (and because some PC serial ports have trouble reading voltages less than 5 V), it is a good idea to use an RS-232 level converter chip, such as Maxim's MAX232 (see Figure 11.15). These chips convert TTL/CMOS level signals

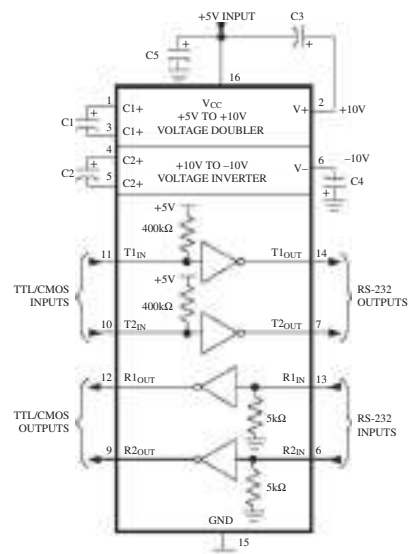


Figure 11.15 MAX232 level converter.

to RS-232 level signals, and vice versa. It is also important to note that they also invert the signal. For example, when given a +5 V input, it will output about -8 V; when given 0 V, it will output about +8 V. These chips are able to provide these outputs using a 5 V power supply and ground. This is made possible using a technique called **charge pumping**, which uses capacitors to store and boost voltage.

One of the parameters of PicBasic's *Serout* command is the mode. Along with the baud rate, this parameter specifies whether the serial data is driven *true* or *inverted*. Because we are using an RS-232 level converter chip, *true* is used because the chip automatically inverts the signal. The MAX232 chip is used to convert the TTL output of the A/D converter PIC to RS-232 level signals as well as convert the RS-232 output from the PC to TTL level signals for the robot/LCD interface.

DB9 serial ports (see Figure 11.16) are no longer common on PCs because USB and other interfaces have made them obsolete; however, one was available on the computer used for this project. Although the DB9 port has nine pins, only three are useful for our purpose; the other pins are for **handshaking**, a method to help regulate data flow. The only pins necessary for our purposes are listed in Table 11.2. Pin 2 is where the PC will receive the digitized sEMG signal, and Pin 3 is where the PC will send the estimated force and bin number to the interface PIC (in both cases, via the MAX232 chip).

6. Decide on a programming language

PicBasic Pro was chosen, mostly for the ease of use of the serial communication and LCD interface commands.

7. Draw the detailed wiring diagram

Figure 11.17 shows a circuit diagram for the conditioning circuit. The first stage is an instrumentation amplifier with a gain of 939 with the resistor values shown. The next stage is a simple *RC* filter followed by a buffer op amp. If the buffer op amp were not included, then the resistance of the following stage would **load** the filter (with impedance) and change its behavior. In other words, it would not act as a simple *RC* filter. Next is a **two-pole Sallen-Key** low-pass filter, a type of **active filter** (i.e., it exploits the feedback of an op amp). An entire course can be devoted to analog filter design, but suffice it to say that active filters are more robust than passive

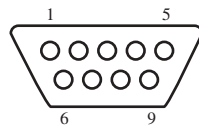


Figure 11.16 Serial port.

Table 11.2 Serial port pins

Pin #	Description
2	Receive data
3	Transmit data
5	Ground

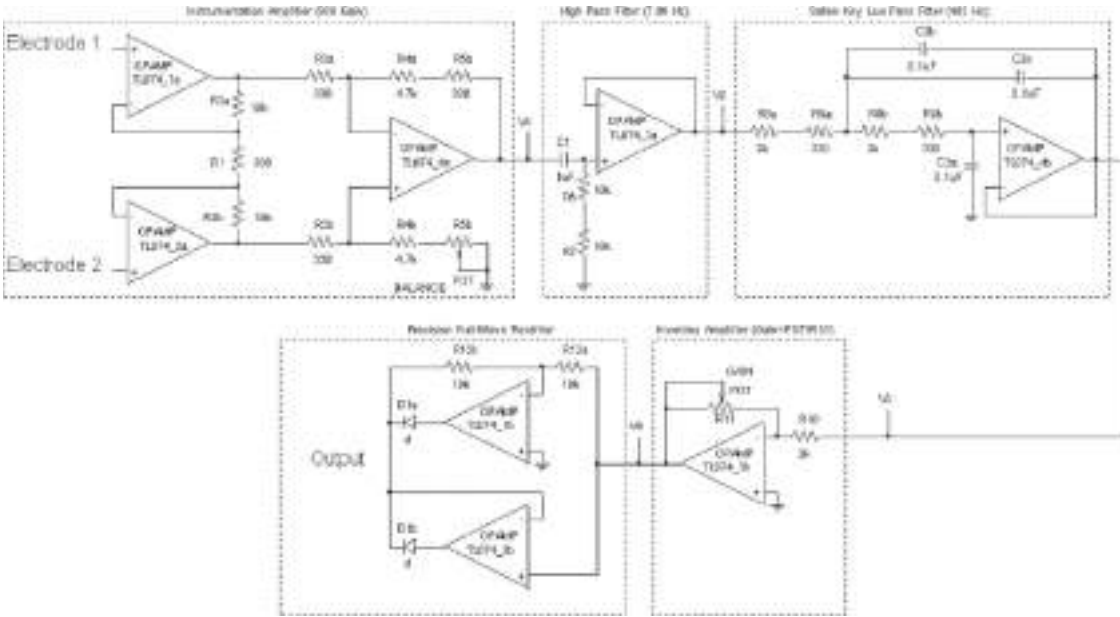


Figure 11.17 EMG robot conditioning circuit diagram.



Internet Link

- 11.8 PCB123 software for designing custom printed circuit boards
- 11.9 Example of steps in the printed circuit board process

filters (e.g., an RC filter) and that additional “poles” (an RC filter is a single-pole filter) are better at attenuating unwanted frequencies. The next stage is an inverting op amp where the feedback resistor is a potentiometer used to adjust the overall gain of the system. Finally, the last stage is a precision full-wave rectifier, which requires no forward bias to turn on the diodes.

After the sEMG signal passes through this circuit, it is amplified by about 1000 $\times$, depending on the potentiometer setting of the inverting amplifier, bandpass filtered between 8 and 483 Hz, and full-wave rectified. To make this circuit more robust, the design was prototyped on a custom-made **printed circuit board (PCB)**, rather than on a breadboard, using *PCB123*, a free PCB layout program available online (see Internet Link 11.8). Figure 11.18 shows the traces and soldering pads created with the software for the PCB. Figure 11.19 shows the assembled PCB after the components are soldered on. Internet Link 11.9 points to a document that illustrates all of the steps necessary to create a PCB. See Section 2.10.3 for more information about PCBs and soldering.

The only chips used in this example are two TL074s, quad-package JFET op amps. These op amps will operate over a fairly large range, about ± 5 to ± 18 V. To make the system portable, two 9 V batteries can be used. Furthermore, a voltage regulator can be used to produce the +5 V necessary to operate the PICs.

The output of the conditioning circuit is connected to an analog pin on the PIC16F819. Other than the circuitry required to make this PIC operate, which is the same as the PIC16F84, only this analog input and a wire going from a digital pin to

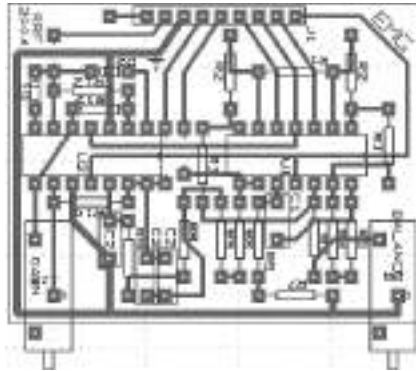


Figure 11.18 EMG robot conditioning circuit PCB layout.

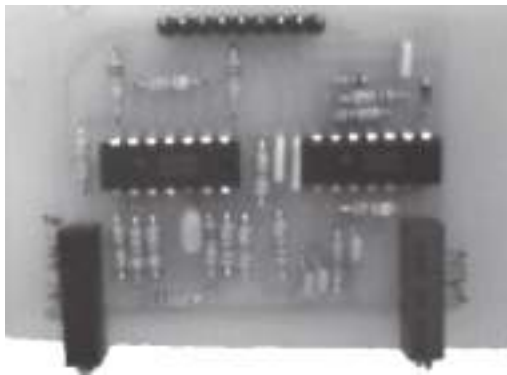


Figure 11.19 EMG robot conditioning circuit photo.

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a TTL input of the MAX232 chip are needed. A wire then connects the corresponding RS-232 output of the MAX232 to pin 2 on the PC's serial port. Similarly, a wire connects pin 3 of the serial port to an RS-232 input on the MAX232 chip. The corresponding TTL output is connected to a digital pin on the 16F876 interface PIC. A sample wiring diagram for connecting an LCD to a PIC is shown in Figure 7.13.

At least 9 V is required to register a logic 1 on the Adept robot's input port. On each of the PORT A outputs of the PIC, a transistor and separate power source (such as the positive voltage source used to operate the op amps) are incorporated to help increase the voltage. The schematic in Figure 11.20 shows what is needed to interface each of the PORT A pins to a corresponding Adept input pin. It should be noted that this circuit inverts the logic. If the PIC output is high, the transistor will be saturated, and the Adept input will be at ground potential. Conversely, if the PIC output is low, the transistor will be off and no current will flow through it. With no voltage drop across the 10k resistor, the Adept input will be at 9 V. This negative logic can be accounted for in the Adept code (or, just as easily, in the PIC code).

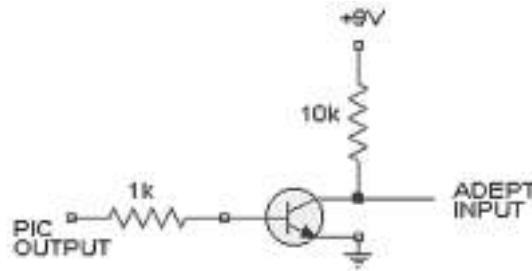


Figure 11.20 EMG robot PIC to Adept interface circuit.

8. Draw a program flowchart

The flowchart in Figure 11.21 describes the operation of the A/D converter PIC. After initializing variables and defining how the A/D conversion is performed, the remaining portion is a simple loop that continuously samples the A/D converter and sends the data out through a serial pin.

Figure 11.22 shows the flowchart describing the operation of the interface PIC. This PIC waits to receive 2 bytes on its serial pin (estimated force and bin number), displays those values on an LCD, and outputs the bin number on PORTA. Other than displaying information on an LCD, this PIC is essentially a serial-to-parallel converter. The parallel value is what is read by the Adept robot.

9. Write the code

PICs are 8-bit processors, and, as such, any integer value over 8 bits (255+) must be stored in two or more registers. Because the PIC16F819 performs 10 bit A/D conversions, the result is stored in two registers, *ADRESL* and *ADRESH*. One can choose

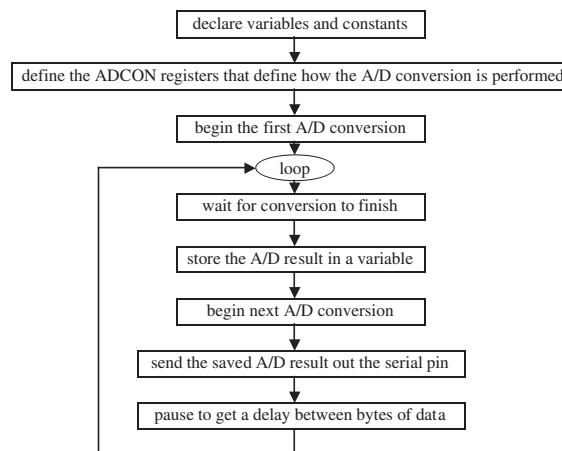


Figure 11.21 EMG robot A/D converter PIC flowchart.

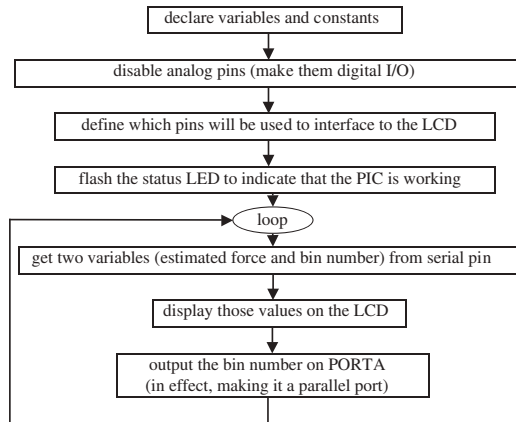


Figure 11.22 EMG robot interface PIC flowchart.

how to “justify” the result: either the eight least significant bits are in one register, or the eight most significant bits are in one register. The other two bits are padded with zeros. Justification, conversion, which pin is being used for the conversion, initiating a conversion, and other A/D parameters are defined by the *ADCON0* and *ADCON1* registers (see the PIC16F819 data sheet for more information). The code for the A/D converter PIC is shown below.

```

' *****
'* Name      : ADC.BAS                                     *
'* Version   : 2.0                                         *
'* Notes     : PIC16f819                                   *
'*           : Reads analog value, serially sends binary result *
' *****
DEFINE OSC 20      ' 20MHz crystal

' Initialize variables
ADC_LSB Var BYTE   ' 8 LSB of the 10 bit A/D conversion
ADC_MSB Var BYTE   ' 2 MSB of the 10 bit A/D conversion (in bits 0 & 1)
i      Var BYTE    ' looping variable
serMode Con 6      ' baud rate of serial;      84=9600    bps
'                                           32=19200    bps
'                                           6=38400    bps

' Setup A/D registers
ADCON0 = %10000000 ' TAD=32Tosc, A/D pin=RA0
ADCON1 = %10001110 ' Right justified (8 LSB are in ADRESL, 2 MSB are in ADRESH)

' Configure I/O ports
TRISA = %11111111  ' PORTA is all inputs
TRISB = 0           ' PORTB is all outputs

```

```

LED Var PORTB.3           ' Status LED
ADC_pin Var PORTA.0        ' A/D pin
SERIAL_pin Var PORTB.4     ' Serial out pin
ADC_on Var ADCON0.0        ' A/D on/off bit (turn off to save power)
ADC_go Var ADCON0.2        ' A/D Go/Done bit (manually set to 1 to
                           ' start conversion; automatically is reset
                           ' to 0 when finished with conversion)

initialize:
  ADC_on = 1               ' turn the ADC channel on
  Pause 250                ' let things settle a bit (probably not necessary)
  High LED                 ' turn on LED to indicate ADC in process
  ADC_go = 1               ' start the 1st A/D conversion
  Gosub getADC              ' wait until it's done

main:
  ADC_go = 1               ' start the next A/D conversion
  Gosub sendADC             ' send the data while doing the A/D conversion
  Pauseus 126               ' pause 126 us (results in 1500 Hz sampling rate)
  Gosub getADC              ' get the results of the A/D conversion
  Goto main                 ' do it forever

getADC:
  Do While (ADC_go == 1)    ' wait until the conversion is done
  Loop                     ' (should already be done, because SEROUT takes a while)
  ADC_MSB = ADRESH          ' save 2 most sig. bits (padded w/ 0s)
  ADC_LSB = ADRESL          ' save 8 least sig. bits
  Return

sendADC:
  Serout2 serial_pin, serMode, [ADC_MSB]      ' send the MSB (padded with six 0s)
  Serout2 serial_pin, serMode, [ADC_LSB]      ' send LSB
  Return

End

```

Most of the code for the interface PIC (see below) is self-evident except, perhaps, for the *DEFINE* statements. *DEFINE* is used to change elements that are predefined in PicBasic Pro. For example, PicBasic Pro assumes a 4 MHz clock and a specific set of pins to be used with an LCD. Because we are using a 20 MHz crystal and a different pin configuration for the LCD, we need to *DEFINE* new parameters. Specifying *DEFINE OSC 20* lets PicBasic know to change all of the time-sensitive commands (e.g., *Pause*, *Serin*, *Lcdout*) to account for the faster clock speed. If we did not do this, all of these commands would happen five times too fast, or not work at all.

```

'*****
'* Name      : PC2PIC.bas                      *
'* Version   : 2.0                              *
'* Notes     : PIC16F876                        *
'*           : Reads two values from serial pin, displays them *
'*           : on an LCD, and converts one of the values to a /*
'*           : value on PORTA                    *
'*****

```

```

' Be sure to set Configure | configuration bits | oscillator - HS
' before programming (if using 20Mhz osc)

```

```

ADCON1 = %11000110      ' turning all of porta to digital
TRISA  = %00000000      ' turning all of porta to outputs

```

```

DEFINE OSC      20      ' 20 MHz oscillator
DEFINE LCD_DREG PORTB  ' LCD data port
DEFINE LCD_BITS 4      ' 4 parallel data bits
DEFINE LCD_DBIT  0      ' data bits on PORTB.0 -> PORTB.3
DEFINE LCD_RSREG PORTC  ' Register Select (RS) port
DEFINE LCD_RSBIT 6      ' RS on PORTC.6
DEFINE LCD_EREG  PORTC  ' Enable (E) port
DEFINE LCD_EBIT  7      ' Enable on PORTC.7
DEFINE LCD_LINES 2      ' 40X2 LCD Display
DEFINE LCD_COMMANDUS 3000 ' command delay time (us) {found
                          ' experimentally 3000}
DEFINE LCD_DATAUS 75    ' data delay time (us) {found experimentally 75}

```

```

LED      Var    PORTB.7  ' Status LED
serin_pin Var    PORTB.6  ' serial in pin

i        Var    BYTE     ' looping variable
command  Var    BYTE     ' 1st byte received from serial pin
force    Con    BYTE     ' 2nd byte received from serial pin
mode     Con    6        ' serial mode (6=38400 baud)

```

```

Lcdout $FE, 1      ' clear LCD
For i =1 to 8      ' flash the status LED
    High LED
    Pause 100
    Low LED
    Pause 100
Next i

```

```

PORTA = 0
Pause 1000
High LED
Pause 500

```



```

.....
'      EMG          |      Force: ## lbs
'Signal Strength    |      Level: #
.....

Lcdout $FE, 128, "      EMG          |      Force: lbs"
Lcdout $FE, 192, "Signal Strength    |      Level: "

main:
    Serin2 serin_pin, mode, [command, force] ' get 2 serial values
    Lcdout $FE, 128+31, #force
    Lcdout " "
    Lcdout $FE, 192+31, #command
    Lcdout " "

    'Convert serial value to parallel value on portA (for ADEPT robot)
    PORTA = command

Goto main

```

10. Build and test the system

As with any system, especially more complicated ones, it is vital to test in parts. Break the system down into its smallest functional units and test the inputs and outputs of those units to ensure they are performing as expected. In the signal conditioning circuit, for example, we could test just the full-wave rectifier by passing a sine wave through it and confirming that the output signal is rectified. Also, each of the filters could be tested by inputting a frequency sweep and confirming that the amplitude at the cutoff frequency is about 70.7% of the input amplitude.

With any PIC, it's a good idea to include a status LED that indicates that the PIC is on and functioning to some degree. While troubleshooting, it is also useful to flash the status LED at different points in the code to help you track the execution. LCDs are extremely useful, once they are functioning, in debugging code because they can easily be used to display diagnostic messages and values being stored in variables.

Serial communication between a PIC and PC can be tested using a terminal program. Hyperterminal, the terminal program bundled with Windows, allows you to read from and write to the serial ports. One just needs to be sure to specify the port settings (e.g., baud rate) so that they match the format that the PIC is sending or expecting to receive.

Examples could be given for each element of the system, but the point is to build and test everything incrementally.

Again, a demonstration of the working system can be viewed at Video Demo 11.6.



Video Demo

11.6 Robot
controlled by an
EMG biosignal

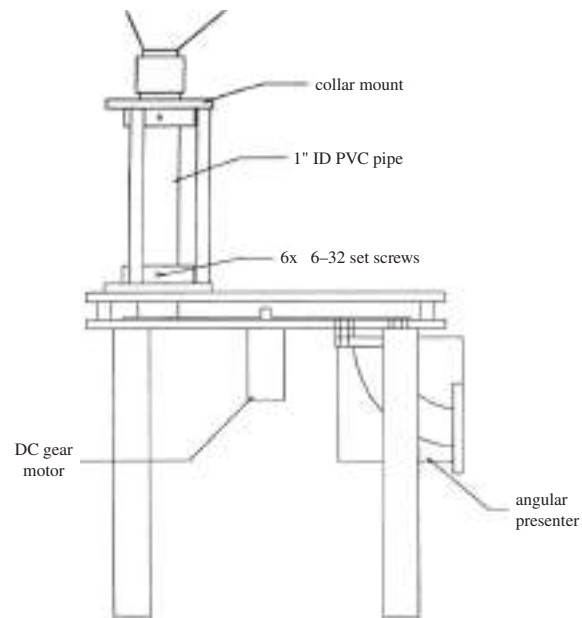
11.4.2 Mechatronic Design of a Coin Counter

In this section, we present solutions to the following design problem: Design a coin counter that includes an electromechanical device to accept a handful of mixed denomination U.S. coins and that will align and present the coins in serial order to a sensor array capable of acquiring data that can be used to determine the denominations of individual coins. The sensor output is to be interfaced to electronics that can compute both the number of coins presented and the total value of the coins and display those two values in some sort of multiplexed fashion on a single display visible to the user.

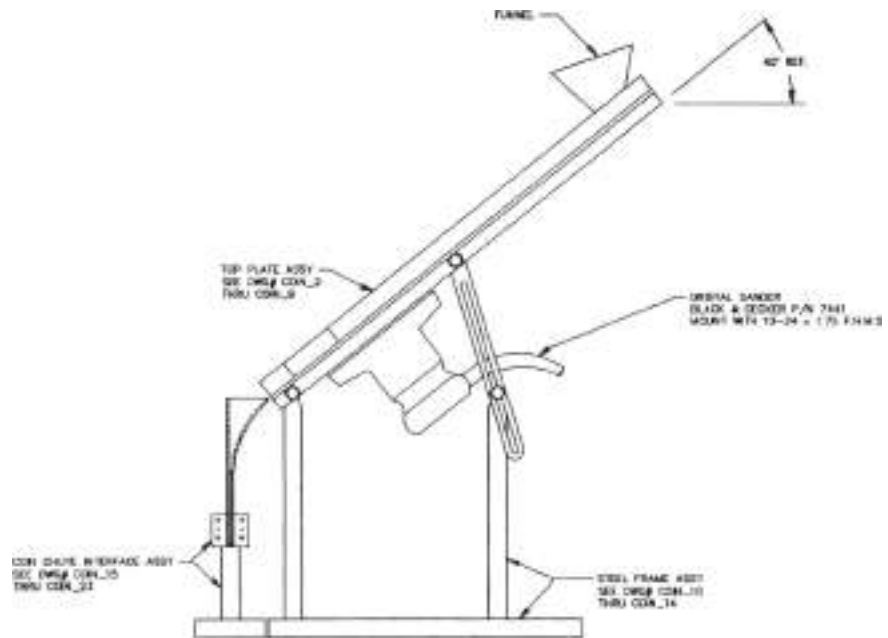
We presented this design challenge to a junior-level mechatronics class of 80 students broken down into groups of 4, and more than half the groups created successful solutions given a design period of six weeks. All groups were able to present the coins sequentially and display a count of the number of coins. Multiplexing the value of the coins with the count on a single display was more challenging, requiring creative use of digital logic, and not all groups were successful in implementing a design for this part. Given more time to redesign, most groups would have been successful. As you will see, there is no single correct solution to the problem, and the designs are as varied as the people who developed them.

This problem has two significant parts: the design of an electromechanical coin presentation system to align coins sequentially in some fashion so they may be presented to an array of sensors, and the design of an electronic calculator to use the sensor data to display the count and value of the coins. We consider the two parts in succession, realizing that the student design groups often divided their efforts between the mechanical design of the coin presenter and the electronic design of the calculator. Students with significant machine shop experience tackled the electromechanical coin presentation design while students more comfortable with the electronic experience they gained in the course focused on the sensor and counter design. As in all design projects, certain people have affinities for certain parts of the overall design, and it is important to assign responsibilities, communicate progress, document work, and assure compatibility among the various subsystems. We do not want to digress too much on the design process itself here, other than to mention that team coordination and communication in the design process are as critical as the design itself.

The mechanical component of the design requires a chamber to accept a handful of mixed denomination coins and a mechanism to select coins individually and present them to a sensor array that can read their attributes and output digital signals for computation. By observing existing mechanical coin sorters, many students designed inclined rotating disk mechanisms that had circular holes cut in them to accept individual coins. Examples of the mechanical systems designed to present a handful of coins in series are shown in Figure 11.23. Two of the three approaches (Figures 11.23a and 11.23c) use a DC motor to rotate a perforated disk that entrained a single coin. As the disk rotated, the coin would drop into the slot containing the sensor array. Most designs included a DC motor to rotate the disk continuously. Other

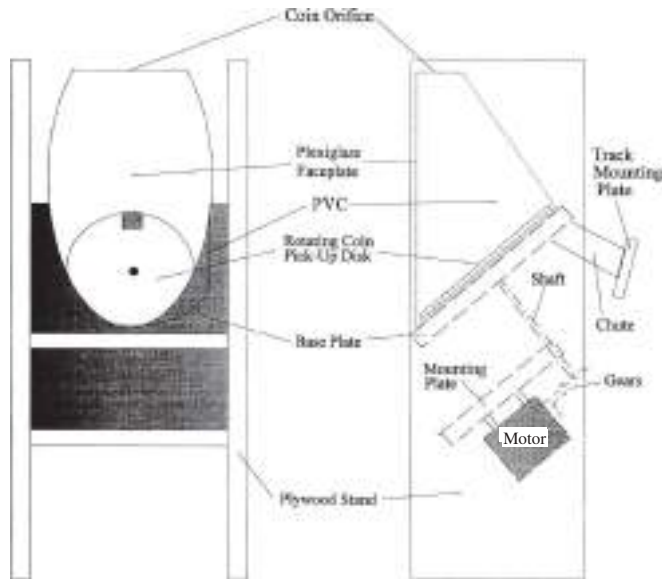


(a) horizontal slotted disk design



(b) "pachinko" design

Figure 11.23 Example of coin counter presentation mechanisms.



(c) inclined slotted disk design

Figure 11.23 (continued)

designs (e.g., the one in Figure 11.23b) included vibrating chutes and pachinko-like mechanical arrays. As individual coins were separated, they entered a chute and rolled down a rectangular slot containing the sensor array.

Although people determine the value of coins by sight and feel, automated methods require a well-designed sensing system. The size, weight, and thickness of coins are unique for different denominations. For the sake of simplicity, all groups elected to design a diameter sensor using a set of phototransistor-photodiode pairs. These photo-optic pairs were carefully positioned so that the combination of signals would be unique for each different denomination of coin (see Figure 11.24). For this project, the coin denominations were limited to the U.S. penny, nickel, and quarter to provide significant size differences. Diameter was the primary attribute for assessing each coin's value, assuming that they rolled down the slot smoothly. This meant that the largest coin, the quarter, activated all sensors, and the smallest, the penny, only one. Furthermore, the signals from the sensors would be pulses of different widths affected by the size and speed of the coins. The pulses do not begin or end at the same time (see Figure 11.25), complicating the synchronizing of logic in the design of the evaluator and counter. The sensor outputs were converted to TTL signals using 7404 Schmitt triggers, making the outputs compatible with the computational part of the circuit design.

The sensors produce pulses at different starting times and for different durations depending on the size and speed of the coin. This subtlety requires careful sequential logic design to ensure that the coin is identified correctly. If the TTL signals from the

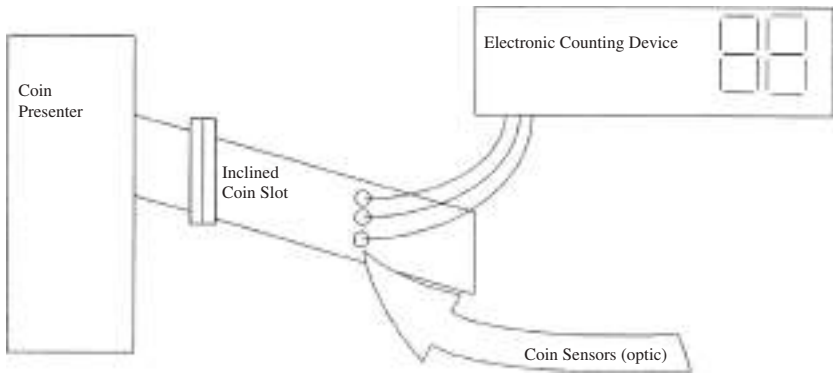


Figure 11.24 Sensor array and chute design.

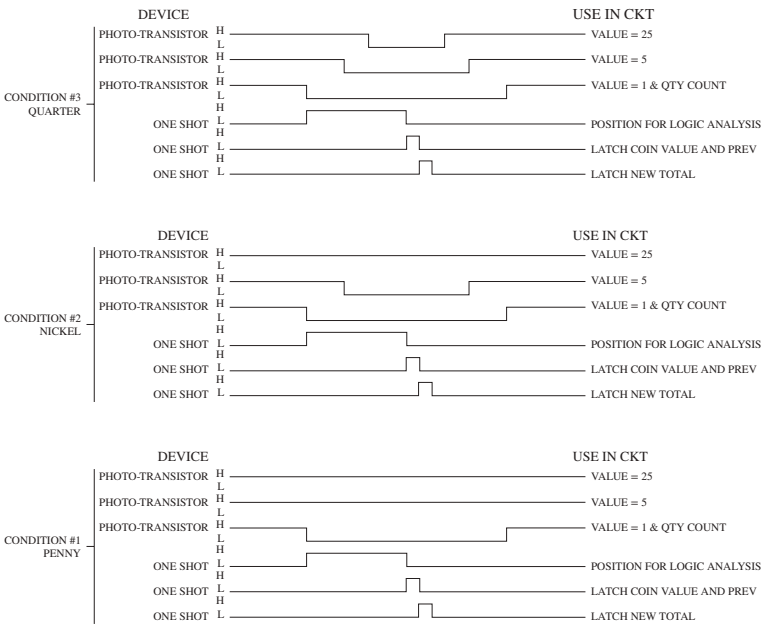


Figure 11.25 TTL outputs corresponding to different coins.

sensors were synchronized, then the Boolean expressions for the different denomination coins can be written as follows:

$$X = A \cdot B \cdot C \tag{11.14}$$

$$Y = A \cdot B \cdot \overline{C} \tag{11.15}$$

$$Z = A \cdot \overline{B} \cdot \overline{C} \tag{11.16}$$

where C corresponds to the output of the top sensor, B to the output of the middle sensor, and A to the output of the bottom sensor. X corresponds to the passage of a quarter, Y to the passage of a nickel, and Z to that of a penny.

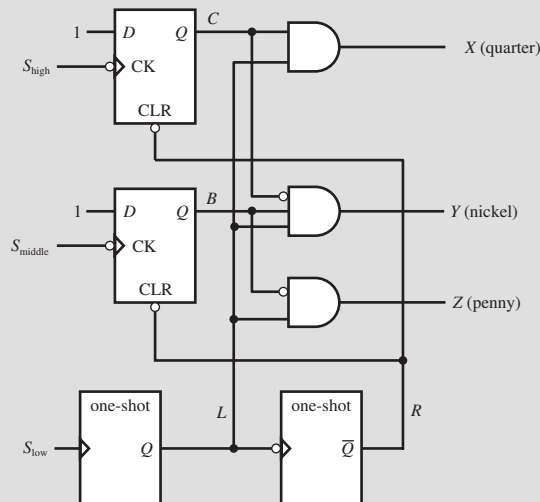
When this project was assigned, we had not yet started teaching microcontroller programming and interfacing in our course. In lieu of this, we had students develop solutions using basic TTL ICs. Combinational and sequential logic is required to determine the denomination of the coin and increment the displayed output by a value corresponding to the denomination. There were as many solutions for this problem as there were design groups. Figures 11.26 and 11.27 display two student group solutions for the coin counter processing and display circuit. The outputs were transmitted to a digital display driver to multiplex the current number of coins and the accumulated value.

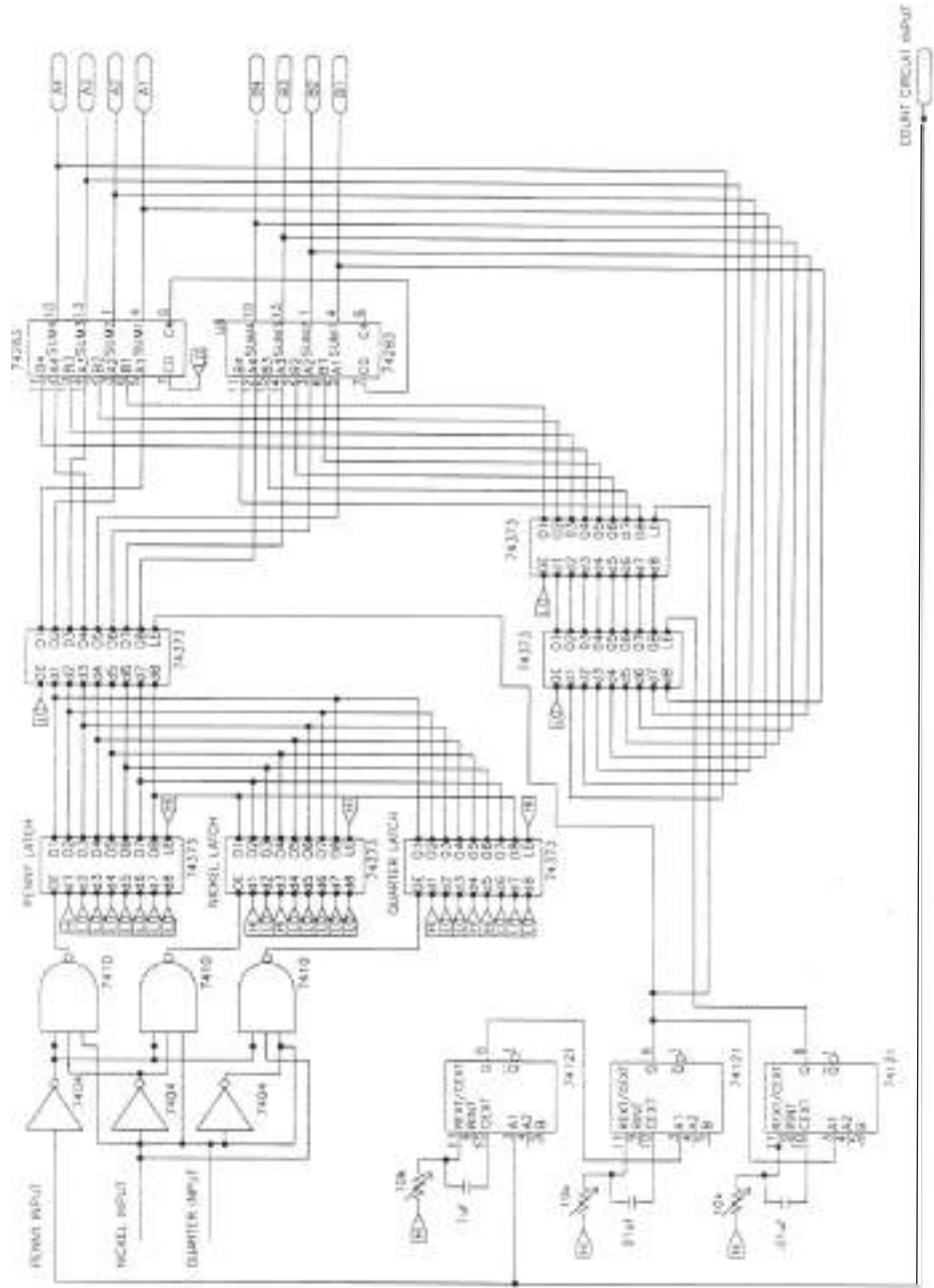
■ CLASS DISCUSSION ITEM 11.2

Coin Counter Circuits

Figure 11.26 shows the coin counter electrical schematic from a student group report. The design uses one-shots to latch the value corresponding to the coin and adds that value to the previous sum. There are mistakes in the input portion of the first half of the circuit used to determine whether the coin is a penny, nickel, or quarter. The error is in the combinational logic portion of the circuit. Based on the timing diagrams shown in Figure 11.25, convince yourself that the logic circuit will not identify the coin correctly.

Even if the logic were correct, the design could still have problems due to timing because the one-shot pulse lengths are fixed but the sensor pulse widths depend on how fast the coin rolls past. A sequential logic circuit that would unequivocally identify the coin as a penny, nickel, or quarter follows. Draw a timing diagram that supports the argument that this sequential logic circuit is a robust design. Include signals S_{low} (low sensor), S_{middle} (middle sensor), S_{high} (high sensor), B , C , L , R , X , Y , and Z in your diagram. Refer to Figure 11.25 for the phototransistor sensor signal timing for each type of coin.





(a) first half of circuit

Figure 11.26 Counter design 1.

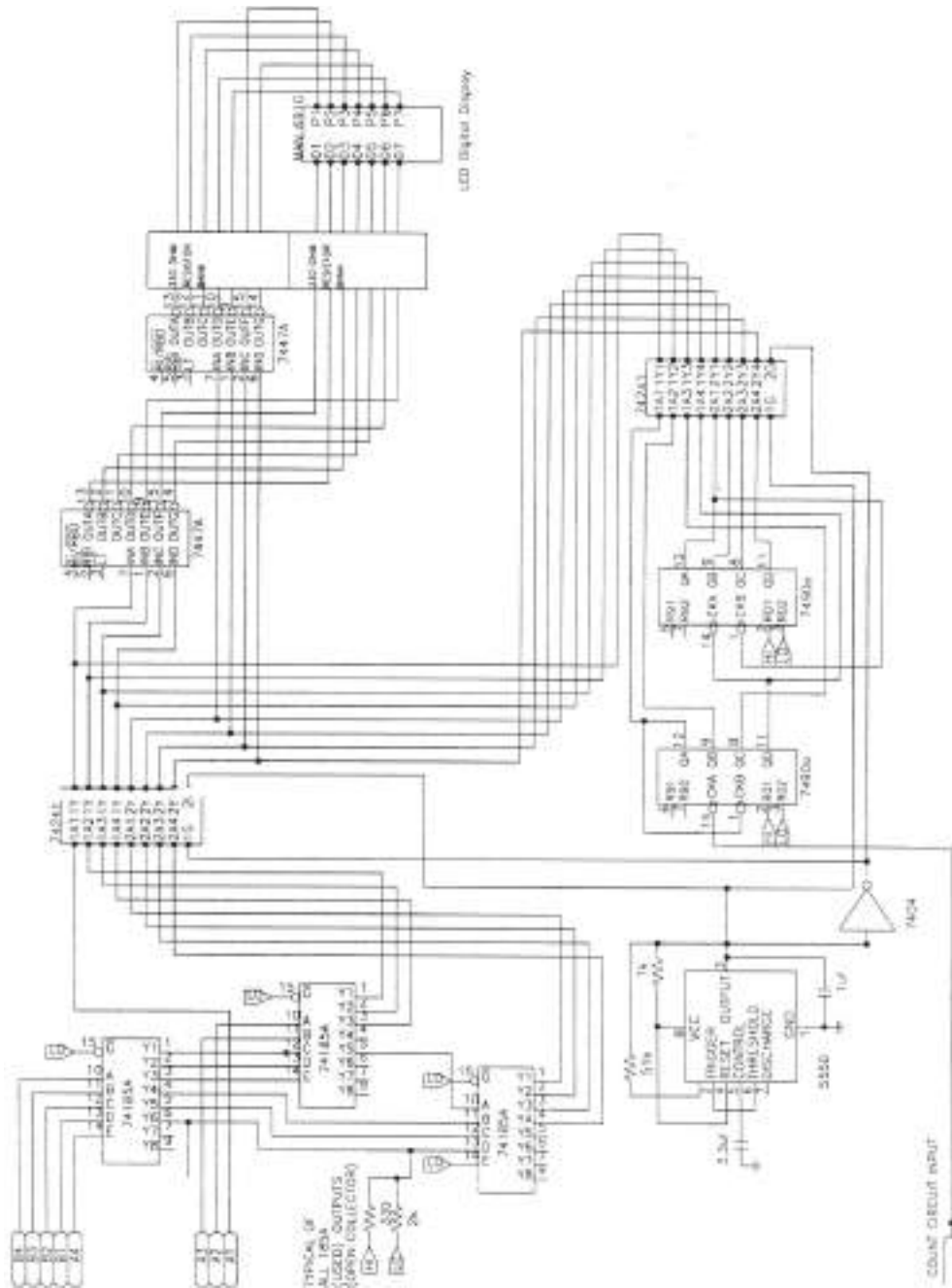
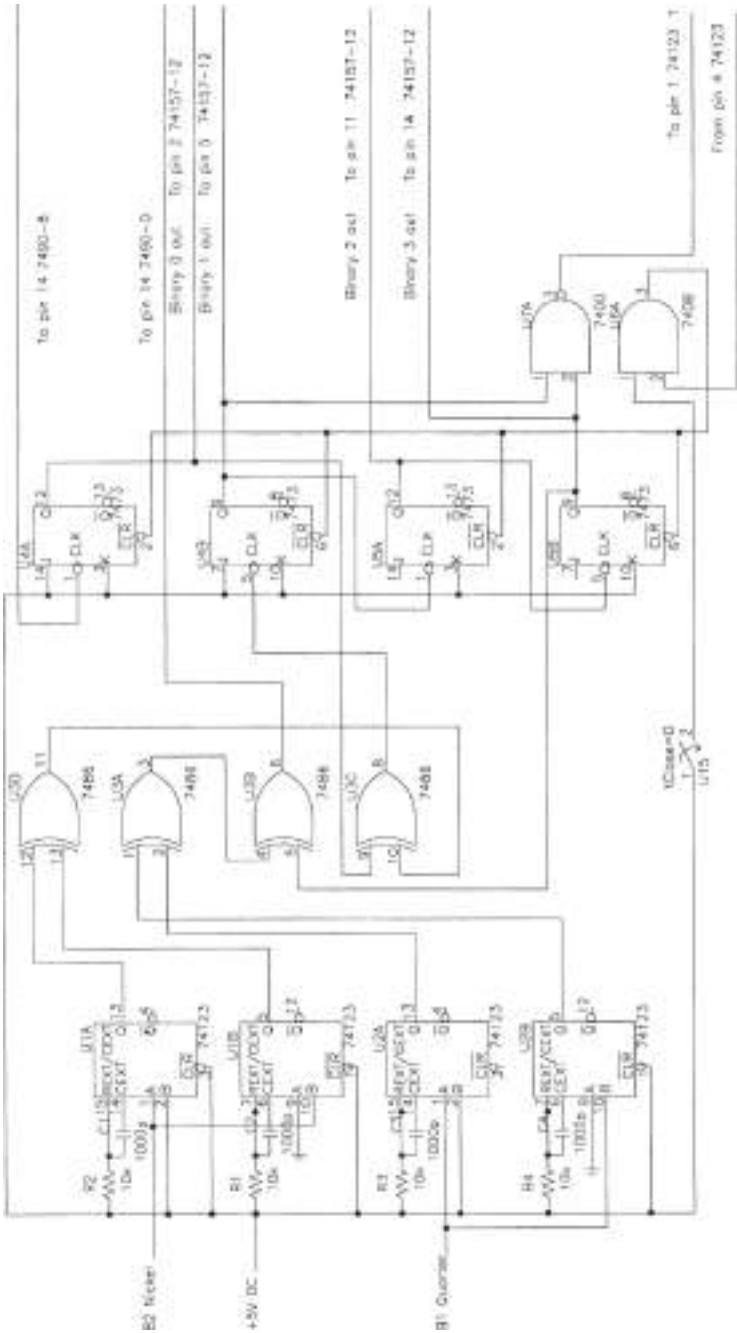
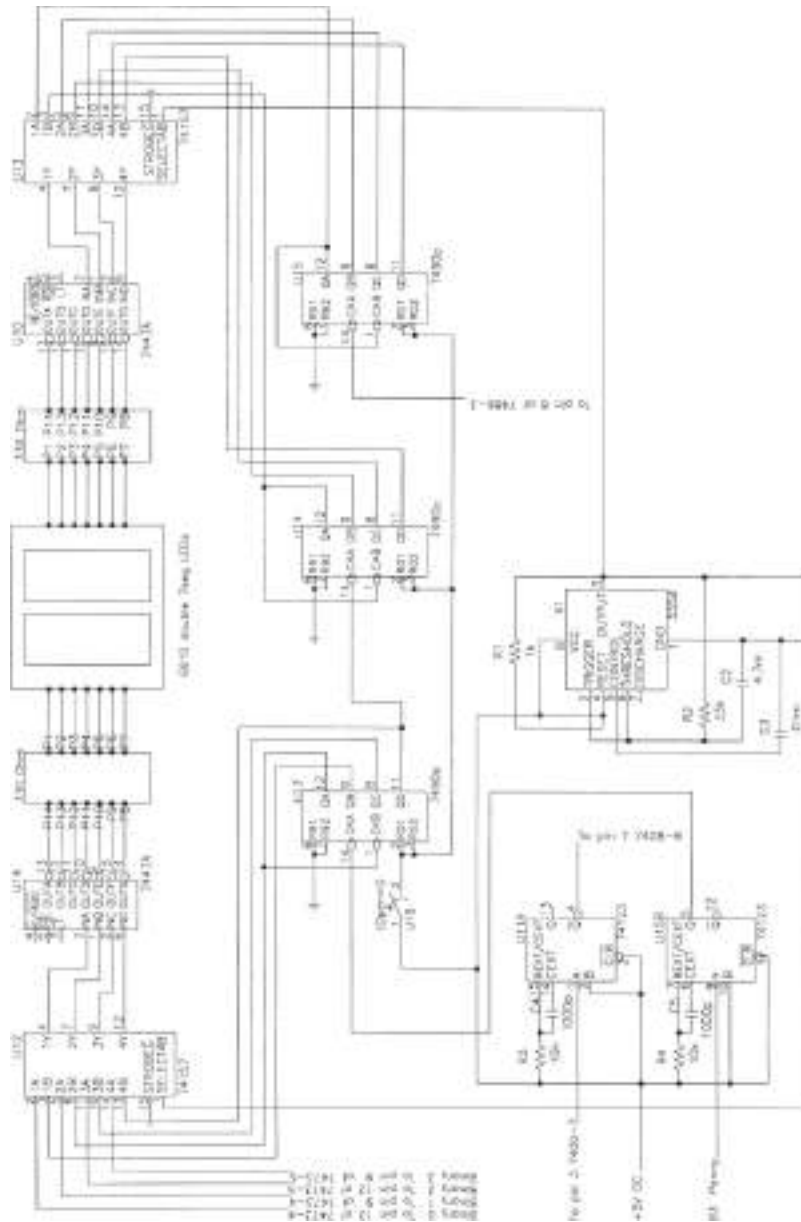


Figure 11.26 (continued)



(a) first half of circuit

Figure 11.27 Counter design 2.



(b) second half of circuit

Figure 11.27 (continued)

11.4.3 Mechatronic Design of a Robotic Walking Machine

In this section, we present a case study of the mechatronic design of an articulated walking machine. It was executed by undergraduate engineering students in 1994, following the completion of our introductory mechatronics course for which this book is used. In 1987, the Society of Automotive Engineers (SAE) began sponsoring an annual Robotic Walking Machine Decathlon, pitting teams from different universities in a challenge to design articulated walking machines that could execute 10 different performance events including a dash, a slalom, obstacle avoidance, and crossing a crevasse. Half of the events included walking motion and obstacle avoidance under tether control, that is, control from a human-operated switch box with an electrical umbilical to the machine. The other half of the events required autonomous control via onboard, preprogrammed systems with no human intervention. Over the years we have seen scores of different walking machine designs, some very simple and capable of completing just a few events, and others of great sophistication and creativity capable of completing all events. The excitement and fun of such competitions is in seeing the fruit of design concepts actually functioning to specifications. Our intent here is not to examine the varieties of walking machines but to focus on a specific design example to illustrate the mechatronic aspects. We begin by displaying three different walking machines, all of which won the national SAE contest (see Figure 11.28).

First, we now present as a case study the design of the 1994 Colorado State walking machine that the students, applying their ever-present wit, named *Airratic*. This design was a refinement of the first pneumatic design from 1992, which was a dramatic break from the evolving electromechanical designs of the previous seven years. With the air-powered designs, the students had to contend with a whole new set of design constraints: providing an onboard source of stored, pressurized air; controlling the mechanical motion of the articulated legs with pneumatic cylinders; distributing and controlling the air; controlling the pressure; reducing coordinated walking motion to sets of computer commands; interfacing a computer to the pneumatic control system; minimizing the weight and size of the machine; ensuring the safety of the system, including sensors on the machine for obstacle avoidance; and making the design changeable and adaptable during test trials on the competition floor.

Because the designers elected to power the walking machine pneumatically, an onboard fiber-wound pressure tank was selected as the energy source for the strategically placed pneumatic pistons that controlled the position and movements of the legs. As shown in Figure 11.29, the skeletal structure of the walking machine consisted of welded aluminum members with 16 double-acting pneumatic cylinders. The four corner legs have 3 degrees of freedom, and the front and rear-center legs have 2 degrees of freedom. The mechanical design of the six legs was such that control algorithms could easily produce forward, reverse, sidewise, and diagonal motion, as well as full-up and full-down motion of the main frame, by simple coordinated control of the 16 cylinders. Each leg included an axial cylinder that could be



(a) "Lurch"—Scotch yoke mechanism leg design (1989)



(b) "Airachnid"—First pneumatic design (1992)



(c) "Airratic"—Refined pneumatic design (1994)

Figure 11.28 Student-designed walking machines from Colorado State University.

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extended or retracted. Ten other cylinders were arranged to position the legs in different patterns in the horizontal plane.

For static stability the machine must be supported by a minimum of three legs at all times, requiring a total of six legs for locomotion. Most walking motions could be

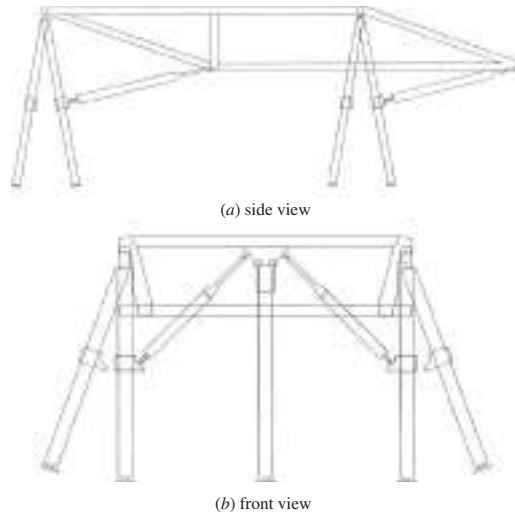


Figure 11.29 Aluminum frame and telescoping pneumatic legs.

divided into the coordinated movement of two sets of three legs each, called Group 1 Legs and Group 2 Legs. Figure 11.30 displays the flowchart used to develop the control code for one class of coordinated motion: forward motion of the machine.

The essence of the control system involves the coordination of 16 pneumatic cylinders using computer-controlled solenoid valves. Each solenoid valve switches air from the main cylinder to one side of the pneumatic cylinder and exhausts pressurized air from the other side, as shown in Figure 11.31. Needle valves were manually adjusted on each solenoid valve to govern cylinder actuating speed.

The complexity of the flowchart in Figure 11.30 warrants a microprocessor-based solution. This and similar flowcharts for each motion command were very helpful in designing the computer code necessary to control and coordinate the motion. The onboard computer controls the solenoid valves via 74373 tristate inverting buffer interface chips receiving signals from an 8-bit port on the computer. As shown in Figure 11.32, the 8-bit port is multiplexed to provide 18 bits of information for coordinated control of the cylinders.

The controller selected in 1994 was a Motorola 68HC811E2 EVM 8-bit microprocessor-based single-board computer. It has 128 K of RAM, and 64 K acts as pseudo-ROM for downloading control programs from an external PC or laptop computer. Thirty I/O bits are provided and expanded via multiplexing to the 48 bits required for the control of all of the components of the machine. Computer code was created on a laptop computer in the high-level language C, then compiled and downloaded to the Motorola EVM for testing. This provided a convenient development environment for testing and modifying the control strategies.

In addition to various walking motions, the machine included sensor feedback using two optical retroreflective sensors. The sensors were mounted on a rotating platform to allow scanning a portion of the region in front of the machine. A digital

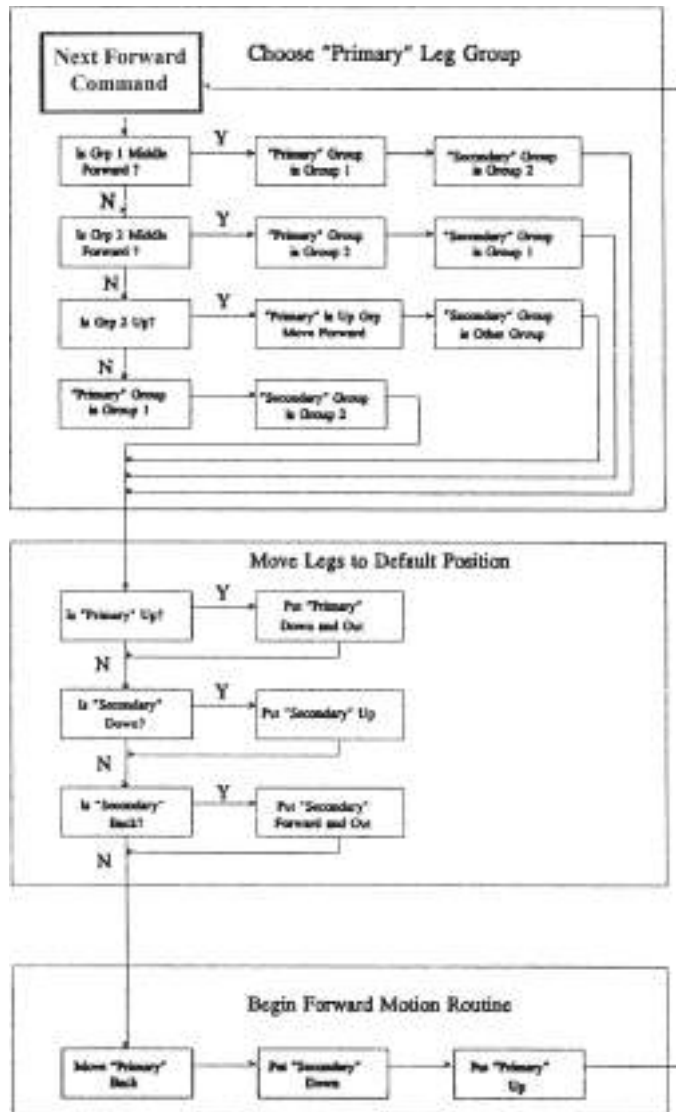


Figure 11.30 Flowchart for forward motion routine.

encoder provided position information corresponding to the sense state of the two sensors. The sensor data was read from the I/O bus of the microprocessor, and software control routines used the data to avoid obstacles.

In summary, we examined an example of a student-designed mechatronic system that received first place in the 1994 SAE Walking Machine Decathlon. It illustrated the use of pneumatic actuators for motion, optical sensors for feedback, and an onboard microcomputer for controlling the machine in both operator-controlled

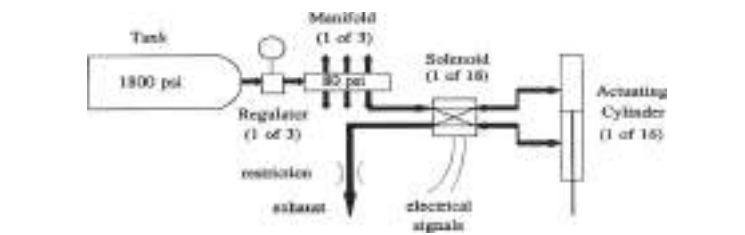


Figure 11.31 Pneumatic system.

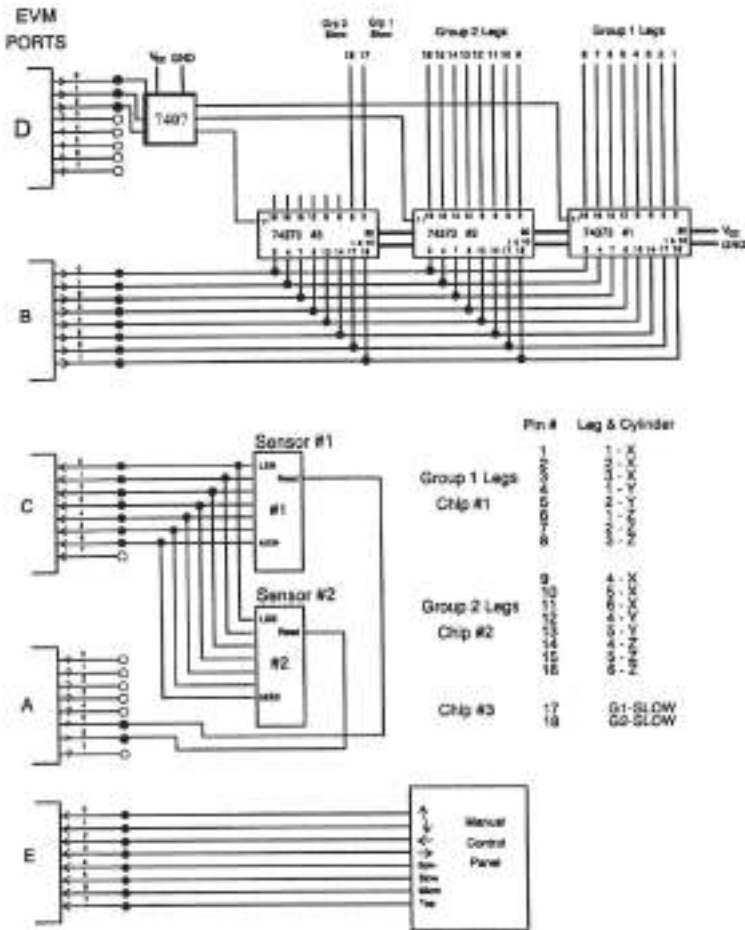


Figure 11.32 Computer ports and I/O board.

and autonomous modes. Projects such as this require a significant amount of time to complete. This project involved eight months of work. The experience gained in designing a complex mechatronic system is very valuable, particularly if the design is actually built, debugged, and challenged to achieve its design goals. In this project, the students were so excited about their success that they even programmed the machine to dance. This was so well received by the audience that they all joined in a country-style line dance at the finale.

11.5 LIST OF VARIOUS MECHATRONIC SYSTEMS

We conclude the book with a partial list of mechatronic systems that you can find in your everyday environment. A very large proportion of engineering systems designed today can be declared as mechatronic systems.

- Airbag safety systems, antilock and automatic braking systems, remote automatic door locks, cruise control, stability and traction control, accident avoidance, hybrid car power management, and other automobile systems
- NC mills, NC lathes, rapid prototyping systems, and other automated manufacturing equipment
- Copy machines, document scanners, and other semi- or fully automatic office equipment
- MRI equipment, arthroscopic instruments, ultrasonic probes, and other medical diagnostic equipment
- Autofocus cameras, video and CD/DVD players, camcorders, and other sophisticated consumer electronic products
- Laser printers, hard-drive and laser-disk head-positioning systems, game controllers, and other computer peripherals
- Welding robots, automatic guided vehicles (AGVs), NASA Mars rover, and other robots
- Flight control actuators, landing gear systems, cockpit controls and instrumentation, and other subsystems on airplanes and drones
- Garage door openers, security systems, heating, ventilation, and air conditioning (HVAC) controls, and other home support systems
- Washing machines, dishwashers, freezer automatic ice makers, and other home appliances
- Variable speed drills, digital torque wrenches, and other modern hand tools
- Materials testing machines, automobile test dummies, and other laboratory support equipment
- PLC-controlled bar code or RF-ID-assisted conveyor systems and other factory automation systems
- Manual and semiautomatic controllers for hydraulic cranes and other construction equipment

- Automatic labeling systems and charge-coupled device (CCD) camera inspections in an IC manufacturing operation
- Video game and virtual reality input controllers

QUESTIONS AND EXERCISES

- 11.1. Document a complete and thorough answer to Class Discussion Item 11.1.
- 11.2. For sample mechatronic systems mentioned in the preceding list, specify the required electronics, sensors, and actuators.
- 11.3. For sample mechatronic systems mentioned in the preceding list, recommend a control architecture and support your choice.
- 11.4. Document a complete and thorough answer to Class Discussion Item 11.2.
- 11.5. Write a PicBasic Pro program to mimic the function of the sequential logic circuit shown in Class Discussion Item 11.2.

BIBLIOGRAPHY

- Bolton, W., *Mechatronics*, 5th ed., Prentice Hall, Englewood Cliffs, NJ, 2013.
- Ogata, K., *Modern Control Engineering*, 5th ed., Prentice Hall, Englewood Cliffs, NJ, 2009.
- Palm, W., *Modeling, Analysis, and Control of Dynamic Systems*, 2nd ed., John Wiley, New York, 1999.

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Measurement Fundamentals

APPENDIX OBJECTIVES

After you read, discuss, study, and apply ideas in this appendix, you will:

1. Be able to define SI units and use them in calculations
2. Know how to use statistics fundamentals to characterize measured data
3. Be able to compute the error associated with a measurement

A.1 SYSTEMS OF UNITS

Fundamental to the design, analysis, and use of any measurement system is a complete understanding of a consistent **system of units** used to quantify the physical parameters being measured. To define a system of units, we must select units of measure for fundamental quantities to serve as a basis for the definition of other physical quantities. Units for mass, length, time, temperature, electric current, amount of substance, and luminous intensity form one possible combination that serves this purpose. Other units used to measure physical quantities in mechatronic systems can be defined in terms of these seven **base units**.

■ CLASS DISCUSSION ITEM A.1

Definition of Base Units

Although everyone has intuitive knowledge of the physical quantities associated with the base units, it is difficult to define them in everyday terms. Try to define length. You will probably use some synonym for length in your definition. Also try to define the others. All are equally difficult to put into simple terms.

The seven base units we use to define mass, length, time, temperature, electric current, amount of substance, and luminous intensity are, respectively, the kilogram, meter, second, kelvin, ampere, mole, and candela. These units form the basis for the International System of Units, abbreviated **SI**, from the French *Le Systeme International d'Unites*.

The **kilogram** is the only unit defined in terms of a material standard; although, this changed in 2018 per the info in Video Demo A.1. It was originally established by a platinum-iridium prototype in the laboratory of the Bureau des Poids et Mesures in Paris. Unfortunately, the name kilogram can be confusing since it contains the prefix kilo. The gram is not the standard, the kilogram is.

The **meter** is defined as 1,650,763.73 wavelengths of the emission resulting from the transition between the $2p_{10}$ and $5d_5$ electron energy levels of the krypton 86 atom. This atomic standard for the meter was proposed long ago by Maxwell (1873) but not implemented until 1960. The earlier meter definition, the distance between two scribed lines on a platinum-iridium bar, like the kilogram, required a prototype for the definition. Now the practical measurement of the unit is deliberately separated from the definition, making the definition independent of a unique prototype. An alternative standard meter was defined in 1983 as the length of the path traveled by light in vacuum during a time interval of $1/299,792,458$ sec.

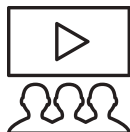
The **second** is defined as the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom. The definition of the second was previously based on the mean solar second, which was defined as a fraction ($1/86,400$) of the earth's daily rotation. Irregularities in the earth's rotation amounting to 1 or 2 seconds per year limited the accuracy of this definition.

The unit of absolute thermodynamic temperature is the **kelvin**. The Kelvin scale has an absolute zero of 0 K, and no temperatures exist below this level. There is a misconception that all molecular motion ceases at this value. Actually, the molecular energy is at a minimum. A standard fixed calibration point on the temperature scale is the triple point of water, which is set at a value of 273.16 K to maintain a relationship with the Celsius scale. Although the Kelvin scale is established using only the absolute zero and triple points, additional fixed points have been defined based on the boiling and melting points of other materials. These points are useful when calibrating temperature measurement devices. Temperature in kelvin and temperature in degrees **celsius** are related by the following equation:

$$T_C = T_K - 273.15 \quad (\text{A.1})$$

where T_K is the Kelvin temperature and T_C is the Celsius temperature expressed in degrees celsius ($^{\circ}\text{C}$). Note that the triple point of water is 0.01°C , corresponding to 273.16 K. The Celsius temperature scale is sometimes referred to as the **centigrade scale** because it is calibrated to the 100°C temperature interval between the freezing point of water (0°C) and the boiling point of water (100°C). An interval or difference of temperature (ΔT) has the same value in both the Celsius and Kelvin scales ($\Delta T_C = \Delta T_K$).

The **ampere** is defined as the constant current that, if maintained in two straight parallel conductors of infinite length and negligible circular cross section and placed



Video Demo

9.6 How we're redefining the kg

1 meter apart in a vacuum, would produce a force between the conductors equal to 2×10^{-7} newtons per meter of length. Unfortunately, this creates a difficult measurement problem, since the definition is in terms of other base units. Therefore, any errors in the other base units would compound the errors in the measurement of the ampere.

The **mole** is defined as the amount of substance that contains as many elementary entities as there are atoms in 0.012 kg of carbon 12 (^{12}C).

The **candela** is defined as the luminous intensity, in the perpendicular direction, of a surface area of $1/600,000 \text{ m}^2$ of a black body at the freezing point of platinum under a pressure of $101,325 \text{ N/m}^2$.

A.1.1 Three Classes of SI Units

SI units are divided into three classes: base units, derived units, and supplemental units. The complete set of **SI base units** and their symbols are listed in Table A.1.

Derived units are expressed as algebraic combinations of the base units. Any known physical parameter can be quantified using a derived unit. Some examples of derived units are listed in Table A.2. Several derived units have been given special names and symbols, which may be used to express other derived units in a simpler way than in terms of base units. Some examples of these **supplemental units** are listed in Table A.3.

Often the base, derived, and supplemental units are modified with prefixes to enable convenient representation of large or small numerical ranges. The **prefixes** express orders of magnitude (powers of 10) of the unit, providing an alternative to scientific notation. The prefix names, symbols, and values are listed in Table A.4.

Table A.1 SI base units

Quantity	Name	Symbol
Length	Meter	m
Mass	Kilogram	kg
Time	Second	s
Electric current	Ampere	A
Thermodynamic temperature	Kelvin	K
Amount of matter	Mole	mol
Luminous intensity	Candela	cd

Table A.2 Examples of SI-derived units expressed in terms of base units

Quantity	Name	Expression
Area	Square meter	m^2
Volume	Cubic meter	m^3
Speed	Meter per second	m/s
Acceleration	Meter per second squared	$(\text{m/s})^2$
Mass density	Kilogram per cubic meter	kg/m^3
Current density	Ampere per square meter	A/m^2

Table A.3 SI-derived units with special names (supplemental units)

Quantity	Name	Symbol	Expression
Frequency	Hertz	Hz	1/s
Force	Newton	N	kg · m/s ²
Pressure, stress	Pascal	Pa	N/m ² = kg/m · s ²
Energy, work	Joule	J	N · m = kg · m ² /s ²
Power, radiant flux	Watt	W	J/s = kg · m ² /s ³
Electric charge	Coulomb	C	A · s
Voltage, electric potential	Volt	V	W/A = kg · m ² /A · s ³
Capacitance	Farad	F	C/V = s ⁴ A ² /m ² kg
Electric resistance	Ohm	Ω	V/A = m ² kg/s ³ A ²
Conductance	Siemens or mho	S or Ω	1/Ω = s ³ A ² /m ² kg
Magnetic field	Tesla	T	N/A · m = kg/s ² A
Magnetic flux	Weber	Wb	T · m ² = m ² kg/s ² A
Inductance	Henry	H	V · s/A = m ² kg/s ² A ²

Table A.4 Unit prefixes

Name	Symbol	Quantity
yotta	Y	10 ²⁴
zetta	Z	10 ²¹
exa	E	10 ¹⁸
peta	P	10 ¹⁵
tera	T	10 ¹²
giga	G	10 ⁹
mega	M	10 ⁶
kilo	k	10 ³
hecto	h	10 ²
deca	da	10
deci	d	10 ⁻¹
centi	c	10 ⁻²
milli	m	10 ⁻³
micro	μ	10 ⁻⁶
nano	n	10 ⁻⁹
pico	p	10 ⁻¹²
femto	f	10 ⁻¹⁵
atto	a	10 ⁻¹⁸
zepto	z	10 ⁻²¹
yocto	y	10 ⁻²⁴

EXAMPLE A.1 Unit Prefixes

The output of a 125 million watt power station can be expressed as

$$125,000,000 \text{ W} \quad \text{or} \quad 125 \text{ MW}$$

An example of a tiny interval of time, common in high-performance electronics, can be expressed as

$$5.27 \times 10^{-13} \text{ s} \quad \text{or} \quad 0.527 \text{ ps}$$

■ CLASS DISCUSSION ITEM A.2

Common Use of SI Prefixes

For each of the prefixes listed in Table A.4, think of or research an example of a measurable physical quantity for which the prefix is commonly used to express the value.

A.1.2 Conversion Factors

English units are still common in engineering practice in the United States. Table A.5 lists several factors that help when converting between English and SI units.

Table A.5 Useful English to SI conversion factors

Physical quantity	English unit	SI unit
Length	1 in	2.540 cm
	1 ft	0.3048 m
	1 mi (mile)	1.609 km
Mass	1 lbm (pound mass)	0.4536 kg
Force	1 lbf (pound force)	4.448 N
Temperature	Fahrenheit temperature (T_F)	$T_k = 5/9 \cdot (T_F - 32) + 273.15$
Pressure	1 lb/in ² (psi)	6.895×10^3 Pa
	1 atm	1.013×10^5 Pa
Power	1 Btu/h	0.2929 W
	1 hp	745.7 W
Magnetic field	1 gauss	1.000×10^{-4} tesla

■ CLASS DISCUSSION ITEM A.3

Physical Feel for SI Units

To help gain a physical feel for SI units, it is helpful to consider and remember concrete examples for each of the units. For each of the following common physical items, list the appropriate SI unit and approximate value:

- Length of a typical human foot
- Length of a city block
- Mass of a 2-liter bottle of soda pop
- Mass of an average adult human body
- Force required to pick up a 2-liter bottle of soda pop
- Force exerted by an average adult human body on a scale
- Human body temperature
- Comfortable room temperature
- Atmospheric pressure
- Typical air pressure in a building's pneumatic system
- Power dissipated by a typical incandescent lightbulb
- Typical maximum power generated by an automobile

A.2 SIGNIFICANT FIGURES

Whenever we deal with numerical data, we need to be aware of precision, accuracy, and different ways to present the data. Also, in establishing a rational approach to making numerical calculations with measured values, we must present decimal numbers with the appropriate number of digits.

The significant digits or **significant figures** in a number are those known with certainty. A measured value represented by N digits consists of $N - 1$ significant digits that are certain and 1 digit that is estimated. For example, when reading a dial on a pressure gage one might record 4.85 Pa. Here the 4 and 8 are certain, but the 5 may be an interpolated value. Hence, an observer is involved in the estimation of significance. If a number is reported with leading zeros, the leading zeros are not significant since they are only used to fix the decimal place (see Example A.2).

Today, with the common use of digital computers for data processing, one must be aware of the fact that a 12-digit number resulting from a computer calculation may have only 3 significant digits! The rest may be meaningless.

EXAMPLE A.2

Significant Figures

Note the number of significant figures and the corresponding significant digits for each of the numbers that follow:

Number	Number of significant figures	List of significant digits
50.1	3	5, 0, 1
0.0501	3	5, 0, 1
5.010	4	5, 0, 1, 0

EXAMPLE A.3

Scientific Notation

Scientific notation is useful in clearly representing the number of significant figures. Here are the representations of the numbers in Example A.2:

Number using scientific notation	Number of significant figures
5.01×10^1	3
5.01×10^{-2}	3
5.010×10^0	4

Mathematical computations present another difficulty when the argument values contain different numbers of significant figures. We must be careful in rounding off and retaining the appropriate number of significant figures in computed results.

When you are required to round a number to N significant figures, dispose of all digits to the right of the N th place. If the discarded part exceeds one half of the N th digit, increase the N th digit by 1. If it is less than one half of the N th digit, leave it as it is. If it is exactly one half of the N th digit, a common rule is to leave the N th digit unchanged if it is even or increase it by 1 if it is odd. It is important to be consistent when you apply these rules.

When adding quantities, determine the number of significant figures to the right of the decimal place in the least accurate number. Then retain only one more decimal place in the remaining numbers by truncation. Now add the numbers and round off to the same number of decimal places as in the least accurate number. This process is demonstrated in Example A.4.

Addition and Significant Figures

EXAMPLE A.4

We wish to add the following numbers:

$$\begin{array}{r} 5.0365 \\ +1.04 \\ +6.09314 \end{array}$$

Since the least number of significant figures to the right of the decimal place in the least accurate number (1.04) is two, we truncate the other numbers to three decimal places and add:

$$\begin{array}{r} 5.036 \\ +1.04 \\ +6.093 \end{array}$$

The result of this addition is

$$12.169$$

Since the number of decimal places in the least accurate number is two, we round off the result to two decimal places, giving

$$12.17$$

When subtracting two quantities, round off the more accurate number to the number of decimal places in the least accurate number. Subtract and provide a result with the same number of decimal places as in the least accurate number, as demonstrated in Example A.5.

Subtraction and Significant Figures

EXAMPLE A.5

We wish to subtract the following numbers:

$$\begin{array}{r} 8.59320 \\ -1.04 \end{array}$$

(continued)

(continued)

Since the least accurate number (1.04) has two decimal places, we round off the other number also to two decimal places and subtract

$$\begin{array}{r} 8.59 \\ -1.04 \\ \hline \end{array}$$

The result of this subtraction is

$$7.55$$

When multiplying and dividing numbers, round off the more accurate numbers to one more significant figure than the least accurate number. Compute and round the result to the same number of significant figures as in the least accurate number as demonstrated in Example A.6.

EXAMPLE A.6**Multiplication and Division and Significant Figures**

Given the multiplication and division problem:

$$(1.03)(51.7946)(3.01)(695.01)(7001.59)$$

We round off the more accurate numbers to four significant figures (one more than the three in 1.03 and 3.01):

$$(1.03)(51.79)(3.01)(695.0)(7002.)$$

The result of this multiplication after retaining three significant figures is

$$0.0000330 = 3.30 \times 10^{-5}$$

A.3 STATISTICS

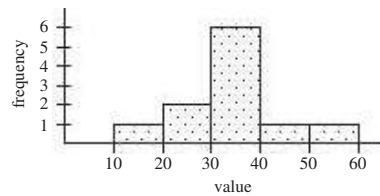
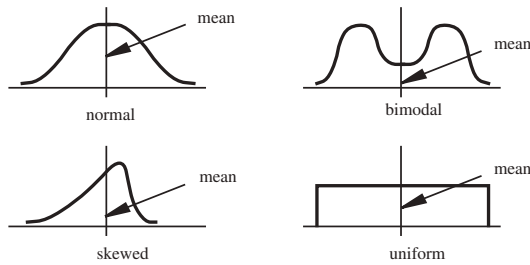
When we process sets of data obtained from experimental measurements, we must handle the data in a rational, systematic, and organized fashion. The field of **statistics** provides models and rules for doing this properly.

Often, we seek a number or a small set of numbers to represent or characterize a large set of data. The first step is to assess the range of the data by noting the minimum and maximum values known as the **extreme values**. We then look at how the data points are distributed between these extreme values. This distribution can be graphically represented using a **histogram**, which results from sorting the values into subranges and displaying the number of data points in each subrange. The histogram for the set of experimental data given in Table A.6 is illustrated in Figure A.1.

The number of data points falling into each subrange of the histogram is called the **frequency**. The histogram may approximate a specific shape such as a normal, skewed, bimodal, or uniform distribution as illustrated in Figure A.2. The normal distribution represents a typical statistical spread of data around an average (mean) value. The skewed distribution represents some weighting in the statistics to one side of the mean. The bimodal distribution represents the case where there may be two

Table A.6 Set of experimental data

Index	Value
1	25.5
2	42.1
3	36.4
4	32.1
5	15.6
6	38.6
7	55.3
8	29.1
9	32.1
10	34.0
11	35.0

**Figure A.1** Histogram of experimental data.**Figure A.2** Distributions of data.

merged populations with two different means. The uniform distribution represents completely random data.

Many data points are required to create a histogram. Statistics provides rules for distilling the histogram down to just a few numbers representing the characteristics of the data set. The most important statistical measure is the **arithmetic mean**, which is also called the **average** or simply the mean. Denoted by $\bar{x}$, it is the sum of each of the data values x_i divided by the number of data points N :

$$\bar{x} = \frac{\sum_{i=1}^N x_i}{N} \quad (\text{A.2})$$

Other statistical measures that characterize a set of data are the **median**, which is the data point that has an equal number of data points on either sides; the **mode**, which is the value that occurs most frequently; and the **geometric mean**, defined as the N th root of the product of the values:

$$GM = \sqrt[N]{x_1 x_2 \dots x_N} \quad (\text{A.3})$$

The geometric mean is more desirable than the arithmetic mean for averaging ratios since the reciprocal of the GM is equal to the GM of the reciprocals.

For the set of data in Table A.6, the mean is 34.2, the median is 34.0, the mode is 32.1, and the geometric mean is 32.7.

■ CLASS DISCUSSION ITEM A.4

Statistical Calculations

Verify the calculations for the mean, median, mode, and geometric mean for the data in Table A.6.

■ CLASS DISCUSSION ITEM A.5

Your Class Age Histogram

In one of your class lectures, form a single line of people in order of birth date with the youngest being first. Now form a birth year histogram by assembling into rows according to birth year. Store the histogram data (year, frequency) for use in Question A.2 at the end of the Appendix.

The spread or dispersion of a data set over its range is characterized by another statistical measure, known as the **variance**, defined by

$$v = \sigma^2 = \sum_{i=1}^N \frac{(x_i - \bar{x})^2}{N - 1} \quad (\text{A.4})$$

where x_i is an individual measurement and N is the total number of measurements, called the **sample size** of the experiment. The **standard deviation** σ also describes variance, but in the units of the individual measurements. It is defined as the square root of the variance:

$$\sigma = \sqrt{v} = \sqrt{\sum_{i=1}^N \frac{(x_i - \bar{x})^2}{N - 1}} \quad (\text{A.5})$$

The standard deviation estimates the magnitude of the spread of the experimental data around the mean value. A small standard deviation indicates that the data set has a narrow spread.

■ CLASS DISCUSSION ITEM A.6

Relationship Between Standard Deviation and Sample Size

The denominator in Equation A.5 is often confusing since one might assume it to be N , providing a value known as the **root mean square** (rms). Why is the denominator $(N - 1)$ and not N ? Consider the situation where there is only one sample ($N = 1$). Also, consider how many data values x_i must be specified to define the entire data set if the mean is known.

A.4 ERROR ANALYSIS

The process of making measurements is imperfect, and uncertainty will always be associated with measured values. It is important to recognize sources of error and estimate the magnitude of error when one makes a measurement. Usually a manufacturer defines the accuracy of an instrument in published specifications, but other factors come into play.

There are three types of errors: systematic errors, random errors, and blunders. A **systematic error** is one that reoccurs in the same way each time a measurement is made. The method used to minimize the magnitude of systematic error is **calibration**, where the measuring instrument is used to record values from a standard input and is adjusted (calibrated) to compensate for any discrepancy. **Random errors** occur due to the stochastic variations in a measurement process. Some of the statistical tools presented in the previous section enable us to reduce the effects of these errors. **Blunders** occur when the engineer or scientist makes a mistake. Blunders can be avoided by careful design and review, and through the use of methodical procedures.

Figure A.3 illustrates systematic and random errors. The center of the target represents the desired value, and the shot pattern represents measured data. The systematic error, called inaccuracy, is associated with the shift of the shot pattern from the center of the target and could be corrected by improved sighting, known as

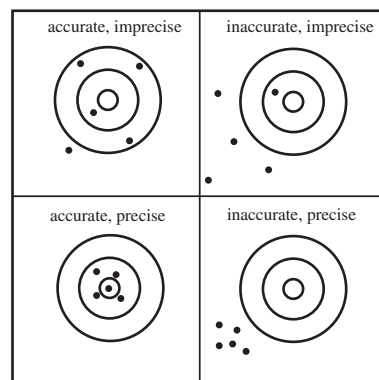


Figure A.3 Accuracy and precision.

calibration. The random error, called imprecision, is the size of the shot pattern and cannot be improved by adjusting the sighting. **Accuracy** is the closeness to the true value, and **precision** is the repeatability or consistency of the measurements.

Statistical calculations help us estimate a more precise value when a sample of imprecise measurements is taken in the presence of random errors. The average, or mean, provides this estimate.

A.4.1 Rules for Estimating Errors

When designing a measurement protocol to compute a parameter defined in terms of measured variables, it is necessary to estimate the error in the parameter due to the combined errors in the variables. A procedure for computing this overall error follows:

1. Prepare a table of data including the $\pm$ error estimate for each variable. Generally, the estimated error contains no more than two significant figures.
2. If the parameter to be computed is X , where X is a function of measured variables (v_i),

$$X = X(v_1, v_2, \dots, v_n) \quad (\text{A.6})$$

compute the partial derivatives $\partial X/\partial v_1, \partial X/\partial v_2, \dots, \partial X/\partial v_n$ and evaluate each to three significant figures using the recorded data ($v_1, v_2, \dots, v_n$).

3. Compute the total absolute error E using

$$E = \Delta X = \left| \frac{\partial X}{\partial v_1} \Delta v_1 \right| + \left| \frac{\partial X}{\partial v_2} \Delta v_2 \right| + \dots + \left| \frac{\partial X}{\partial v_n} \Delta v_n \right| \quad (\text{A.7})$$

where Δv_i is the error in the recorded value v_i . Round E to two significant figures.

A more conventional error measure is the **root-mean-square (rms)** error given by the square root of the sum of the squares of the individual error terms:

$$E_{\text{rms}} = \sqrt{\left(\frac{\partial X}{\partial v_1} \Delta v_1 \right)^2 + \left(\frac{\partial X}{\partial v_2} \Delta v_2 \right)^2 + \dots + \left(\frac{\partial X}{\partial v_n} \Delta v_n \right)^2} \quad (\text{A.8})$$

The rms error measure yields a closer approximation of the actual error.

4. Compute X using Equation A.6 to one more decimal place than the rounded error E . For example, if $E = \pm 0.039$, and X is computed to be 8.9234, then this value is rounded to the same number of decimal places as E , giving 8.923. When computing X , treat $v_1, v_2, \dots, v_n$ as exact numbers.
5. The result is

$$X = 8.923 \pm 0.039$$

The following list is a summary of important points to keep in mind when treating numbers and calculating errors in laboratory data analysis:

1. Note the number of significant figures that a particular instrument displays.

2. Record all values with the correct number of significant digits. If the instrument display does not provide a digital output, this may require that the observer estimate the accuracy of the measurement.
3. Different instruments in a system may have different numbers of significant digits.
4. When computing results using equations, retain the appropriate number of significant digits when performing calculations.
5. If events can be repeated, better estimates of values can be obtained by averaging. The standard deviation of these samples gives a measure of precision in the average.

QUESTIONS AND EXERCISES

- A.1.** Express each of the following quantities with a more appropriate SI prefix equivalent:
- a. 100,000,000 kg
 - b. 0.000000025 m
 - c. 16.9×10^{-10} s
- A.2.** Plot the histogram and calculate the mean, standard deviation, median, mode, and geometric mean for the data obtained from Class Discussion Item A.5.
- A.3.** What are the total absolute and rms errors in the calculated maximum stress in a rectangular cantilever beam subject to an end load of $12,520 \pm 10$ N? The beam geometry, as measured by a metric ruler accurate to 0.5 mm, is 0.95 m long by 11.8 cm wide by 12.1 cm high. The maximum stresses occur on the upper and lower surfaces of the beam at the support and are given by

$$\sigma_{\max} = \frac{Mc}{I}$$

where M is the bending moment given by the product of the force and the beam length, c is the distance from the neutral axis given by half the height, and I is the second moment of area of the beam cross section given by

$$I = \frac{1}{12}wh^3$$

where w and h are the width and height of the beam cross section, respectively.

BIBLIOGRAPHY

- Beckwith, T., Marangoni, R., and Lienhard, J., *Mechanical Measurements*, Addison-Wesley, Reading, MA, 1993.
- Chapra, S., and Canale, R., *Introduction to Computing for Engineers*, McGraw-Hill, New York, 1994.
- Chatfield, C., *Statistics for Technology*, Penguin Books, Middlesex, England, 1970.
- Doebelin, E., *Measurement Systems Applications and Design*, 4th Edition, McGraw-Hill, New York, 1990.

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Physical Principles

APPENDIX OBJECTIVES ---

After you read, discuss, study, and apply ideas in this appendix, you will be able to:

1. Identify possible relationships between various physical quantities
2. Identify approaches for measuring nearly all physical quantities

Sensor and transducer design always involves the application of some law or principle of physics or chemistry that relates the variable of interest to some measurable quantity. The following list summarizes many of the physical laws and principles that have potential application in sensor and transducer design. Some examples of applications are also provided. This list is extremely useful to a transducer designer who is searching for a method to measure a physical quantity. Practically every transducer applies one or more of these principles in its operation. The parameters related by the respective principles are highlighted.

- *Ampere's law:* The integral of the **magnetic field** around a closed loop is proportional to the **current** piercing the loop.
A magnetic pickup sensor uses this effect as a nonintrusive method of measuring current in a conductor.
- *Archimedes' principle:* The buoyant **force** exerted on a submerged or floating object is equal to the weight of the fluid displaced. The **volume** displaced depends on the fluid **density**.
A ball submersion hydrometer uses this effect to measure the density of a fluid (e.g., automotive coolant).
- *Bernoulli's equation:* Conservation of energy in a fluid provides or establishes the relationship between **pressure** and **velocity** of the fluid.
A pitot tube uses this effect to measure air speed of an aircraft. Video Demo B.1 shows an example of how to relate pressure readings to flow velocity.



Video Demo

B.1 Flow over a cylinder in a wind tunnel

- *Biot-Savart's law:* The contribution of a **current** element to a **magnetic field** at a point depends on the distance to the current element and the current direction. No example of utilizing this law, here and in several other items.
- *Biot's law:* The rate of **heat conduction** through a medium is directly proportional to the **temperature** difference across the medium.
This principle is basic to time constants associated with temperature transducers.
- *Blagdeno law:* The freezing **temperature** of a liquid drops and the boiling temperature rises with **concentration** of impurities in the liquid.
- *Boyle's law:* An ideal gas maintains a constant **pressure-volume** product under constant **temperature**.
- *Bragg's law:* The intensity of an X-ray beam diffracted by a **crystal lattice** is related to the crystal plane separation and the **wavelength** of the beam.
An X-ray diffraction system uses this effect to measure the crystal lattice geometry of a crystalline specimen.
- *Brewster's law:* The **index of refraction** of a material is related to the angle of **polarized light** reflection or transmission.
A Brewster's window on a laser tube is used to extract some of the power in the form of a laser beam. Lasers are used extensively in measurement systems.
- *Butterfly effect:* Chaotic nonlinear systems exhibit a sensitive dependence on initial conditions.
This effect doesn't really have application to sensor and transducer design, but it is interesting anyway.
- *Centrifugal force:* A body moving along a curved path experiences an apparent outward **force**.
- *Charles' law:* An ideal gas maintains a constant **pressure-temperature** product at constant **volume**.
- *Christiansen effect:* Powders suspended in a liquid (i.e., a colloidal solution) result in altered fluid **refraction** properties.
- *Compton effect:* The energy of **light/radiation** can decrease, and the **wavelength** can increase, when it reflects off charged particles.
- *Corbino effect:* **Current** flow is induced in a conducting disk rotating in a **magnetic field**.
- *Coriolis effect:* A body moving relative to a rotating frame of reference (e.g., the earth) experiences a **force** relative to the frame (see Internet Link B.1).
A Coriolis flow meter uses this effect to measure mass flow rate in a u-tube in rotational vibration.
- *Coulomb's law:* **Electric charges** exert a **force** on each other.
- *Curie-Weiss law:* There is a transition **temperature** at which ferromagnetic materials exhibit **paramagnetic** behavior.
- *d'Alembert's principle:* **Acceleration** of a **mass** is equivalent to an equal and opposite applied **force**.
- *Debye frequency effect:* The **conductance** of an electrolyte increases (i.e., the **resistance** decreases) with **frequency**.



Internet Link

B.1 Coriolis effect video demonstrations



Internet Link

B.2 Gyroscopic
effect video
demonstrations

- *Doppler effect:* The **frequency** received from a wave source (e.g., sound or light) depends on the **speed** of the source.

A laser doppler velocimeter (LDV) uses the frequency shift of laser light reflected off of particles suspended in a fluid to measure fluid velocity.

- *Edison effect:* When metal is heated in a vacuum, it emits charged particles (i.e., **thermionic emission**) at a rate dependent on the **temperature**.

A vacuum tube amplifier is based on this effect, where electrons are emitted and controlled to produce amplification of current.

- *Faraday's law of electrolysis:* The rate of **ion deposition** or **depletion** is proportional to the electrolytic **current**.

- *Faraday's law of induction:* A coil resists a change in **magnetic field** linkage with an **electromotive force**.

The induced voltages in the secondary coils of a linear variable differential transformer (LVDT) are a result of this effect.

- *Gauss effect:* The **resistance** of a conductor increases when **magnetized**.

- *Gladstone-Dale law:* The **index of refraction** of a substance is dependent on **density**.

- *Gyroscopic effect:* A body rotating about one axis resists rotation about other axes (see Internet Link B.2).

A navigation gyroscope uses this effect to track the orientation of a body with the aid of a gimbal-mounted flywheel that maintains constant orientation in space.

- *Hall effect:* A **voltage** is generated perpendicular to **current** flow in a **magnetic field**.

A Hall effect proximity sensor detects when a magnetic field changes due to the presence of a metallic object.

- *Hertz effect:* **Ultraviolet light** affects the discharge of a spark across a gap.

- *Hooke's Law:* Axial **stress** in a uniaxially loaded, linear elastic material is directly proportional to axial **strain**.

Resistance measurements from a strain gage can be converted to strain readings, which can be directly related to stresses in a loaded part.

- *Johnsen-Rahbek effect:* **Friction** at interfaces between a conductor, semiconductor, or insulator increases with **voltage** across the interfaces.

- *Joule's law:* **Heat** is produced by **current** flowing through a **resistor**.

The design of a hot-wire anemometer is based on this principle.

- *Kerr effect:* Applying a **voltage** across a substance can cause **optical polarization**.

Liquid crystal displays (LCDs) function as a result of this principle.

- *Kohlrausch's law:* An **electrolytic** substance has a limiting conductance (minimum **resistance**).

- *Lambert's cosine law:* The reflected **luminance** of a surface varies with the cosine of the **angle of incidence**.

- *Lenz's law:* Induced **current** flows in the direction to oppose the change in **magnetic field** that produces it.

- *Lorentz's force law:* A **current**-carrying conductor in a **magnetic field** experiences a **force**.
Based on this law, a galvanometer measures current by measuring the deflection of a pivoted coil in a permanent magnetic field.
- *Magnetostrictive effect:* a ferromagnetic material **constricts** when surrounded by a **magnetic field**.
This effect is used by magnetoresistive linear displacement sensors (see Video Demo B.2).
- *Magneto-rheological effect:* A magneto-rheological fluid's **viscosity** can increase dramatically in the presence of a **magnetic field**.
- *Magnus effect:* When fluid flows over a rotating body, the body experiences a **force** in a direction perpendicular to the flow.
- *Meissner effect:* A **superconducting** material within a **magnetic field** blocks this field and experiences no internal field.
- *Moore's law:* The density of transistors that can be manufactured on an integrated circuit doubles every 18 months.
This law doesn't really have direct application to sensor and transducer design, but it is interesting anyway.
- *Murphy's law:* Whatever can go wrong will go wrong and at the wrong time and in the wrong place.
This law doesn't really have application to sensor and transducer design, but your experiments in the laboratory will often provide evidence of its effects.
- *Nernst effect:* **Heat flow** across **magnetic field** lines produces a **voltage**.
- *Newton's law:* **Acceleration** of an object is proportional to **force** acting on the object.
- *Ohm's law:* **Current** through a **resistor** is proportional to the **voltage** drop across the resistor.
- *Parkinson's law:* Human work expands to fill the time allotted for it.
This law doesn't really have application to sensor and transducer design, but you will most certainly experience it at times.
- *Peltier effect:* When **current** flows through the junction between two metals, **heat** is absorbed or liberated at the junction.
Thermocouple measurements can be adversely affected by this principle.
- *Photoconductive effect:* When **light** strikes certain semiconductor materials, the **resistance** of the material decreases.
A photodiode, which is used extensively in photodetector pairs, functions based on this effect.
- *Photoelectric effect:* When **light** strikes a metal cathode, electrons are emitted and attracted to an anode, resulting in **current** flow.
The operation of a photomultiplier tube is based on this effect.
- *Photovoltaic effect:* When **light** strikes a semiconductor in contact with a metal base, a **voltage** is produced.

**Video Demo**

B.2 Magneto-restrictive position sensor



Video Demo

B.3 Shape-memory alloy orthodontic wire

The operation of a solar cell is based on this effect.

- **Piezoelectric effect:** **Charge** is displaced across a crystal when it is strained.
A piezoelectric accelerometer measures charge polarization across a piezoelectric crystal subject to deformations due to the inertia of a mass.
A piezoelectric microphone's ability to convert sound pressure waves to a voltage signal is a result of this principle.
- **Piezoresistive effect:** **Resistance** is proportional to an applied **stress**.
This effect is partially responsible for the response of a strain gage.
- **Pinch effect:** The cross section of a liquid conductor reduces with **current**.
- **Poisson effect:** A material deforms in a direction perpendicular to an applied **stress**.
This effect is partially responsible for the response of a strain gage.
- **Pyroelectric effect:** A crystal becomes **polarized** when its **temperature** changes.
- **Raleigh criteria:** Relates the **acceleration** of a fluid to bubble formation.
- **Raoult's effect:** **Resistance** of a conductor changes when its length is changed.
This effect is partially responsible for the response of a strain gage.
- **Seebeck effect:** Dissimilar metals in contact result in a **voltage** difference across the junction that depends on **temperature**.
This is the primary effect that explains the function of a thermocouple.
- **Shape memory effect:** A deformed metal, when heated, returns to its original shape (see Video Demo B.3).
- **Snell's law:** Reflected and refracted rays of **light** at an optical interface are related to the angle of incidence.
- **Stark effect:** The **spectral lines** of an electromagnetic source split when the source is in a strong **electric field**.
- **Stefan-Boltzmann law:** The **heat** radiated from a black body is proportional to the fourth power of its **temperature**.
The design of a pyrometer is based on this principle.
- **Stokes' law:** The **wavelength** of light emitted from a fluorescent material is always longer than that of the absorbed photons.
- **Thomson effect:** When **current** flows through a material with a temperature gradient, **heat** is absorbed or liberated through the gradient. This is a continuous version of the Peltier effect.
Thermocouple measurements can be adversely affected by this principle.
- **Tribo-electric effect:** Relative motion and **friction** between two dissimilar metals produces a **voltage** between the interface.
- **Wiedemann-Franz law:** The ratio of **thermal** to **electrical conductivity** of a material is proportional to its absolute **temperature**.
- **Wien effect:** The **conductance** of an electrolyte increases (i.e., the **resistance** decreases) with applied **voltage**.
- **Wien's displacement law:** As the **temperature** of an incandescent material increases, the spectrum of emitted **light** shifts toward blue.

Mechanics of Materials

APPENDIX OBJECTIVES

After you read, discuss, study, and apply ideas in this appendix, you will:

1. Understand the basic relationships between stress and strain
2. Be able to determine the principal stress values and directions for a general state of planar stress
3. Be able to construct Mohr's circle for a state of planar stress

C.1 STRESS AND STRAIN RELATIONS

As shown in Figure C.1, when a cylindrical rod is loaded axially, it will lengthen by an amount ΔL and deform radially by an amount ΔD . The **axial strain** (ϵ_{axial}) is defined as the change in length per unit length:

$$\epsilon_{\text{axial}} = \frac{\Delta L}{L} \quad (\text{C.1})$$

Note that strain is a dimensionless quantity. The **axial stress** (σ_{axial}) is related to axial strain through **Hooke's law**, which states that for a uniaxially loaded linear elastic material the axial stress is directly proportional to the axial strain:

$$\sigma_{\text{axial}} = E \epsilon_{\text{axial}} \quad (\text{C.2})$$

where E is the constant of proportionality called the **modulus of elasticity** or **Young's modulus**. The axial stress in the rod is

$$\sigma_{\text{axial}} = F/A \quad (\text{C.3})$$

where F is the axial force and A is the cross-sectional area of the rod. Therefore, the axial strain is related to the axial stress and load:

$$\epsilon_{\text{axial}} = \frac{\sigma_{\text{axial}}}{E} = \frac{F/A}{E} \quad (\text{C.4})$$

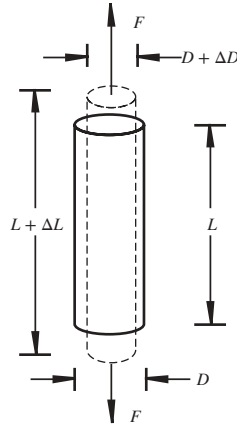


Figure C.1 Axial and transverse deformation of a cylindrical bar.

The **transverse strain** is defined as the change in width divided by the original width:

$$\epsilon_{\text{transverse}} = \frac{\Delta D}{D} \quad (\text{C.5})$$

The ratio of the transverse and axial strain is defined as **Poisson's ratio** (ν):

$$\nu = -\frac{\epsilon_{\text{transverse}}}{\epsilon_{\text{axial}}} \quad (\text{C.6})$$

Note that for axial elongation ($\epsilon_{\text{axial}} > 0$), $\epsilon_{\text{transverse}}$ (from Equation C.6), and therefore ΔD (from Equation C.5) are negative, implying contraction in the transverse radial direction. Poisson's ratio for most metals is approximately 0.3, implying the transverse strain is -30% of the axial strain.

A general state of planar stress at a point, acting on an infinitesimal square element, is illustrated in Figure C.2a. It includes two normal stress components (σ_x and σ_y) and a shear stress component (τ_{xy}). Their values depend on the orientation of the element. At any point, there is always an orientation of an element that results in the maximum normal stress magnitude and zero shear stress ($\tau_{xy} = 0$). The two orthogonal normal stress directions corresponding to this orientation are called the **principal axes**, and the normal stress magnitudes are referred to as the **principal stresses** (σ_{max} and σ_{min}). Figure C.2b illustrates this orientation and its corresponding state of stress. The magnitude and direction of the principal stresses are related to the stresses in any other orientation by

$$\sigma_{\text{max}} = \left(\frac{\sigma_x + \sigma_y}{2} \right) + \sqrt{\left(\frac{\sigma_x - \sigma_y}{2} \right)^2 + \tau_{xy}^2} \quad (\text{C.7})$$

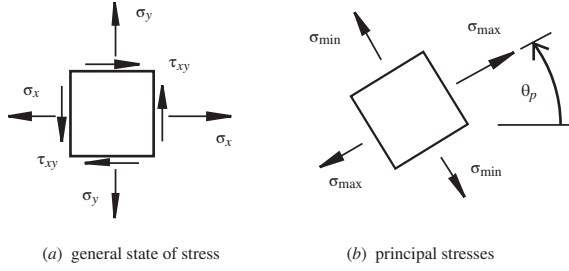


Figure C.2 General state of planar stress and principal stresses.

$$\sigma_{\min} = \left(\frac{\sigma_x + \sigma_y}{2} \right) - \sqrt{\left(\frac{\sigma_x - \sigma_y}{2} \right)^2 + \tau_{xy}^2} \quad (\text{C.8})$$

$$\tan(2\theta_p) = \frac{2\tau_{xy}}{\sigma_x - \sigma_y} \quad (\text{C.9})$$

where θ_p is the angle from σ_x to $\sigma_{\max}$, measured counterclockwise.

The principal stresses are important quantities when determining if a material will yield or fail when loaded because they determine the maximum values of stress, which can be compared to the yield strength of the material. The maximum shear stress is also important when assessing failure and is given by

$$\tau_{\max} = \sqrt{\left(\frac{\sigma_x - \sigma_y}{2} \right)^2 + \tau_{xy}^2} = \frac{\sigma_{\max} - \sigma_{\min}}{2} \quad (\text{C.10})$$

This relation can be used to rewrite Equations C.7 and C.8 as

$$\sigma_{\max} = \sigma_{\text{avg}} + \tau_{\max} \quad (\text{C.11})$$

$$\sigma_{\min} = \sigma_{\text{avg}} - \tau_{\max} \quad (\text{C.12})$$

where

$$\sigma_{\text{avg}} = \frac{\sigma_x + \sigma_y}{2} \quad (\text{C.13})$$

The orientation of the element that results in $\tau_{\max}$ is given by

$$\tan(2\theta_s) = -\frac{\sigma_x - \sigma_y}{2\tau_{xy}} \quad (\text{C.14})$$

As with θ_p , θ_s is measured counterclockwise from the direction of σ_x . For the cylindrical bar in Figure C.1, with an element oriented in the axial (y) direction, $\sigma_{\max} = \sigma_y = F/A$, $\sigma_x = 0$, and $\theta_p = 0$ because the element is aligned in the direction of the principal stress. Also, $\theta_s = 45^\circ$ and $\tau_{\max} = \sigma_y/2 = F/2A$.

The state of stress and its relation to the magnitude and direction of the principal stresses are often illustrated with **Mohr's circle**, which displays the relationship between the shear stress and the normal stresses in different directions (see Figure C.3).

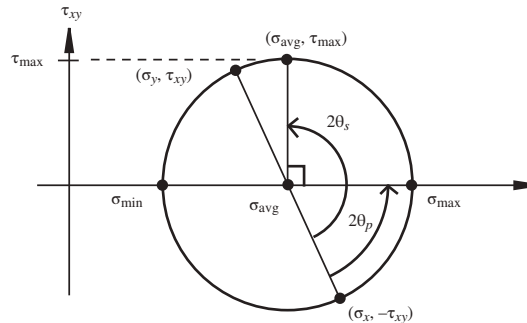


Figure C.3 Mohr's circle of plane stresses.



Internet Link

C.1 Mohr's circle equation derivation for uniaxial stress



Video Demo

C.1 Mohr's circle for uniaxial stress

C.2 Failure theories for brittle and ductile materials

Remember, tensile normal stresses are positive and compressive normal stresses are negative. For the example shown in Figure C.3, corresponding to the element shown in Figure C.2, both normal stresses are tensile. The sign of the shear stress is positive when it would cause the element to rotate clockwise about its center and negative when it would cause the element to rotate counterclockwise. For the element in Figure C.2, τ_{xy} is negative on the σ_x side of the element since it would cause the element to rotate counterclockwise, and τ_{xy} is positive on the σ_y side for the opposite reason. Note that the angle between the original stress directions and the principal stresses (θ_p) is measured in the same direction around the circle as with the actual element, but angles on the circle are twice the actual angles ($2\theta_p$). Since θ_p is measured counterclockwise from σ_x to $\sigma_{\max}$ in Figure C.2, the angle between the σ_x point and $\sigma_{\max}$ is $2\theta_p$ counterclockwise in Figure C.3. Also note that the orientation of the principal stresses and the orientation of the maximum shear stress are always 90° apart on Mohr's circle (45° apart on the actual element). This is confirmed by the fact that $\tan(2\theta_p)$ and $\tan(2\theta_s)$ are negative reciprocals of one another (see Equations C.9 and C.14). For more information, Internet Link C.1 points to a derivation of the equation for Mohr's circle for uniaxial stress, and Video Demo C.1 discusses and illustrates the results. Video Demo C.2 discusses how Mohr's circle can help one understand why brittle and ductile materials exhibit different fracture planes when they break.

■ CLASS DISCUSSION ITEM C.1

Fracture Plane Orientation in a Tensile Failure

When a metal bar fails under axial tension, the resulting fracture planes are oriented at 45° with respect to the bar's axis. Why?

BIBLIOGRAPHY

Beer, F., and Johnston, E., *Mechanics of Materials*, 5th Edition, McGraw-Hill, New York, 2008.
Dally, J., and Riley, W., *Experimental Stress Analysis*, 3rd Edition, McGraw-Hill, New York, 1991.

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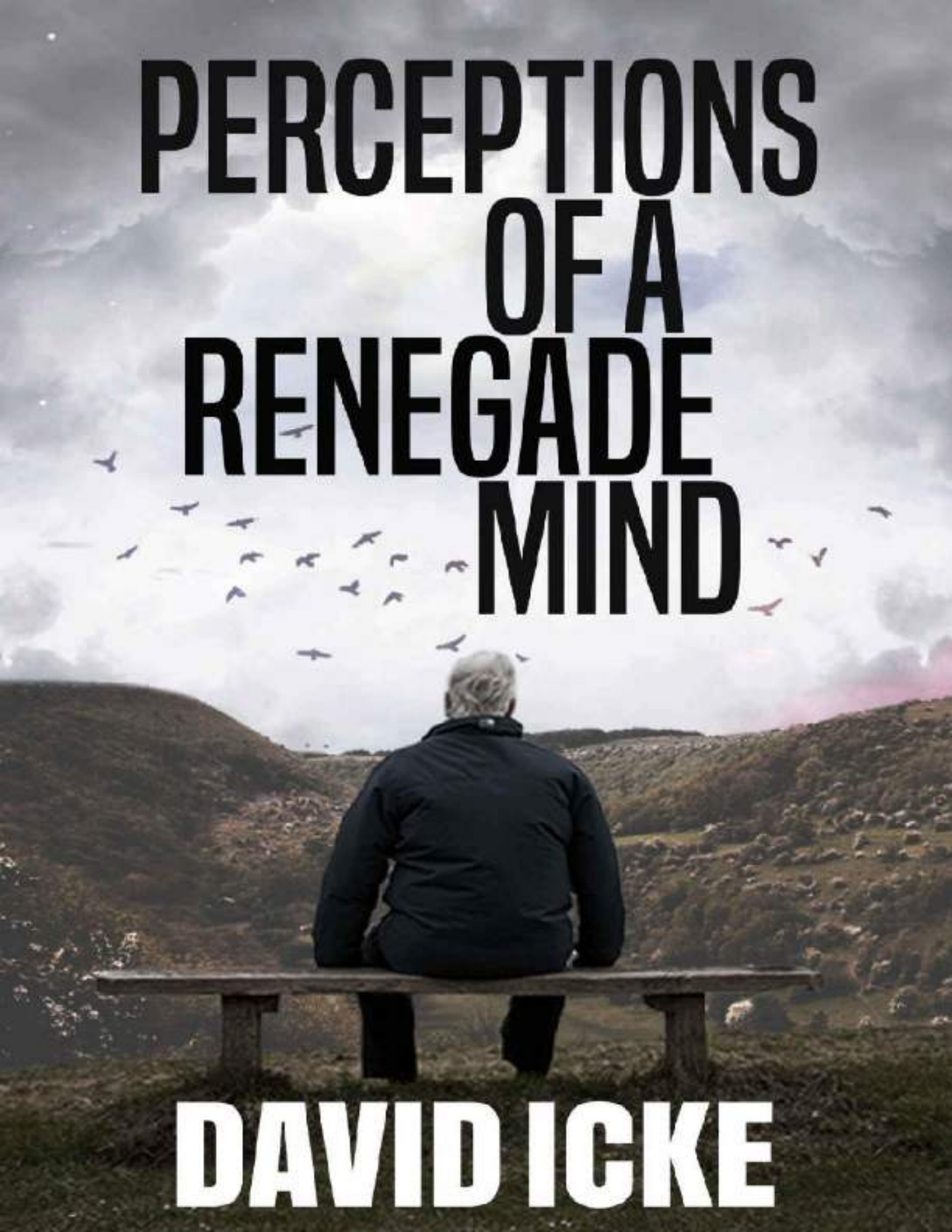
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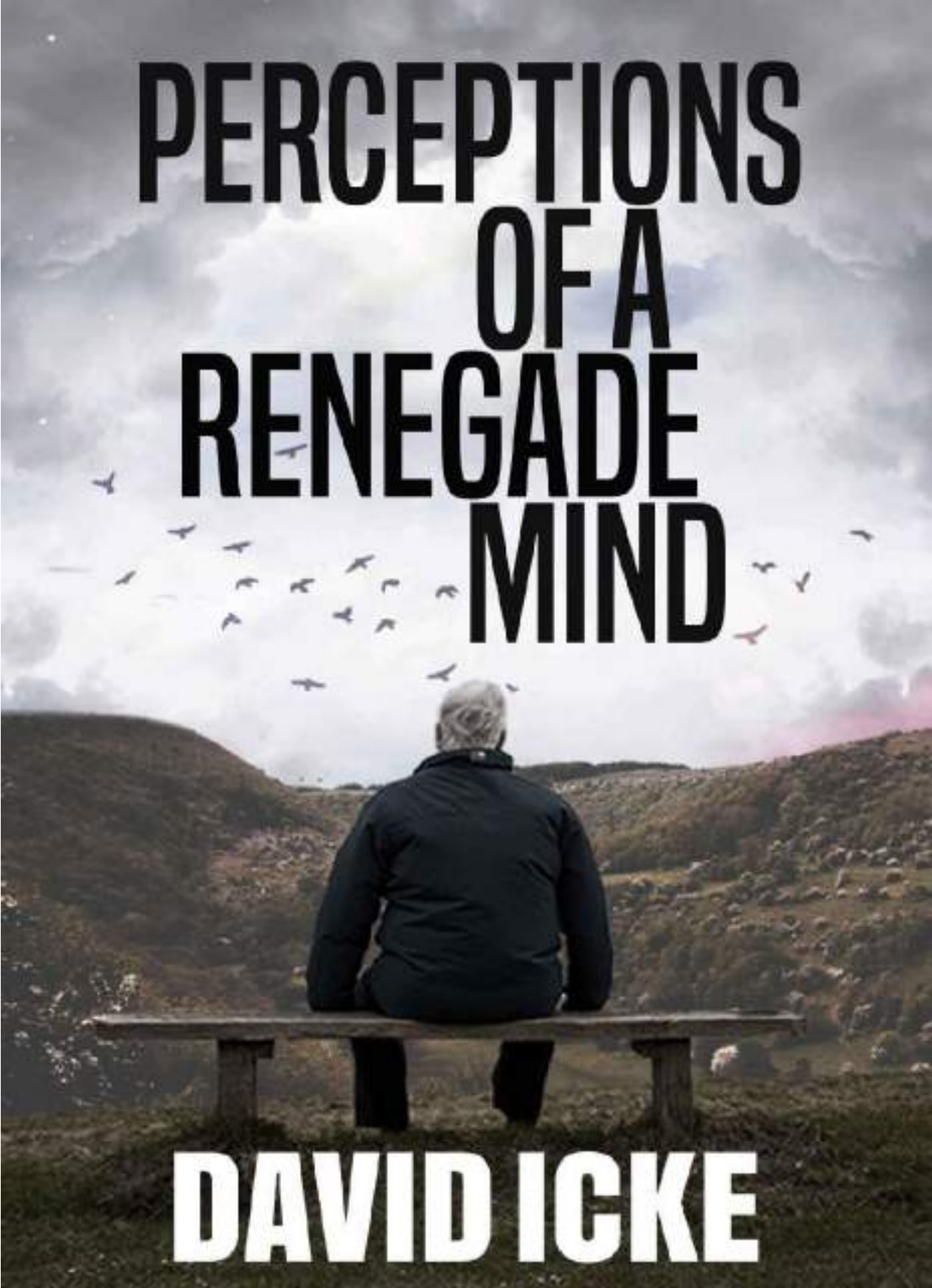
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A person with grey hair, wearing a dark jacket, is seen from behind, sitting on a wooden bench. They are looking out over a vast, hilly landscape under a cloudy sky. Numerous birds are flying in the sky, some appearing to fly towards the person. The overall mood is contemplative and expansive.

PERCEPTIONS OF A RENEGADE MIND

DAVID ICKE



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DAVID ICKE

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Renegade:

Adjective

‘Having rejected tradition: Unconventional.’

Merriam-Webster Dictionary

Acquiescence to tyranny is the death of the spirit

You may be 38 years old, as I happen to be. And one day, some great opportunity stands before you and calls you to stand up for some great principle, some great issue, some great cause. And you refuse to do it because you are afraid ... You refuse to do it because you want to live longer ... You're afraid that you will lose your job, or you are afraid that you will be criticised or that you will lose your popularity, or you're afraid that somebody will stab you, or shoot at you or bomb your house; so you refuse to take the stand.

Well, you may go on and live until you are 90, but you're just as dead at 38 as you would be at 90. And the cessation of breathing in your life is but the belated announcement of an earlier death of the spirit.

Martin Luther King

**How the few control the many and always have – the many do
whatever they're told**

'Forward, the Light Brigade!'
Was there a man dismayed?
Not though the soldier knew
Someone had blundered.
Theirs not to make reply,
Theirs not to reason why,
Theirs but to do and die.
Into the valley of Death
Rode the six hundred.

Cannon to right of them,
Cannon to left of them,
Cannon in front of them
Volleyed and thundered;
Stormed at with shot and shell,
Boldly they rode and well,
Into the jaws of Death,
Into the mouth of hell
Rode the six hundred

Alfred Lord Tennyson (1809-1892)

The mist is lifting slowly
I can see the way ahead
And I've left behind the empty streets
That once inspired my life
And the strength of the emotion
Is like thunder in the air
'Cos the promise that we made each other
Haunts me to the end

The secret of your beauty
And the mystery of your soul
I've been searching for in everyone I meet
And the times I've been mistaken
It's impossible to say
And the grass is growing
Underneath our feet

The words that I remember
From my childhood still are true
That there's none so blind
As those who will not see
And to those who lack the courage
And say it's dangerous to try
Well they just don't know
That love eternal will not be denied

I know you're out there somewhere
Somewhere, somewhere
I know you're out there somewhere

Somewhere you can hear my voice
I know I'll find you somehow
Somehow, somehow
I know I'll find you somehow
And somehow I'll return again to you

The Moody Blues

Are you a gutless wonder - or a Renegade Mind?

Monuments put from pen to paper,
Turns me into a gutless wonder,
And if you tolerate this,
Then your children will be next.
Gravity keeps my head down,
Or is it maybe shame ...

Manic Street Preachers

Rise like lions after slumber
In unvanquishable number.
Shake your chains to earth like dew
Which in sleep have fallen on you.
Ye are many – they are few.

Percy Shelley

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CHAPTER ONE

I'm thinking' – Oh, but *are* you?

Think for yourself and let others enjoy the privilege of doing so too
Voltaire

French-born philosopher, mathematician and scientist René Descartes became famous for his statement in Latin in the 17th century which translates into English as: 'I think, therefore I am.'

On the face of it that is true. Thought reflects perception and perception leads to both behaviour and self-identity. In that sense 'we' are what we think. But who or what is doing the thinking and is thinking the only route to perception? Clearly, as we shall see, 'we' are not always the source of 'our' perception, indeed with regard to humanity as a whole this is rarely the case; and thinking is far from the only means of perception. Thought is the village idiot compared with other expressions of consciousness that we all have the potential to access and tap into. This has to be true when we *are* those other expressions of consciousness which are infinite in nature. We have forgotten this, or, more to the point, been manipulated to forget.

These are not just the esoteric musings of the navel. The whole foundation of human control and oppression is control of perception. Once perception is hijacked then so is behaviour which is dictated by perception. Collective perception becomes collective behaviour and collective behaviour is what we call human society. Perception is all and those behind human control know that which is

why perception is the target 24/7 of the psychopathic manipulators that I call the Global Cult. They know that if they dictate perception they will dictate behaviour and collectively dictate the nature of human society. They are further aware that perception is formed from information received and if they control the circulation of information they will to a vast extent direct human behaviour. Censorship of information and opinion has become globally Nazi-like in recent years and never more blatantly than since the illusory 'virus pandemic' was triggered out of China in 2019 and across the world in 2020. Why have billions submitted to house arrest and accepted fascistic societies in a way they would have never believed possible? Those controlling the information spewing from government, mainstream media and Silicon Valley (all controlled by the same Global Cult networks) told them they were in danger from a 'deadly virus' and only by submitting to house arrest and conceding their most basic of freedoms could they and their families be protected. This monumental and provable lie became the *perception* of the billions and therefore the *behaviour* of the billions. In those few words you have the whole structure and modus operandi of human control. Fear is a perception – False Emotion Appearing Real – and fear is the currency of control. In short ... get them by the balls (or give them the impression that you have) and their hearts and minds will follow. Nothing grips the dangly bits and freezes the rear-end more comprehensively than fear.

World number 1

There are two 'worlds' in what appears to be one 'world' and the prime difference between them is knowledge. First we have the mass of human society in which the population is maintained in coldly-calculated ignorance through control of information and the 'education' (indoctrination) system. That's all you really need to control to enslave billions in a perceptual delusion in which what are perceived to be *their* thoughts and opinions are ever-repeated mantras that the system has been downloading all their lives through 'education', media, science, medicine, politics and academia

in which the personnel and advocates are themselves overwhelmingly the perceptual products of the same repetition. Teachers and academics in general are processed by the same programming machine as everyone else, but unlike the great majority they never leave the 'education' program. It gripped them as students and continues to grip them as programmers of subsequent generations of students. The programmed become the programmers – the programmed programmers. The same can largely be said for scientists, doctors and politicians and not least because as the American writer Upton Sinclair said: 'It is difficult to get a man to understand something when his salary depends upon his not understanding it.' If your career and income depend on thinking the way the system demands then you will – bar a few free-minded exceptions – concede your mind to the Perceptual Mainframe that I call the Postage Stamp Consensus. This is a tiny band of perceived knowledge and possibility 'taught' (downloaded) in the schools and universities, pounded out by the mainstream media and on which all government policy is founded. Try thinking, and especially speaking and acting, outside of the 'box' of consensus and see what that does for your career in the Mainstream Everything which bullies, harasses, intimidates and ridicules the population into compliance. Here we have the simple structure which enslaves most of humanity in a perceptual prison cell for an entire lifetime and I'll go deeper into this process shortly. Most of what humanity is taught as fact is nothing more than programmed belief. American science fiction author Frank Herbert was right when he said: 'Belief can be manipulated. Only knowledge is dangerous.' In the 'Covid' age belief is promoted and knowledge is censored. It was always so, but never to the extreme of today.

World number 2

A 'number 2' is slang for 'doing a poo' and how appropriate that is when this other 'world' is doing just that on humanity every minute of every day. World number 2 is a global network of secret societies and semi-secret groups dictating the direction of society via

governments, corporations and authorities of every kind. I have spent more than 30 years uncovering and exposing this network that I call the Global Cult and knowing its agenda is what has made my books so accurate in predicting current and past events. Secret societies are secret for a reason. They want to keep their hoarded knowledge to themselves and their chosen initiates and to hide it from the population which they seek through ignorance to control and subdue. The whole foundation of the division between World 1 and World 2 is *knowledge*. What number 1 knows number 2 must not. Knowledge they have worked so hard to keep secret includes (a) the agenda to enslave humanity in a centrally-controlled global dictatorship, and (b) the nature of reality and life itself. The latter (b) must be suppressed to allow the former (a) to prevail as I shall be explaining. The way the Cult manipulates and interacts with the population can be likened to a spider's web. The 'spider' sits at the centre in the shadows and imposes its will through the web with each strand represented in World number 2 by a secret society, satanic or semi-secret group, and in World number 1 – the world of the seen – by governments, agencies of government, law enforcement, corporations, the banking system, media conglomerates and Silicon Valley ([Fig 1](#) overleaf). The spider and the web connect and coordinate all these organisations to pursue the same global outcome while the population sees them as individual entities working randomly and independently. At the level of the web governments *are* the banking system *are* the corporations *are* the media *are* Silicon Valley *are* the World Health Organization working from their inner cores as one unit. Apparently unconnected countries, corporations, institutions, organisations and people are on the *same team* pursuing the same global outcome. Strands in the web immediately around the spider are the most secretive and exclusive secret societies and their membership is emphatically restricted to the Cult inner-circle emerging through the generations from particular bloodlines for reasons I will come to. At the core of the core you would get them in a single room. That's how many people are dictating the direction of human society and its transformation

through the 'Covid' hoax and other means. As the web expands out from the spider we meet the secret societies that many people will be aware of – the Freemasons, Knights Templar, Knights of Malta, Opus Dei, the inner sanctum of the Jesuit Order, and such like. Note how many are connected to the Church of Rome and there is a reason for that. The Roman Church was established as a revamp, a rebranding, of the relocated 'Church' of Babylon and the Cult imposing global tyranny today can be tracked back to Babylon and Sumer in what is now Iraq.



Figure 1: The global web through which the few control the many. (Image Neil Hague.)

Inner levels of the web operate in the unseen away from the public eye and then we have what I call the cusp organisations located at the point where the hidden meets the seen. They include a series of satellite organisations answering to a secret society founded in London in the late 19th century called the Round Table and among them are the Royal Institute of International Affairs (UK, founded in 1920); Council on Foreign Relations (US, 1921); Bilderberg Group (worldwide, 1954); Trilateral Commission (US/worldwide, 1972); and the Club of Rome (worldwide, 1968) which was created to exploit environmental concerns to justify the centralisation of global power to 'save the planet'. The Club of Rome instigated with others the human-caused climate change hoax which has led to all the 'green

new deals' demanding that very centralisation of control. Cusp organisations, which include endless 'think tanks' all over the world, are designed to coordinate a single global policy between political and business leaders, intelligence personnel, media organisations and anyone who can influence the direction of policy in their own sphere of operation. Major players and regular attenders will know what is happening – or some of it – while others come and go and are kept overwhelmingly in the dark about the big picture. I refer to these cusp groupings as semi-secret in that they can be publicly identified, but what goes on at the inner-core is kept very much 'in house' even from most of their members and participants through a fiercely-imposed system of compartmentalisation. Only let them know what they need to know to serve your interests and no more. The structure of secret societies serves as a perfect example of this principle. Most Freemasons never get higher than the bottom three levels of 'degree' (degree of knowledge) when there are 33 official degrees of the Scottish Rite. Initiates only qualify for the next higher 'compartment' or degree if those at that level choose to allow them. Knowledge can be carefully assigned only to those considered 'safe'. I went to my local Freemason's lodge a few years ago when they were having an 'open day' to show how cuddly they were and when I chatted to some of them I was astonished at how little the rank and file knew even about the most ubiquitous symbols they use. The mushroom technique – keep them in the dark and feed them bullshit – applies to most people in the web as well as the population as a whole. Sub-divisions of the web mirror in theme and structure transnational corporations which have a headquarters somewhere in the world dictating to all their subsidiaries in different countries. Subsidiaries operate in their methodology and branding to the same centrally-dictated plan and policy in pursuit of particular ends. The Cult web functions in the same way. Each country has its own web as a subsidiary of the global one. They consist of networks of secret societies, semi-secret groups and bloodline families and their job is to impose the will of the spider and the global web in their particular country. Subsidiary networks control and manipulate the national political system, finance, corporations, media, medicine, etc. to

ensure that they follow the globally-dictated Cult agenda. These networks were the means through which the 'Covid' hoax could be played out with almost every country responding in the same way.

The 'Yessir' pyramid

Compartmentalisation is the key to understanding how a tiny few can dictate the lives of billions when combined with a top-down sequence of imposition and acquiescence. The inner core of the Cult sits at the peak of the pyramidal hierarchy of human society (Fig 2 overleaf). It imposes its will – its agenda for the world – on the level immediately below which acquiesces to that imposition. This level then imposes the Cult will on the level below them which acquiesces and imposes on the next level. Very quickly we meet levels in the hierarchy that have no idea there even is a Cult, but the sequence of imposition and acquiescence continues down the pyramid in just the same way. 'I don't know why we are doing this but the order came from "on-high" and so we better just do it.' Alfred Lord Tennyson said of the cannon fodder levels in his poem *The Charge of the Light Brigade*: 'Theirs not to reason why; theirs but to do and die.' The next line says that 'into the valley of death rode the six hundred' and they died because they obeyed without question what their perceived 'superiors' told them to do. In the same way the population capitulated to 'Covid'. The whole hierarchical pyramid functions like this to allow the very few to direct the enormous many. Eventually imposition-acquiescence-imposition-acquiescence comes down to the mass of the population at the foot of the pyramid. If they acquiesce to those levels of the hierarchy imposing on them (governments/law enforcement/doctors/media) a circuit is completed between the population and the handful of super-psychopaths in the Cult inner core at the top of the pyramid. Without a circuit-breaking refusal to obey, the sequence of imposition and acquiescence allows a staggeringly few people to impose their will upon the entirety of humankind. We are looking at the very sequence that has subjugated billions since the start of 2020. Our freedom has not been taken from us. Humanity has given it

away. Fascists do not impose fascism because there are not enough of them. Fascism is imposed by the population acquiescing to fascism. Put another way allowing their perceptions to be programmed to the extent that leads to the population giving their freedom away by giving their perceptions – their mind – away. If this circuit is not broken by humanity ceasing to cooperate with their own enslavement then nothing can change. For that to happen people have to critically think and see through the lies and window dressing and then summon the backbone to act upon what they see. The Cult spends its days working to stop either happening and its methodology is systematic and highly detailed, but it can be overcome and that is what this book is all about.

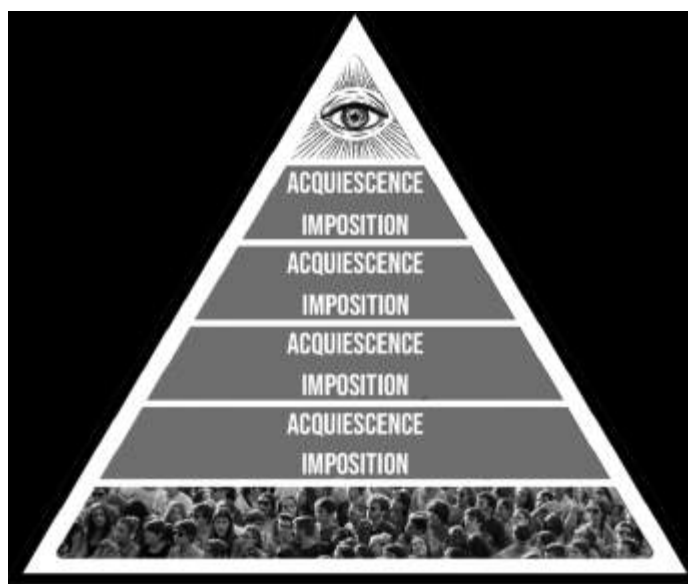


Figure 2: The simple sequence of imposition and compliance that allows a handful of people at the peak of the pyramid to dictate the lives of billions.

The Life Program

Okay, back to world number 1 or the world of the 'masses'. Observe the process of what we call 'life' and it is a perceptual download from cradle to grave. The Cult has created a global structure in which perception can be programmed and the program continually topped-up with what appears to be constant confirmation that the program is indeed true reality. The important word here is 'appears'.

This is the structure, the fly-trap, the Postage Stamp Consensus or Perceptual Mainframe, which represents that incredibly narrow band of perceived possibility delivered by the 'education' system, mainstream media, science and medicine. From the earliest age the download begins with parents who have themselves succumbed to the very programming their children are about to go through. Most parents don't do this out of malevolence and mostly it is quite the opposite. They do what they believe is best for their children and that is what the program has told them is best. Within three or four years comes the major transition from parental programming to full-blown state (Cult) programming in school, college and university where perceptually-programmed teachers and academics pass on their programming to the next generations. Teachers who resist are soon marginalised and their careers ended while children who resist are called a problem child for whom Ritalin may need to be prescribed. A few years after entering the 'world' children are under the control of authority figures representing the state telling them when they have to be there, when they can leave and when they can speak, eat, even go to the toilet. This is calculated preparation for a lifetime of obeying authority in all its forms. Reflex-action fear of authority is instilled by authority from the start. Children soon learn the carrot and stick consequences of obeying or defying authority which is underpinned daily for the rest of their life. Fortunately I daydreamed through this crap and never obeyed authority simply because it told me to. This approach to my alleged 'betters' continues to this day. There can be consequences of pursuing open-minded freedom in a world of closed-minded conformity. I spent a lot of time in school corridors after being ejected from the classroom for not taking some of it seriously and now I spend a lot of time being ejected from Facebook, YouTube and Twitter. But I can tell you that being true to yourself and not compromising your self-respect is far more exhilarating than bowing to authority for authority's sake. You don't have to be a sheep to the shepherd (authority) and the sheep dog (fear of not obeying authority).

The perceptual download continues throughout the formative years in school, college and university while script-reading 'teachers', 'academics' 'scientists', 'doctors' and 'journalists' insist that ongoing generations must be as programmed as they are. Accept the program or you will not pass your 'exams' which confirm your 'degree' of programming. It is tragic to think that many parents pressure their offspring to work hard at school to download the program and qualify for the next stage at college and university. The late, great, American comedian George Carlin said: 'Here's a bumper sticker I'd like to see: We are proud parents of a child who has resisted his teachers' attempts to break his spirit and bend him to the will of his corporate masters.' Well, the best of luck finding many of those, George. Then comes the moment to leave the formal programming years in academia and enter the 'adult' world of work. There you meet others in your chosen or prescribed arena who went through the same Postage Stamp Consensus program before you did. There is therefore overwhelming agreement between almost everyone on the basic foundations of Postage Stamp reality and the rejection, even contempt, of the few who have a mind of their own and are prepared to use it. This has two major effects. Firstly, the consensus confirms to the programmed that their download is really how things are. I mean, everyone knows that, right? Secondly, the arrogance and ignorance of Postage Stamp adherents ensure that anyone questioning the program will have unpleasant consequences for seeking their own truth and not picking their perceptions from the shelf marked: 'Things you must believe without question and if you don't you're a dangerous lunatic conspiracy theorist and a harebrained nutter'.

Every government, agency and corporation is founded on the same Postage Stamp prison cell and you can see why so many people believe the same thing while calling it their own 'opinion'. Fusion of governments and corporations in pursuit of the same agenda was the definition of fascism described by Italian dictator Benito Mussolini. The pressure to conform to perceptual norms downloaded for a lifetime is incessant and infiltrates society right

down to family groups that become censors and condemners of their own 'black sheep' for not, ironically, being sheep. We have seen an explosion of that in the 'Covid' era. Cult-owned global media unleashes its propaganda all day every day in support of the Postage Stamp and targets with abuse and ridicule anyone in the public eye who won't bend their mind to the will of the tyranny. Any response to this is denied (certainly in my case). They don't want to give a platform to expose official lies. Cult-owned-and-created Internet giants like Facebook, Google, YouTube and Twitter delete you for having an unapproved opinion. Facebook boasts that its AI censors delete 97-percent of 'hate speech' before anyone even reports it. Much of that 'hate speech' will simply be an opinion that Facebook and its masters don't want people to see. Such perceptual oppression is widely known as fascism. Even Facebook executive Benny Thomas, a 'CEO Global Planning Lead', said in comments secretly recorded by investigative journalism operation Project Veritas that Facebook is 'too powerful' and should be broken up:

I mean, no king in history has been the ruler of two billion people, but Mark Zuckerberg is ... And he's 36. That's too much for a 36-year-old ... You should not have power over two billion people. I just think that's wrong.

Thomas said Facebook-owned platforms like Instagram, Oculus, and WhatsApp needed to be separate companies. 'It's too much power when they're all one together'. That's the way the Cult likes it, however. We have an executive of a Cult organisation in Benny Thomas that doesn't know there is a Cult such is the compartmentalisation. Thomas said that Facebook and Google 'are no longer companies, they're countries'. Actually they are more powerful than countries on the basis that if you control information you control perception and control human society.

I love my oppressor

Another expression of this psychological trickery is for those who realise they are being pressured into compliance to eventually

convince themselves to believe the official narratives to protect their self-respect from accepting the truth that they have succumbed to meek and subservient compliance. Such people become some of the most vehement defenders of the system. You can see them everywhere screaming abuse at those who prefer to think for themselves and by doing so reminding the compliers of their own capitulation to conformity. 'You are talking dangerous nonsense you Covidiot!!' Are you trying to convince me or yourself? It is a potent form of Stockholm syndrome which is defined as: 'A psychological condition that occurs when a victim of abuse identifies and attaches, or bonds, positively with their abuser.' An example is hostages bonding and even 'falling in love' with their kidnappers. The syndrome has been observed in domestic violence, abused children, concentration camp inmates, prisoners of war and many and various Satanic cults. These are some traits of Stockholm syndrome listed at goodtherapy.org:

- Positive regard towards perpetrators of abuse or captor [see 'Covid'].
- Failure to cooperate with police and other government authorities when it comes to holding perpetrators of abuse or kidnapping accountable [or in the case of 'Covid' cooperating with the police to enforce and defend their captors' demands].
- Little or no effort to escape [see 'Covid'].
- Belief in the goodness of the perpetrators or kidnappers [see 'Covid'].
- Appeasement of captors. This is a manipulative strategy for maintaining one's safety. As victims get rewarded – perhaps with less abuse or even with life itself – their appeasing behaviours are reinforced [see 'Covid'].
- Learned helplessness. This can be akin to 'if you can't beat 'em, join 'em'. As the victims fail to escape the abuse or captivity, they may start giving up and soon realize it's just easier for everyone if they acquiesce all their power to their captors [see 'Covid'].

- Feelings of pity toward the abusers, believing they are actually victims themselves. Because of this, victims may go on a crusade or mission to 'save' [protect] their abuser [see the venom unleashed on those challenging the official 'Covid' narrative].
- Unwillingness to learn to detach from their perpetrators and heal. In essence, victims may tend to be less loyal to themselves than to their abuser [*definitely* see 'Covid'].

Ponder on those traits and compare them with the behaviour of great swathes of the global population who have defended governments and authorities which have spent every minute destroying their lives and livelihoods and those of their children and grandchildren since early 2020 with fascistic lockdowns, house arrest and employment deletion to 'protect' them from a 'deadly virus' that their abusers' perceptually created to bring about this very outcome. We are looking at mass Stockholm syndrome. All those that agree to concede their freedom will believe those perceptions are originating in their own independent 'mind' when in fact by conceding their reality to Stockholm syndrome they have by definition conceded any independence of mind. Listen to the 'opinions' of the acquiescing masses in this 'Covid' era and what gushes forth is the repetition of the official version of everything delivered unprocessed, unfiltered and unquestioned. The whole programming dynamic works this way. I must be free because I'm told that I am and so I think that I am.

You can see what I mean with the chapter theme of 'I'm thinking – Oh, but *are* you?' The great majority are not thinking, let alone for themselves. They are repeating what authority has told them to believe which allows them to be controlled. Weaving through this mentality is the fear that the 'conspiracy theorists' are right and this again explains the often hysterical abuse that ensues when you dare to contest the official narrative of anything. Denial is the mechanism of hiding from yourself what you don't want to be true. Telling people what they want to hear is easy, but it's an infinitely greater challenge to tell them what they would rather not be happening.

One is akin to pushing against an open door while the other is met with vehement resistance no matter what the scale of evidence. I don't want it to be true so I'll convince myself that it's not. Examples are everywhere from the denial that a partner is cheating despite all the signs to the reflex-action rejection of any idea that world events in which country after country act in exactly the same way are centrally coordinated. To accept the latter is to accept that a force of unspeakable evil is working to destroy your life and the lives of your children with nothing too horrific to achieve that end. Who the heck wants that to be true? But if we don't face reality the end is duly achieved and the consequences are far worse and ongoing than breaking through the walls of denial today with the courage to make a stand against tyranny.

Connect the dots – but how?

A crucial aspect of perceptual programming is to portray a world in which everything is random and almost nothing is connected to anything else. Randomness cannot be coordinated by its very nature and once you perceive events as random the idea they could be connected is waved away as the rantings of the tinfoil-hat brigade. You can't plan and coordinate random you idiot! No, you can't, but you can hide the coldly-calculated and long-planned behind the *illusion* of randomness. A foundation manifestation of the Renegade Mind is to scan reality for patterns that connect the apparently random and turn pixels and dots into pictures. This is the way I work and have done so for more than 30 years. You look for similarities in people, modus operandi and desired outcomes and slowly, then ever quicker, the picture forms. For instance: There would seem to be no connection between the 'Covid pandemic' hoax and the human-caused global-warming hoax and yet they are masks (appropriately) on the same face seeking the same outcome. Those pushing the global warming myth through the Club of Rome and other Cult agencies are driving the lies about 'Covid' – Bill Gates is an obvious one, but they are endless. Why would the same people be involved in both when they are clearly not connected? Oh, but they

are. Common themes with personnel are matched by common goals. The 'solutions' to both 'problems' are centralisation of global power to impose the will of the few on the many to 'save' humanity from 'Covid' and save the planet from an 'existential threat' (we need 'zero Covid' and 'zero carbon emissions'). These, in turn, connect with the 'dot' of globalisation which was coined to describe the centralisation of global power in every area of life through incessant political and corporate expansion, trading blocks and superstates like the European Union. If you are the few and you want to control the many you have to centralise power and decision-making. The more you centralise power the more power the few at the centre will have over the many; and the more that power is centralised the more power those at the centre have to centralise even quicker. The momentum of centralisation gets faster and faster which is exactly the process we have witnessed. In this way the hoaxed 'pandemic' and the fakery of human-caused global warming serve the interests of globalisation and the seizure of global power in the hands of the Cult inner-circle which is behind 'Covid', 'climate change' and globalisation. At this point random 'dots' become a clear and obvious picture or pattern.

Klaus Schwab, the classic Bond villain who founded the Cult's Gates-funded World Economic Forum, published a book in 2020, *The Great Reset*, in which he used the 'problem' of 'Covid' to justify a total transformation of human society to 'save' humanity from 'climate change'. Schwab said: 'The pandemic represents a rare but narrow window of opportunity to reflect, reimagine, and reset our world.' What he didn't mention is that the Cult he serves is behind both hoaxes as I show in my book *The Answer*. He and the Cult don't have to reimagine the world. They know precisely what they want and that's why they destroyed human society with 'Covid' to 'build back better' in their grand design. Their job is not to imagine, but to get humanity to imagine and agree with their plans while believing it's all random. It must be pure coincidence that 'The Great Reset' has long been the Cult's code name for the global imposition of fascism and replaced previous code-names of the 'New World

Order' used by Cult frontmen like Father George Bush and the 'New Order of the Ages' which emerged from Freemasonry and much older secret societies. New Order of the Ages appears on the reverse of the Great Seal of the United States as 'Novus ordo seclorum' underneath the Cult symbol used since way back of the pyramid and all seeing-eye (Fig 3). The pyramid is the hierarchy of human control headed by the illuminated eye that symbolises the force behind the Cult which I will expose in later chapters. The term 'Annuit Coeptis' translates as 'He favours our undertaking'. We are told the 'He' is the Christian god, but 'He' is not as I will be explaining.



Figure 3: The all-seeing eye of the Cult 'god' on the Freemason-designed Great Seal of the United States and also on the dollar bill.

Having you on

Two major Cult techniques of perceptual manipulation that relate to all this are what I have called since the 1990s Problem-Reaction-Solution (PRS) and the Totalitarian Tiptoe (TT). They can be uncovered by the inquiring mind with a simple question: Who benefits? The answer usually identifies the perpetrators of a given action or happening through the concept of 'he who most benefits from a crime is the one most likely to have committed it'. The Latin 'Cue bono?' – Who benefits? – is widely attributed to the Roman orator and statesman Marcus Tullius Cicero. No wonder it goes back so far when the concept has been relevant to human behaviour since

history was recorded. Problem-Reaction-Solution is the technique used to manipulate us every day by covertly creating a problem (or the illusion of one) and offering the solution to the problem (or the illusion of one). In the first phase you create the problem and blame someone or something else for why it has happened. This may relate to a financial collapse, terrorist attack, war, global warming or pandemic, anything in fact that will allow you to impose the 'solution' to change society in the way you desire at that time. The 'problem' doesn't have to be real. PRS is manipulation of perception and all you need is the population to believe the problem is real. Human-caused global warming and the 'Covid pandemic' only have to be *perceived* to be real for the population to accept the 'solutions' of authority. I refer to this technique as NO-Problem-Reaction-Solution. Billions did not meekly accept house arrest from early 2020 because there was a real deadly 'Covid pandemic' but because they perceived – believed – that to be the case. The antidote to Problem-Reaction-Solution is to ask who benefits from the proposed solution. Invariably it will be anyone who wants to justify more control through deletion of freedom and centralisation of power and decision-making.

The two world wars were Problem-Reaction-Solutions that transformed and realigned global society. Both were manipulated into being by the Cult as I have detailed in books since the mid-1990s. They dramatically centralised global power, especially World War Two, which led to the United Nations and other global bodies thanks to the overt and covert manipulations of the Rockefeller family and other Cult bloodlines like the Rothschilds. The UN is a stalking horse for full-blown world government that I will come to shortly. The land on which the UN building stands in New York was donated by the Rockefellers and the same Cult family was behind Big Pharma scalpel and drug 'medicine' and the creation of the World Health Organization as part of the UN. They have been stalwarts of the eugenics movement and funded Hitler's race-purity expert' Ernst Rudin. The human-caused global warming hoax has been orchestrated by the Club of Rome through the UN which is

manufacturing both the 'problem' through its Intergovernmental Panel on Climate Change and imposing the 'solution' through its Agenda 21 and Agenda 2030 which demand the total centralisation of global power to 'save the world' from a climate hoax the United Nations is itself perpetrating. What a small world the Cult can be seen to be particularly among the inner circles. The bedfellow of Problem-Reaction-Solution is the Totalitarian Tiptoe which became the Totalitarian Sprint in 2020. The technique is fashioned to hide the carefully-coordinated behind the cover of apparently random events. You start the sequence at 'A' and you know you are heading for 'Z'. You don't want people to know that and each step on the journey is presented as a random happening while all the steps strung together lead in the same direction. The speed may have quickened dramatically in recent times, but you can still see the incremental approach of the Tiptoe in the case of 'Covid' as each new imposition takes us deeper into fascism. Tell people they have to do this or that to get back to 'normal', then this and this and this. With each new demand adding to the ones that went before the population's freedom is deleted until it disappears. The spider wraps its web around the flies more comprehensively with each new diktat. I'll highlight this in more detail when I get to the 'Covid' hoax and how it has been pulled off. Another prime example of the Totalitarian Tiptoe is how the Cult-created European Union went from a 'free-trade zone' to a centralised bureaucratic dictatorship through the Tiptoe of incremental centralisation of power until nations became mere administrative units for Cult-owned dark suits in Brussels.

The antidote to ignorance is knowledge which the Cult seeks vehemently to deny us, but despite the systematic censorship to that end the Renegade Mind can overcome this by vociferously seeking out the facts no matter the impediments put in the way. There is also a method of thinking and perceiving – *knowing* – that doesn't even need names, dates, place-type facts to identify the patterns that reveal the story. I'll get to that in the final chapter. All you need to know about the manipulation of human society and to what end is still out there – *at the time of writing* – in the form of books, videos

and websites for those that really want to breach the walls of programmed perception. To access this knowledge requires the abandonment of the mainstream media as a source of information in the awareness that this is owned and controlled by the Cult and therefore promotes mass perceptions that suit the Cult. Mainstream media lies all day, every day. That is its function and very reason for being. Where it does tell the truth, here and there, is only because the truth and the Cult agenda very occasionally coincide. If you look for fact and insight to the BBC, CNN and virtually all the rest of them you are asking to be conned and perceptually programmed.

Know the outcome and you'll see the journey

Events seem random when you have no idea where the world is being taken. Once you do the random becomes the carefully planned. Know the outcome and you'll see the journey is a phrase I have been using for a long time to give context to daily happenings that appear unconnected. Does a problem, or illusion of a problem, trigger a proposed 'solution' that further drives society in the direction of the outcome? Invariably the answer will be yes and the random – *abracadabra* – becomes the clearly coordinated. So what is this outcome that unlocks the door to a massively expanded understanding of daily events? I will summarise its major aspects – the fine detail is in my other books – and those new to this information will see that the world they thought they were living in is a very different place. The foundation of the Cult agenda is the incessant centralisation of power and all such centralisation is ultimately in pursuit of Cult control on a global level. I have described for a long time the planned world structure of top-down dictatorship as the Hunger Games Society. The term obviously comes from the movie series which portrayed a world in which a few living in military-protected hi-tech luxury were the overlords of a population condemned to abject poverty in isolated 'sectors' that were not allowed to interact. 'Covid' lockdowns and travel bans anyone? The 'Hunger Games' pyramid of structural control has the inner circle of the Cult at the top with pretty much the entire

population at the bottom under their control through dependency for survival on the Cult. The whole structure is planned to be protected and enforced by a military-police state ([Fig 4](#)).

Here you have the reason for the global lockdowns of the fake pandemic to coldly destroy independent incomes and livelihoods and make everyone dependent on the 'state' (the Cult that controls the 'states'). I have warned in my books for many years about the plan to introduce a 'guaranteed income' – a barely survivable pittance – designed to impose dependency when employment was destroyed by AI technology and now even more comprehensively at great speed by the 'Covid' scam. Once the pandemic was played and lockdown consequences began to delete independent income the authorities began to talk right on cue about the need for a guaranteed income and a 'Great Reset'. Guaranteed income will be presented as benevolent governments seeking to help a desperate people – desperate as a direct result of actions of the same governments. The truth is that such payments are a trap. You will only get them if you do exactly what the authorities demand including mass vaccination (genetic manipulation). We have seen this theme already in Australia where those dependent on government benefits have them reduced if parents don't agree to have their children vaccinated according to an insane health-destroying government-dictated schedule. Calculated economic collapse applies to governments as well as people. The Cult wants rid of countries through the creation of a world state with countries broken up into regions ruled by a world government and super states like the European Union. Countries must be bankrupted, too, to this end and it's being achieved by the trillions in 'rescue packages' and furlough payments, trillions in lost taxation, and money-no-object spending on 'Covid' including constant all-medium advertising (programming) which has made the media dependent on government for much of its income. The day of reckoning is coming – as planned – for government spending and given that it has been made possible by printing money and not by production/taxation there is inflation on the way that has the

potential to wipe out monetary value. In that case there will be no need for the Cult to steal your money. It just won't be worth anything (see the German Weimar Republic before the Nazis took over). Many have been okay with lockdowns while getting a percentage of their income from so-called furlough payments without having to work. Those payments are dependent, however, on people having at least a theoretical job with a business considered non-essential and ordered to close. As these business go under because they are closed by lockdown after lockdown the furlough stops and it will for everyone eventually. Then what? The 'then what?' is precisely the idea.



Figure 4: The Hunger Games Society structure I have long warned was planned and now the 'Covid' hoax has made it possible. This is the real reason for lockdowns.

Hired hands

Between the Hunger Games Cult elite and the dependent population is planned to be a vicious military-police state (a fusion of the two into one force). This has been in the making for a long time with police looking ever more like the military and carrying weapons to match. The pandemic scam has seen this process accelerate so fast as

lockdown house arrest is brutally enforced by carefully recruited fascist minds and gormless system-servers. The police and military are planned to merge into a centrally-directed world army in a global structure headed by a world government which wouldn't be elected even by the election fixes now in place. The world army is not planned even to be human and instead wars would be fought, primarily against the population, using robot technology controlled by artificial intelligence. I have been warning about this for decades and now militaries around the world are being transformed by this very AI technology. The global regime that I describe is a particular form of fascism known as a technocracy in which decisions are not made by clueless and co-opted politicians but by unelected technocrats – scientists, engineers, technologists and bureaucrats. Cult-owned-and-controlled Silicon Valley giants are examples of technocracy and they already have far more power to direct world events than governments. They are with their censorship *selecting* governments. I know that some are calling the 'Great Reset' a Marxist communist takeover, but fascism and Marxism are different labels for the same tyranny. Tell those who lived in fascist Germany and Stalinist Russia that there was a difference in the way their freedom was deleted and their lives controlled. I could call it a fascist technocracy or a Marxist technocracy and they would be equally accurate. The Hunger Games society with its world government structure would oversee a world army, world central bank and single world cashless currency imposing its will on a microchipped population ([Fig 5](#)). Scan its different elements and see how the illusory pandemic is forcing society in this very direction at great speed. Leaders of 23 countries and the World Health Organization (WHO) backed the idea in March, 2021, of a global treaty for 'international cooperation' in 'health emergencies' and nations should 'come together as a global community for peaceful cooperation that extends beyond this crisis'. Cut the Orwellian bullshit and this means another step towards global government. The plan includes a cashless digital money system that I first warned about in 1993. Right at the start of 'Covid' the deeply corrupt Tedros

Adhanom Ghebreyesus, the crooked and merely gofer 'head' of the World Health Organization, said it was possible to catch the 'virus' by touching cash and it was better to use cashless means. The claim was ridiculous nonsense and like the whole 'Covid' mind-trick it was nothing to do with 'health' and everything to do with pushing every aspect of the Cult agenda. As a result of the Tedros lie the use of cash has plummeted. The Cult script involves a single world digital currency that would eventually be technologically embedded in the body. China is a massive global centre for the Cult and if you watch what is happening there you will know what is planned for everywhere. The Chinese government is developing a digital currency which would allow fines to be deducted immediately via AI for anyone caught on camera breaking its fantastic list of laws and the money is going to be programmable with an expiry date to ensure that no one can accrue wealth except the Cult and its operatives.



Figure 5: The structure of global control the Cult has been working towards for so long and this has been enormously advanced by the 'Covid' illusion.

Serfdom is so smart

The Cult plan is far wider, extreme, and more comprehensive than even most conspiracy researchers appreciate and I will come to the true depths of deceit and control in the chapters 'Who controls the

Cult?’ and ‘Escaping Wetiko’. Even the world that we know is crazy enough. We are being deluged with ever more sophisticated and controlling technology under the heading of ‘smart’. We have smart televisions, smart meters, smart cards, smart cars, smart driving, smart roads, smart pills, smart patches, smart watches, smart skin, smart borders, smart pavements, smart streets, smart cities, smart communities, smart environments, smart growth, smart planet ... smart *everything* around us. Smart technologies and methods of operation are designed to interlock to create a global Smart Grid connecting the entirety of human society including human minds to create a centrally-dictated ‘hive’ mind. ‘Smart cities’ is code for densely-occupied megacities of total surveillance and control through AI. Ever more destructive frequency communication systems like 5G have been rolled out without any official testing for health and psychological effects (colossal). 5G/6G/7G systems are needed to run the Smart Grid and each one becomes more destructive of body and mind. Deleting independent income is crucial to forcing people into these AI-policed prisons by ending private property ownership (except for the Cult elite). The Cult’s Great Reset now openly foresees a global society in which no one will own any possessions and everything will be rented while the Cult would own literally everything under the guise of government and corporations. The aim has been to use the lockdowns to destroy sources of income on a mass scale and when the people are destitute and in unrepayable amounts of debt (problem) Cult assets come forward with the pledge to write-off debt in return for handing over all property and possessions (solution). Everything – literally everything including people – would be connected to the Internet via AI. I was warning years ago about the coming Internet of Things (IoT) in which all devices and technology from your car to your fridge would be plugged into the Internet and controlled by AI. Now we are already there with much more to come. The next stage is the Internet of Everything (IoE) which is planned to include the connection of AI to the human brain and body to replace the human mind with a centrally-controlled AI mind. Instead of perceptions

being manipulated through control of information and censorship those perceptions would come direct from the Cult through AI. What do you think? You think whatever AI decides that you think. In human terms there would be no individual 'think' any longer. Too incredible? The ravings of a lunatic? Not at all. Cult-owned crazies in Silicon Valley have been telling us the plan for years without explaining the real motivation and calculated implications. These include Google executive and 'futurist' Ray Kurzweil who highlights the year 2030 for when this would be underway. He said:

Our thinking ... will be a hybrid of biological and non-biological thinking ... humans will be able to extend their limitations and 'think in the cloud' ... We're going to put gateways to the cloud in our brains ... We're going to gradually merge and enhance ourselves ... In my view, that's the nature of being human – we transcend our limitations.

As the technology becomes vastly superior to what we are then the small proportion that is still human gets smaller and smaller and smaller until it's just utterly negligible.

The sales-pitch of Kurzweil and Cult-owned Silicon Valley is that this would make us 'super-human' when the real aim is to make us post-human and no longer 'human' in the sense that we have come to know. The entire global population would be connected to AI and become the centrally-controlled 'hive-mind' of externally-delivered perceptions. The Smart Grid being installed to impose the Cult's will on the world is being constructed to allow particular locations – even one location – to control the whole global system. From these prime control centres, which absolutely include China and Israel, anything connected to the Internet would be switched on or off and manipulated at will. Energy systems could be cut, communication via the Internet taken down, computer-controlled driverless autonomous vehicles driven off the road, medical devices switched off, the potential is limitless given how much AI and Internet connections now run human society. We have seen nothing yet if we allow this to continue. Autonomous vehicle makers are working with law enforcement to produce cars designed to automatically pull over if they detect a police or emergency vehicle flashing from up to 100 feet away. At a police stop the car would be unlocked and the

window rolled down automatically. Vehicles would only take you where the computer (the state) allowed. The end of petrol vehicles and speed limiters on all new cars in the UK and EU from 2022 are steps leading to electric computerised transport over which ultimately you have no control. The picture is far bigger even than the Cult global network or web and that will become clear when I get to the nature of the 'spider'. There is a connection between all these happenings and the instigation of DNA-manipulating 'vaccines' (which aren't 'vaccines') justified by the 'Covid' hoax. That connection is the unfolding plan to transform the human body from a biological to a synthetic biological state and this is why synthetic biology is such a fast-emerging discipline of mainstream science. 'Covid vaccines' are infusing self-replicating synthetic genetic material into the cells to cumulatively take us on the Totalitarian Tiptoe from Human 1.0 to the synthetic biological Human 2.0 which will be physically and perceptually attached to the Smart Grid to one hundred percent control every thought, perception and deed. Humanity needs to wake up and *fast*.

This is the barest explanation of where the 'outcome' is planned to go but it's enough to see the journey happening all around us. Those new to this information will already see 'Covid' in a whole new context. I will add much more detail as we go along, but for the minutiae evidence see my mega-works, *The Answer*, *The Trigger* and *Everything You Need to Know But Have Never Been Told*.

Now – how does a Renegade Mind see the 'world'?

CHAPTER TWO

Renegade Perception

It is one thing to be clever and another to be wise

George R.R. Martin

A simple definition of the difference between a programmed mind and a Renegade Mind would be that one sees only dots while the other connects them to see the picture. Reading reality with accuracy requires the observer to (a) know the planned outcome and (b) realise that everything, but *everything*, is connected.

The entirety of infinite reality is connected – that's its very nature – and with human society an expression of infinite reality the same must apply. Simple cause and effect is a connection. The effect is triggered by the cause and the effect then becomes the cause of another effect. Nothing happens in isolation because it *can't*. Life in whatever reality is simple choice and consequence. We make choices and these lead to consequences. If we don't like the consequences we can make different choices and get different consequences which lead to other choices and consequences. The choice and the consequence are not only connected they are indivisible. You can't have one without the other as an old song goes. A few cannot control the world unless those being controlled allow that to happen – cause and effect, choice and consequence. Control – who has it and who doesn't – is a two-way process, a symbiotic relationship, involving the controller and controlled. 'They took my freedom away!!' Well, yes, but you also gave it to them. Humanity is

subjected to mass control because humanity has acquiesced to that control. This is all cause and effect and literally a case of give and take. In the same way world events of every kind are connected and the Cult works incessantly to sell the illusion of the random and coincidental to maintain the essential (to them) perception of dots that hide the picture. Renegade Minds know this and constantly scan the world for patterns of connection. This is absolutely pivotal in understanding the happenings in the world and without that perspective clarity is impossible. First you know the planned outcome and then you identify the steps on the journey – the day-by-day apparently random which, when connected in relation to the outcome, no longer appear as individual events, but as the proverbial *chain* of events leading in the same direction. I'll give you some examples:

Political puppet show

We are told to believe that politics is 'adversarial' in that different parties with different beliefs engage in an endless tussle for power. There may have been some truth in that up to a point – and only a point – but today divisions between 'different' parties are rhetorical not ideological. Even the rhetorical is fusing into one-speak as the parties eject any remaining free thinkers while others succumb to the ever-gathering intimidation of anyone with the 'wrong' opinion. The Cult is not a new phenomenon and can be traced back thousands of years as my books have documented. Its intergenerational initiatives have been manipulating events with increasing effect the more that global power has been centralised. In ancient times the Cult secured control through the system of monarchy in which 'special' bloodlines (of which more later) demanded the right to rule as kings and queens simply by birthright and by vanquishing others who claimed the same birthright. There came a time, however, when people had matured enough to see the unfairness of such tyranny and demanded a say in who governed them. Note the word – *governed* them. Not served them – *governed* them, hence government defined as 'the political direction and control exercised over the

actions of the members, citizens, or inhabitants of communities, societies, and states; direction of the affairs of a state, community, etc.' Governments exercise control over rather than serve just like the monarchies before them. Bizarrely there are still countries like the United Kingdom which are ruled by a monarch *and* a government that officially answers to the monarch. The UK head of state and that of Commonwealth countries such as Canada, Australia and New Zealand is 'selected' by who in a *single family* had unprotected sex with whom and in what order. Pinch me it can't be true. Ouch! Shit, it is. The demise of monarchies in most countries offered a potential vacuum in which some form of free and fair society could arise and the Cult had that base covered. Monarchies had served its interests but they couldn't continue in the face of such widespread opposition and, anyway, replacing a 'royal' dictatorship that people could see with a dictatorship 'of the people' hiding behind the concept of 'democracy' presented far greater manipulative possibilities and ways of hiding coordinated tyranny behind the illusion of 'freedom'.

Democracy is quite wrongly defined as government selected by the population. This is not the case at all. It is government selected by *some* of the population (and then only in theory). This 'some' doesn't even have to be the majority as we have seen so often in first-past-the-post elections in which the so-called majority party wins fewer votes than the 'losing' parties combined. Democracy can give total power to a party in government from a minority of the votes cast. It's a sleight of hand to sell tyranny as freedom. Seventy-four million Trump-supporting Americans didn't vote for the 'Democratic' Party of Joe Biden in the distinctly dodgy election in 2020 and yet far from acknowledging the wishes and feelings of that great percentage of American society the Cult-owned Biden government set out from day one to destroy them and their right to a voice and opinion. Empty shell Biden and his Cult handlers said they were doing this to 'protect democracy'. Such is the level of lunacy and sickness to which politics has descended. Connect the dots and relate them to the desired outcome – a world government run by self-appointed technocrats and no longer even elected

politicians. While operating through its political agents in government the Cult is at the same time encouraging public disdain for politicians by putting idiots and incompetents in theoretical power on the road to deleting them. The idea is to instil a public reaction that says of the technocrats: 'Well, they couldn't do any worse than the pathetic politicians.' It's all about controlling perception and Renegade Minds can see through that while programmed minds cannot when they are ignorant of both the planned outcome and the manipulation techniques employed to secure that end. This knowledge can be learned, however, and fast if people choose to get informed.

Politics may at first sight appear very difficult to control from a central point. I mean look at the 'different' parties and how would you be able to oversee them all and their constituent parts? In truth, it's very straightforward because of their structure. We are back to the pyramid of imposition and acquiescence. Organisations are structured in the same way as the system as a whole. Political parties are not open forums of free expression. They are hierarchies. I was a national spokesman for the British Green Party which claimed to be a different kind of politics in which influence and power was devolved; but I can tell you from direct experience – and it's far worse now – that Green parties are run as hierarchies like all the others however much they may try to hide that fact or kid themselves that it's not true. A very few at the top of all political parties are directing policy and personnel. They decide if you are elevated in the party or serve as a government minister and to do that you have to be a yes man or woman. Look at all the maverick political thinkers who never ascended the greasy pole. If you want to progress within the party or reach 'high-office' you need to fall into line and conform. Exceptions to this are rare indeed. Should you want to run for parliament or Congress you have to persuade the local or state level of the party to select you and for that you need to play the game as dictated by the hierarchy. If you secure election and wish to progress within the greater structure you need to go on conforming to what is acceptable to those running the hierarchy

from the peak of the pyramid. Political parties are perceptual gulags and the very fact that there are party 'Whips' appointed to 'whip' politicians into voting the way the hierarchy demands exposes the ridiculous idea that politicians are elected to serve the people they are supposed to represent. Cult operatives and manipulation has long seized control of major parties that have any chance of forming a government and at least most of those that haven't. A new party forms and the Cult goes to work to infiltrate and direct. This has reached such a level today that you see video compilations of 'leaders' of all parties whether Democrats, Republicans, Conservative, Labour and Green parroting the same Cult mantra of 'Build Back Better' and the 'Great Reset' which are straight off the Cult song-sheet to describe the transformation of global society in response to the Cult-instigated hoaxes of the 'Covid pandemic' and human-caused 'climate change'. To see Caroline Lucas, the Green Party MP that I knew when I was in the party in the 1980s, speaking in support of plans proposed by Cult operative Klaus Schwab representing the billionaire global elite is a real head-shaker.

Many parties – one master

The party system is another mind-trick and was instigated to change the nature of the dictatorship by swapping 'royalty' for dark suits that people believed – though now ever less so – represented their interests. Understanding this trick is to realise that a single force (the Cult) controls all parties either directly in terms of the major ones or through manipulation of perception and ideology with others. You don't need to manipulate Green parties to demand your transformation of society in the name of 'climate change' when they are obsessed with the lie that this is essential to 'save the planet'. You just give them a platform and away they go serving your interests while believing they are being environmentally virtuous. America's political structure is a perfect blueprint for how the two or multi-party system is really a one-party state. The Republican Party is controlled from one step back in the shadows by a group made up of billionaires and their gofers known as neoconservatives or Neocons.

I have exposed them in fine detail in my books and they were the driving force behind the policies of the imbecilic presidency of Boy George Bush which included 9/11 (see *The Trigger* for a comprehensive demolition of the official story), the subsequent 'war on terror' (war of terror) and the invasions of Afghanistan and Iraq. The latter was a No-Problem-Reaction-Solution based on claims by Cult operatives, including Bush and British Prime Minister Tony Blair, about Saddam Hussein's 'weapons of mass destruction' which did not exist as war criminals Bush and Blair well knew.



Figure 6: Different front people, different parties – same control system.

The Democratic Party has its own 'Neocon' group controlling from the background which I call the 'Democons' and here's the penny-drop – the Neocons and Democons answer to the same masters one step further back into the shadows (Fig 6). At that level of the Cult the Republican and Democrat parties are controlled by the same people and no matter which is in power the Cult is in power. This is how it works in almost every country and certainly in Britain with Conservative, Labour, Liberal Democrat and Green parties now all on the same page whatever the rhetoric may be in their feeble attempts to appear different. Neocons operated at the time of Bush through a think tank called The Project for the New American Century which in September, 2000, published a document entitled *Rebuilding America's Defenses: Strategies, Forces, and Resources*

For a New Century demanding that America fight ‘multiple, simultaneous major theatre wars’ as a ‘core mission’ to force regime-change in countries including Iraq, Libya and Syria. Neocons arranged for Bush (‘Republican’) and Blair (‘Labour Party’) to front-up the invasion of Iraq and when they departed the Democons orchestrated the targeting of Libya and Syria through Barack Obama (‘Democrat’) and British Prime Minister David Cameron (‘Conservative Party’). We have ‘different’ parties and ‘different’ people, but the same unfolding script. The more the Cult has seized the reigns of parties and personnel the more their policies have transparently pursued the same agenda to the point where the fascist ‘Covid’ impositions of the Conservative junta of Jackboot Johnson in Britain were opposed by the Labour Party because they were not fascist enough. The Labour Party is likened to the US Democrats while the Conservative Party is akin to a British version of the Republicans and on both sides of the Atlantic they all speak the same language and support the direction demanded by the Cult although some more enthusiastically than others. It’s a similar story in country after country because it’s all centrally controlled. Oh, but what about Trump? I’ll come to him shortly. Political ‘choice’ in the ‘party’ system goes like this: You vote for Party A and they get into government. You don’t like what they do so next time you vote for Party B and they get into government. You don’t like what they do when it’s pretty much the same as Party A and why wouldn’t that be with both controlled by the same force? Given that only two, sometimes three, parties have any chance of forming a government to get rid of Party B that you don’t like you have to vote again for Party A which ... you don’t like. This, ladies and gentlemen, is what they call ‘democracy’ which we are told – wrongly – is a term interchangeable with ‘freedom’.

The cult of cults

At this point I need to introduce a major expression of the Global Cult known as Sabbatian-Frankism. Sabbatian is also spelt as Sabbatean. I will summarise here. I have published major exposés

and detailed background in other works. Sabbatian-Frankism combines the names of two frauds posing as 'Jewish' men, Sabbatai Zevi (1626-1676), a rabbi, black magician and occultist who proclaimed he was the Jewish messiah; and Jacob Frank (1726-1791), the Polish 'Jew', black magician and occultist who said he was the reincarnation of 'messiah' Zevi and biblical patriarch Jacob. They worked across two centuries to establish the Sabbatian-Frankist cult that plays a major, indeed central, role in the manipulation of human society by the Global Cult which has its origins much further back in history than Sabbatai Zevi. I should emphasise two points here in response to the shrill voices that will scream 'anti-Semitism': (1) Sabbatian-Frankists are NOT Jewish and only pose as such to hide their cult behind a Jewish façade; and (2) my information about this cult has come from Jewish sources who have long realised that their society and community has been infiltrated and taken over by interloper Sabbatian-Frankists. Infiltration has been the foundation technique of Sabbatian-Frankism from its official origin in the 17th century. Zevi's Sabbatian sect attracted a massive following described as the biggest messianic movement in Jewish history, spreading as far as Africa and Asia, and he promised a return for the Jews to the 'Promised Land' of Israel. Sabbatianism was not Judaism but an inversion of everything that mainstream Judaism stood for. So much so that this sinister cult would have a feast day when Judaism had a fast day and whatever was forbidden in Judaism the Sabbatians were encouraged and even commanded to do. This included incest and what would be today called Satanism. Members were forbidden to marry outside the sect and there was a system of keeping their children ignorant of what they were part of until they were old enough to be trusted not to unknowingly reveal anything to outsiders. The same system is employed to this day by the Global Cult in general which Sabbatian-Frankism has enormously influenced and now largely controls.

Zevi and his Sabbatians suffered a setback with the intervention by the Sultan of the Islamic Ottoman Empire in the Middle East and what is now the Republic of Turkey where Zevi was located. The

Sultan gave him the choice of proving his 'divinity', converting to Islam or facing torture and death. Funnily enough Zevi chose to convert or at least appear to. Some of his supporters were disillusioned and drifted away, but many did not with 300 families also converting – only in theory – to Islam. They continued behind this Islamic smokescreen to follow the goals, rules and rituals of Sabbatianism and became known as 'crypto-Jews' or the 'Dönme' which means 'to turn'. This is rather ironic because they didn't 'turn' and instead hid behind a fake Islamic persona. The process of appearing to be one thing while being very much another would become the calling card of Sabbatianism especially after Zevi's death and the arrival of the Satanist Jacob Frank in the 18th century when the cult became Sabbatian-Frankism and plumbed still new depths of depravity and infiltration which included – still includes – human sacrifice and sex with children. Wherever Sabbatians go paedophilia and Satanism follow and is it really a surprise that Hollywood is so infested with child abuse and Satanism when it was established by Sabbatian-Frankists and is still controlled by them? Hollywood has been one of the prime vehicles for global perceptual programming and manipulation. How many believe the version of 'history' portrayed in movies when it is a travesty and inversion (again) of the truth? Rabbi Marvin Antelman describes Frankism in his book, *To Eliminate the Opiate*, as 'a movement of complete evil' while Jewish professor Gershom Scholem said of Frank in *The Messianic Idea in Judaism*: 'In all his actions [he was] a truly corrupt and degenerate individual ... one of the most frightening phenomena in the whole of Jewish history.' Frank was excommunicated by traditional rabbis, as was Zevi, but Frank was undeterred and enjoyed vital support from the House of Rothschild, the infamous banking dynasty whose inner-core are Sabbatian-Frankists and not Jews. Infiltration of the Roman Church and Vatican was instigated by Frank with many Dönme 'turning' again to convert to Roman Catholicism with a view to hijacking the reins of power. This was the ever-repeating modus operandi and continues to be so. Pose as an advocate of the religion, culture or country that you want to control and then

manipulate your people into the positions of authority and influence largely as advisers, administrators and Svengalis for those that appear to be in power. They did this with Judaism, Christianity (Christian Zionism is part of this), Islam and other religions and nations until Sabbatian-Frankism spanned the world as it does today.

Sabbatian Saudis and the terror network

One expression of the Sabbatian-Frankist Dönme within Islam is the ruling family of Saudi Arabia, the House of Saud, through which came the vile distortion of Islam known as Wahhabism. This is the violent creed followed by terrorist groups like Al-Qaeda and ISIS or Islamic State. Wahhabism is the hand-chopping, head-chopping 'religion' of Saudi Arabia which is used to keep the people in a constant state of fear so the interloper House of Saud can continue to rule. Al-Qaeda and Islamic State were lavishly funded by the House of Saud while being created and directed by the Sabbatian-Frankist network in the United States that operates through the Pentagon, CIA and the government in general of whichever 'party'. The front man for the establishment of Wahhabism in the middle of the 18th century was a Sabbatian-Frankist 'crypto-Jew' posing as Islamic called Muhammad ibn Abd al-Wahhab. His daughter would marry the son of Muhammad bin Saud who established the first Saudi state before his death in 1765 with support from the British Empire. Bin Saud's successors would establish modern Saudi Arabia in league with the British and Americans in 1932 which allowed them to seize control of Islam's major shrines in Mecca and Medina. They have dictated the direction of Sunni Islam ever since while Iran is the major centre of the Shiite version and here we have the source of at least the public conflict between them. The Sabbatian network has used its Wahhabi extremists to carry out Problem-Reaction-Solution terrorist attacks in the name of 'Al-Qaeda' and 'Islamic State' to justify a devastating 'war on terror', ever-increasing surveillance of the population and to terrify people into compliance. Another insight of the Renegade Mind is the streetwise understanding that

just because a country, location or people are attacked doesn't mean that those apparently representing that country, location or people are not behind the attackers. Often they are *orchestrating* the attacks because of the societal changes that can be then justified in the name of 'saving the population from terrorists'.

I show in great detail in *The Trigger* how Sabbatian-Frankists were the real perpetrators of 9/11 and not '19 Arab hijackers' who were blamed for what happened. Observe what was justified in the name of 9/11 alone in terms of Middle East invasions, mass surveillance and control that fulfilled the demands of the Project for the New American Century document published by the Sabbatian Neocons. What appear to be enemies are on the deep inside players on the same Sabbatian team. Israel and Arab 'royal' dictatorships are all ruled by Sabbatians and the recent peace agreements between Israel and Saudi Arabia, the United Arab Emirates (UAE) and others are only making formal what has always been the case behind the scenes. Palestinians who have been subjected to grotesque tyranny since Israel was bombed and terrorised into existence in 1948 have never stood a chance. Sabbatian-Frankists have controlled Israel (so the constant theme of violence and war which Sabbatians love) and they have controlled the Arab countries that Palestinians have looked to for real support that never comes. 'Royal families' of the Arab world in Saudi Arabia, Bahrain, UAE, etc., are all Sabbatians with allegiance to the aims of the cult and not what is best for their Arabic populations. They have stolen the oil and financial resources from their people by false claims to be 'royal dynasties' with a genetic right to rule and by employing vicious militaries to impose their will.

Satanic 'illumination'

The Satanist Jacob Frank formed an alliance in 1773 with two other Sabbatians, Mayer Amschel Rothschild (1744-1812), founder of the Rothschild banking dynasty, and Jesuit-educated fraudulent Jew, Adam Weishaupt, and this led to the formation of the Bavarian Illuminati, firstly under another name, in 1776. The Illuminati would

be the manipulating force behind the French Revolution (1789-1799) and was also involved in the American Revolution (1775-1783) before and after the Illuminati's official creation. Weishaupt would later become (in public) a Protestant Christian in archetypal Sabbatian style. I read that his name can be decoded as Adam-Weishaupt or 'the first man to lead those who know'. He wasn't a leader in the sense that he was a subordinate, but he did lead those below him in a crusade of transforming human society that still continues today. The theme was confirmed as early as 1785 when a horseman courier called Lanz was reported to be struck by lightning and extensive Illuminati documents were found in his saddlebags. They made the link to Weishaupt and detailed the plan for world takeover. Current events with 'Covid' fascism have been in the making for a very long time. Jacob Frank was jailed for 13 years by the Catholic Inquisition after his arrest in 1760 and on his release he headed for Frankfurt, Germany, home city and headquarters of the House of Rothschild where the alliance was struck with Mayer Amschel Rothschild and Weishaupt. Rothschild arranged for Frank to be given the title of Baron and he became a wealthy nobleman with a big following of Jews in Germany, the Austro-Hungarian Empire and other European countries. Most of them would have believed he was on their side.

The name 'Illuminati' came from the Zohar which is a body of works in the Jewish mystical 'bible' called the Kabbalah. 'Zohar' is the foundation of Sabbatian-Frankist belief and in Hebrew 'Zohar' means 'splendour', 'radiance', 'illuminated', and so we have 'Illuminati'. They claim to be the 'Illuminated Ones' from their knowledge systematically hidden from the human population and passed on through generations of carefully-chosen initiates in the global secret society network or Cult. Hidden knowledge includes an awareness of the Cult agenda for the world and the nature of our collective reality that I will explore later. Cult 'illumination' is symbolised by the torch held by the Statue of Liberty which was gifted to New York by French Freemasons in Paris who knew exactly what it represents. 'Liberty' symbolises the goddess worshipped in

Babylon as Queen Semiramis or Ishtar. The significance of this will become clear. Notice again the ubiquitous theme of inversion with the Statue of 'Liberty' really symbolising mass control (Fig 7). A mirror-image statute stands on an island in the River Seine in Paris from where New York Liberty originated (Fig 8). A large replica of the Liberty flame stands on top of the Pont de l'Alma tunnel in Paris where Princess Diana died in a Cult ritual described in *The Biggest Secret*. Lucifer 'the light bringer' is related to all this (and much more as we'll see) and 'Lucifer' is a central figure in Sabbatian-Frankism and its associated Satanism. Sabbatians reject the Jewish Torah, or Pentateuch, the 'five books of Moses' in the Old Testament known as Genesis, Exodus, Leviticus, Numbers, and Deuteronomy which are claimed by Judaism and Christianity to have been dictated by 'God' to Moses on Mount Sinai. Sabbatians say these do not apply to them and they seek to replace them with the Zohar to absorb Judaism and its followers into their inversion which is an expression of a much greater global inversion. They want to delete all religions and force humanity to worship a one-world religion – Sabbatian Satanism that also includes worship of the Earth goddess. Satanic themes are being more and more introduced into mainstream society and while Christianity is currently the foremost target for destruction the others are planned to follow.



Figure 7: The Cult goddess of Babylon disguised as the Statue of Liberty holding the flame of Lucifer the 'light bringer'.



Figure 8: Liberty's mirror image in Paris where the New York version originated.

Marx brothers

Rabbi Marvin Antelman connects the Illuminati to the Jacobins in *To Eliminate the Opiate* and Jacobins were the force behind the French Revolution. He links both to the Bund der Gerechten, or League of the Just, which was the network that inflicted communism/Marxism on the world. Antelman wrote:

The original inner circle of the Bund der Gerechten consisted of born Catholics, Protestants and Jews [Sabbatian-Frankist infiltrators], and those representatives of respective subdivisions formulated schemes for the ultimate destruction of their faiths. The heretical Catholics laid plans which they felt would take a century or more for the ultimate destruction of the church; the apostate Jews for the ultimate destruction of the Jewish religion.

Sabbatian-created communism connects into this anti-religion agenda in that communism does not allow for the free practice of religion. The Sabbatian 'Bund' became the International Communist Party and Communist League and in 1848 'Marxism' was born with the Communist Manifesto of Sabbatian assets Karl Marx and Friedrich Engels. It is absolutely no coincidence that Marxism, just a different name for fascist and other centrally-controlled tyrannies, is being imposed worldwide as a result of the 'Covid' hoax and nor that Marxist/fascist China was the place where the hoax originated. The reason for this will become very clear in the chapter 'Covid: The calculated catastrophe'. The so-called 'Woke' mentality has hijacked

traditional beliefs of the political left and replaced them with far-right make-believe 'social justice' better known as Marxism. Woke will, however, be swallowed by its own perceived 'revolution' which is really the work of billionaires and billionaire corporations feigning being 'Woke'. Marxism is being touted by Wokers as a replacement for 'capitalism' when we don't have 'capitalism'. We have cartelism in which the market is stitched up by the very Cult billionaires and corporations bankrolling Woke. Billionaires love Marxism which keeps the people in servitude while they control from the top. Terminally naïve Wokers think they are 'changing the world' when it's the Cult that is doing the changing and when they have played their vital part and become surplus to requirements they, too, will be targeted. The Illuminati-Jacobins were behind the period known as 'The Terror' in the French Revolution in 1793 and 1794 when Jacobin Maximillian de Robespierre and his Orwellian 'Committee of Public Safety' killed 17,000 'enemies of the Revolution' who had once been 'friends of the Revolution'. Karl Marx (1818-1883), whose Sabbatian creed of Marxism has cost the lives of at least 100 million people, is a hero once again to Wokers who have been systematically kept ignorant of real history by their 'education' programming. As a result they now promote a Sabbatian 'Marxist' abomination destined at some point to consume them. Rabbi Antelman, who spent decades researching the Sabbatian plot, said of the League of the Just and Karl Marx:

Contrary to popular opinion Karl Marx did not originate the Communist Manifesto. He was paid for his services by the League of the Just, which was known in its country of origin, Germany, as the Bund der Geächteten.

Antelman said the text attributed to Marx was the work of other people and Marx 'was only repeating what others already said'. Marx was 'a hired hack – lackey of the wealthy Illuminists'. Marx famously said that religion was the 'opium of the people' (part of the Sabbatian plan to demonise religion) and Antelman called his books, *To Eliminate the Opiate*. Marx was born Jewish, but his family converted to Christianity (Sabbatian modus operandi) and he

attacked Jews, not least in his book, *A World Without Jews*. In doing so he supported the Sabbatian plan to destroy traditional Jewishness and Judaism which we are clearly seeing today with the vindictive targeting of orthodox Jews by the Sabbatian government of Israel over 'Covid' laws. I don't follow any religion and it has done much damage to the world over centuries and acted as a perceptual straightjacket. Renegade Minds, however, are always asking *why* something is being done. It doesn't matter if they agree or disagree with what is happening – *why* is it happening is the question. The 'why?' can be answered with regard to religion in that religions create interacting communities of believers when the Cult wants to dismantle all discourse, unity and interaction (see 'Covid' lockdowns) and the ultimate goal is to delete all religions for a one-world religion of Cult Satanism worshipping their 'god' of which more later. We see the same 'why?' with gun control in America. I don't have guns and don't want them, but why is the Cult seeking to disarm the population at the same time that law enforcement agencies are armed to their molars and why has every tyrant in history sought to disarm people before launching the final takeover? They include Hitler, Stalin, Pol Pot and Mao who followed confiscation with violent seizing of power. You know it's a Cult agenda by the people who immediately race to the microphones to exploit dead people in multiple shootings. Ultra-Zionist Cult lackey Senator Chuck Schumer was straight on the case after ten people were killed in Boulder, Colorado in March, 2121. Simple rule ... if Schumer wants it the Cult wants it and the same with his ultra-Zionist mate the wild-eyed Senator Adam Schiff. At the same time they were calling for the disarmament of Americans, many of whom live a long way from a police response, Schumer, Schiff and the rest of these pampered clowns were sitting on Capitol Hill behind a razor-wired security fence protected by thousands of armed troops in addition to their own armed bodyguards. Mom and pop in an isolated home? They're just potential mass shooters.

Zion Mainframe

Sabbatian-Frankists and most importantly the Rothschilds were behind the creation of 'Zionism', a political movement that demanded a Jewish homeland in Israel as promised by Sabbatai Zevi. The very symbol of Israel comes from the German meaning of the name Rothschild. Dynasty founder Mayer Amschel Rothschild changed the family name from Bauer to Rothschild, or 'Red-Shield' in German, in deference to the six-pointed 'Star of David' hexagram displayed on the family's home in Frankfurt. The symbol later appeared on the flag of Israel after the Rothschilds were centrally involved in its creation. Hexagrams are not a uniquely Jewish symbol and are widely used in occult ('hidden') networks often as a symbol for Saturn (see my other books for why). Neither are Zionism and Jewishness interchangeable. Zionism is a political movement and philosophy and not a 'race' or a people. Many Jews oppose Zionism and many non-Jews, including US President Joe Biden, call themselves Zionists as does Israel-centric Donald Trump. America's support for the Israel government is pretty much a gimme with ultra-Zionist billionaires and corporations providing fantastic and dominant funding for both political parties. Former Congresswoman Cynthia McKinney has told how she was approached immediately she ran for office to 'sign the pledge' to Israel and confirm that she would always vote in that country's best interests. All American politicians are approached in this way. Anyone who refuses will get no support or funding from the enormous and all-powerful Zionist lobby that includes organisations like mega-lobby group AIPAC, the American Israel Public Affairs Committee. Trump's biggest funder was ultra-Zionist casino and media billionaire Sheldon Adelson while major funders of the Democratic Party include ultra-Zionist George Soros and ultra-Zionist financial and media mogul, Haim Saban. Some may reel back at the suggestion that Soros is an Israel-firster (Sabbatian-controlled Israel-firster), but Renegade Minds watch the actions not the words and everywhere Soros donates his billions the Sabbatian agenda benefits. In the spirit of Sabbatian inversion Soros pledged \$1 billion for a new university network to promote 'liberal values and tackle intolerance'. He made the announcement during his annual speech

at the Cult-owned World Economic Forum in Davos, Switzerland, in January, 2020, after his 'harsh criticism' of 'authoritarian rulers' around the world. You can only laugh at such brazen mendacity. How *he* doesn't laugh is the mystery. Translated from the Orwellian 'liberal values and tackle intolerance' means teaching non-white people to hate white people and for white people to loathe themselves for being born white. The reason for that will become clear.

The 'Anti-Semitism' fraud

Zionists support the Jewish homeland in the land of Palestine which has been the Sabbatian-Rothschild goal for so long, but not for the benefit of Jews. Sabbatians and their global Anti-Semitism Industry have skewed public and political opinion to equate opposing the violent extremes of Zionism to be a blanket attack and condemnation of all Jewish people. Sabbatians and their global Anti-Semitism Industry have skewed public and political opinion to equate opposing the violent extremes of Zionism to be a blanket attack and condemnation of all Jewish people. This is nothing more than a Sabbatian protection racket to stop legitimate investigation and exposure of their agendas and activities. The official definition of 'anti-Semitism' has more recently been expanded to include criticism of Zionism – a *political movement* – and this was done to further stop exposure of Sabbatian infiltrators who created Zionism as we know it today in the 19th century. Renegade Minds will talk about these subjects when they know the shit that will come their way. People must decide if they want to know the truth or just cower in the corner in fear of what others will say. Sabbatians have been trying to label me as 'anti-Semitic' since the 1990s as I have uncovered more and more about their background and agendas. Useless, gutless, fraudulent 'journalists' then just repeat the smears without question and on the day I was writing this section a pair of unquestioning repeaters called Ben Quinn and Archie Bland (how appropriate) outright called me an 'anti-Semite' in the establishment propaganda sheet, the London *Guardian*, with no supporting evidence. The

Sabbatian Anti-Semitism Industry said so and who are they to question that? They wouldn't dare. Ironically 'Semitic' refers to a group of languages in the Middle East that are almost entirely Arabic. 'Anti-Semitism' becomes 'anti-Arab' which if the consequences of this misunderstanding were not so grave would be hilarious. Don't bother telling Quinn and Bland. I don't want to confuse them, bless 'em. One reason I am dubbed 'anti-Semitic' is that I wrote in the 1990s that Jewish operatives (Sabbatians) were heavily involved in the Russian Revolution when Sabbatians overthrew the Romanov dynasty. This apparently made me 'anti-Semitic'. Oh, really? Here is a section from *The Trigger*:

British journalist Robert Wilton confirmed these themes in his 1920 book *The Last Days of the Romanovs* when he studied official documents from the Russian government to identify the members of the Bolshevik ruling elite between 1917 and 1919. The Central Committee included 41 Jews among 62 members; the Council of the People's Commissars had 17 Jews out of 22 members; and 458 of the 556 most important Bolshevik positions between 1918 and 1919 were occupied by Jewish people. Only 17 were Russian. Then there were the 23 Jews among the 36 members of the vicious Cheka Soviet secret police established in 1917 who would soon appear all across the country.

Professor Robert Service of Oxford University, an expert on 20th century Russian history, found evidence that ['Jewish'] Leon Trotsky had sought to make sure that Jews were enrolled in the Red Army and were disproportionately represented in the Soviet civil bureaucracy that included the Cheka which performed mass arrests, imprisonment and executions of 'enemies of the people'. A US State Department Decimal File (861.00/5339) dated November 13th, 1918, names [Rothschild banking agent in America] Jacob Schiff and a list of ultra-Zionists as funders of the Russian Revolution leading to claims of a 'Jewish plot', but the key point missed by all is they were not 'Jews' – they were Sabbatian-Frankists.

Britain's Winston Churchill made the same error by mistake or otherwise. He wrote in a 1920 edition of the *Illustrated Sunday Herald* that those behind the Russian revolution were part of a 'worldwide conspiracy for the overthrow of civilisation and for the reconstitution of society on the basis of arrested development, of envious malevolence, and impossible equality' (see 'Woke' today because that has been created by the same network). Churchill said there was no need to exaggerate the part played in the creation of Bolshevism and in the actual bringing about of the Russian

Revolution 'by these international and for the most part atheistical Jews' ['atheistical Jews' = Sabbatians]. Churchill said it is certainly a very great one and probably outweighs all others: 'With the notable exception of Lenin, the majority of the leading figures are Jews.' He went on to describe, knowingly or not, the Sabbatian modus operandi of placing puppet leaders nominally in power while they control from the background:

Moreover, the principal inspiration and driving power comes from the Jewish leaders. Thus Tchitcherin, a pure Russian, is eclipsed by his nominal subordinate, Litvinoff, and the influence of Russians like Bukharin or Lunacharski cannot be compared with the power of Trotsky, or of Zinovieff, the Dictator of the Red Citadel (Petrograd), or of Krassin or Radek – all Jews. In the Soviet institutions the predominance of Jews is even more astonishing. And the prominent, if not indeed the principal, part in the system of terrorism applied by the Extraordinary Commissions for Combatting Counter-Revolution has been taken by Jews, and in some notable cases by Jewesses.

What I said about seriously disproportionate involvement in the Russian Revolution by Jewish 'revolutionaries' (Sabbatians) is provable fact, but truth is no defence against the Sabbatian Anti-Semitism Industry, its repeater parrots like Quinn and Bland, and the now breathtaking network of so-called 'Woke' 'anti-hate' groups with interlocking leaderships and funding which have the role of discrediting and silencing anyone who gets too close to exposing the Sabbatians. We have seen 'truth is no defence' confirmed in legal judgements with the Saskatchewan Human Rights Commission in Canada decreeing this: 'Truthful statements can be presented in a manner that would meet the definition of hate speech, and not all truthful statements must be free from restriction.' Most 'anti-hate' activists, who are themselves consumed by hatred, are too stupid and ignorant of the world to know how they are being used. They are far too far up their own virtue-signalling arses and it's far too dark for them to see anything.

The 'revolution' game

The background and methods of the 'Russian' Revolution are straight from the Sabbatian playbook seen in the French Revolution

and endless others around the world that appear to start as a revolution of the people against tyrannical rule and end up with a regime change to more tyrannical rule overtly or covertly. Wars, terror attacks and regime overthrows follow the Sabbatian cult through history with its agents creating them as Problem-Reaction-Solutions to remove opposition on the road to world domination. Sabbatian dots connect the Rothschilds with the Illuminati, Jacobins of the French Revolution, the 'Bund' or League of the Just, the International Communist Party, Communist League and the Communist Manifesto of Karl Marx and Friedrich Engels that would lead to the Rothschild-funded Russian Revolution. The sequence comes under the heading of 'creative destruction' when you advance to your global goal by continually destroying the status quo to install a new status quo which you then also destroy. The two world wars come to mind. With each new status quo you move closer to your planned outcome. Wars and mass murder are to Sabbatians a collective blood sacrifice ritual. They are obsessed with death for many reasons and one is that death is an inversion of life. Satanists and Sabbatians are obsessed with death and often target churches and churchyards for their rituals. Inversion-obsessed Sabbatians explain the use of inverted symbolism including the *inverted* pentagram and *inverted* cross. The inversion of the cross has been related to targeting Christianity, but the cross was a religious symbol long before Christianity and its inversion is a statement about the Sabbatian mentality and goals more than any single religion.

Sabbatians operating in Germany were behind the rise of the occult-obsessed Nazis and the subsequent Jewish exodus from Germany and Europe to Palestine and the United States after World War Two. The Rothschild dynasty was at the forefront of this both as political manipulators and by funding the operation. Why would Sabbatians help to orchestrate the horrors inflicted on Jews by the Nazis and by Stalin after they organised the Russian Revolution? Sabbatians hate Jews and their religion, that's why. They pose as Jews and secure positions of control within Jewish society and play the 'anti-Semitism' card to protect themselves from exposure

through a global network of organisations answering to the Sabbatian-created-and-controlled globe-spanning intelligence network that involves a stunning web of military-intelligence operatives and operations for a tiny country of just nine million. Among them are Jewish assets who are not Sabbatians but have been convinced by them that what they are doing is for the good of Israel and the Jewish community to protect them from what they have been programmed since childhood to believe is a Jew-hating hostile world. The Jewish community is just a highly convenient cover to hide the true nature of Sabbatians. Anyone getting close to exposing their game is accused by Sabbatian place-people and gofers of 'anti-Semitism' and claiming that all Jews are part of a plot to take over the world. I am not saying that. I am saying that Sabbatians – the *real* Jew-haters – have infiltrated the Jewish community to use them both as a cover and an 'anti-Semitic' defence against exposure. Thus we have the Anti-Semitism Industry targeted researchers in this way and most Jewish people think this is justified and genuine. They don't know that their 'Jewish' leaders and institutions of state, intelligence and military are not controlled by Jews at all, but cultists and stooges of Sabbatian-Frankism. I once added my name to a pro-Jewish freedom petition online and the next time I looked my name was gone and text had been added to the petition blurb to attack me as an 'anti-Semite' such is the scale of perceptual programming.

Moving on America

I tell the story in *The Trigger* and a chapter called 'Atlantic Crossing' how particularly after Israel was established the Sabbatians moved in on the United States and eventually grasped control of government administration, the political system via both Democrats and Republicans, the intelligence community like the CIA and National Security Agency (NSA), the Pentagon and mass media. Through this seriously compartmentalised network Sabbatians and their operatives in Mossad, Israeli Defense Forces (IDF) and US agencies pulled off 9/11 and blamed it on 19 'Al-Qaeda hijackers' dominated by men from, or connected to, Sabbatian-ruled Saudi

Arabia. The '19' were not even on the planes let alone flew those big passenger jets into buildings while being largely incompetent at piloting one-engine light aircraft. 'Hijacker' Hani Hanjour who is said to have flown American Airlines Flight 77 into the Pentagon with a turn and manoeuvre most professional pilots said they would have struggled to do was banned from renting a small plane by instructors at the Freeway Airport in Bowie, Maryland, just *six weeks* earlier on the grounds that he was an incompetent pilot. The Jewish population of the world is just 0.2 percent with even that almost entirely concentrated in Israel (75 percent Jewish) and the United States (around two percent). This two percent and globally 0.2 percent refers to *Jewish* people and not Sabbatian interlopers who are a fraction of that fraction. What a sobering thought when you think of the fantastic influence on world affairs of tiny Israel and that the Project for the New America Century (PNAC) which laid out the blueprint in September, 2000, for America's war on terror and regime change wars in Iraq, Libya and Syria was founded and dominated by Sabbatians known as 'Neocons'. The document conceded that this plan would not be supported politically or publicly without a major attack on American soil and a Problem-Reaction-Solution excuse to send troops to war across the Middle East. Sabbatian Neocons said:

... [The] process of transformation ... [war and regime change] ... is likely to be a long one, absent some catastrophic and catalysing event – like a new Pearl Harbor.

Four months later many of those who produced that document came to power with their inane puppet George Bush from the long-time Sabbatian Bush family. They included Sabbatian Dick Cheney who was officially vice-president, but really de-facto president for the entirety of the 'Bush' government. Nine months after the 'Bush' inauguration came what Bush called at the time 'the Pearl Harbor of the 21st century' and with typical Sabbatian timing and symbolism 2001 was the 60th anniversary of the attack in 1941 by the Japanese Air Force on Pearl Harbor, Hawaii, which allowed President Franklin Delano Roosevelt to take the United States into a Sabbatian-

instigated Second World War that he said in his election campaign that he never would. The evidence is overwhelming that Roosevelt and his military and intelligence networks knew the attack was coming and did nothing to stop it, but they did make sure that America's most essential naval ships were not in Hawaii at the time. Three thousand Americans died in the Pearl Harbor attacks as they did on September 11th. By the 9/11 year of 2001 Sabbatians had widely infiltrated the US government, military and intelligence operations and used their compartmentalised assets to pull off the 'Al-Qaeda' attacks. If you read *The Trigger* it will blow your mind to see the utterly staggering concentration of 'Jewish' operatives (Sabbatian infiltrators) in essential positions of political, security, legal, law enforcement, financial and business power before, during, and after the attacks to make them happen, carry them out, and then cover their tracks – and I do mean *staggering* when you think of that 0.2 percent of the world population and two percent of Americans which are Jewish while Sabbatian infiltrators are a fraction of that. A central foundation of the 9/11 conspiracy was the hijacking of government, military, Air Force and intelligence computer systems in real time through 'back-door' access made possible by Israeli (Sabbatian) 'cyber security' software. Sabbatian-controlled Israel is on the way to rivalling Silicon Valley for domination of cyberspace and is becoming the dominant force in cyber-security which gives them access to entire computer systems and their passcodes across the world. Then add to this that Zionists head (officially) Silicon Valley giants like Google (Larry Page and Sergey Brin), Google-owned YouTube (Susan Wojcicki), Facebook (Mark Zuckerberg and Sheryl Sandberg), and Apple (Chairman Arthur D. Levinson), and that ultra-Zionist hedge fund billionaire Paul Singer has a \$1 billion stake in Twitter which is only nominally headed by 'CEO' pothead Jack Dorsey. As cable news host Tucker Carlson said of Dorsey: 'There used to be debate in the medical community whether dropping a ton of acid had permanent effects and I think that debate has now ended.' Carlson made the comment after Dorsey told a hearing on Capitol Hill (if you cut through his bullshit) that he

believed in free speech so long as he got to decide what you can hear and see. These 'big names' of Silicon Valley are only front men and women for the Global Cult, not least the Sabbatians, who are the true controllers of these corporations. Does anyone still wonder why these same people and companies have been ferociously censoring and banning people (like me) for exposing any aspect of the Cult agenda and especially the truth about the 'Covid' hoax which Sabbatians have orchestrated?

The Jeffrey Epstein paedophile ring was a Sabbatian operation. He was officially 'Jewish' but he was a Sabbatian and women abused by the ring have told me about the high number of 'Jewish' people involved. The Epstein horror has Sabbatian written all over it and matches perfectly their modus operandi and obsession with sex and ritual. Epstein was running a Sabbatian blackmail ring in which famous people with political and other influence were provided with young girls for sex while everything was being filmed and recorded on hidden cameras and microphones at his New York house, Caribbean island and other properties. Epstein survivors have described this surveillance system to me and some have gone public. Once the famous politician or other figure knew he or she was on video they tended to do whatever they were told. Here we go again ...when you've got them by the balls their hearts and minds will follow. Sabbatians use this blackmail technique on a wide scale across the world to entrap politicians and others they need to act as demanded. Epstein's private plane, the infamous 'Lolita Express', had many well-known passengers including Bill Clinton while Bill Gates has flown on an Epstein plane and met with him four years after Epstein had been jailed for paedophilia. They subsequently met many times at Epstein's home in New York according to a witness who was there. Epstein's infamous side-kick was Ghislaine Maxwell, daughter of Mossad agent and ultra-Zionist mega-crooked British businessman, Bob Maxwell, who at one time owned the *Daily Mirror* newspaper. Maxwell was murdered at sea on his boat in 1991 by Sabbatian-controlled Mossad when he became a liability with his

business empire collapsing as a former Mossad operative has confirmed (see *The Trigger*).

Money, money, money, funny money ...

Before I come to the Sabbatian connection with the last three US presidents I will lay out the crucial importance to Sabbatians of controlling banking and finance. Sabbatian Mayer Amschel Rothschild set out to dominate this arena in his family's quest for total global control. What is freedom? It is, in effect, choice. The more choices you have the freer you are and the fewer your choices the more you are enslaved. In the global structure created over centuries by Sabbatians the biggest decider and restrictor of choice is ... money. Across the world if you ask people what they would like to do with their lives and why they are not doing that they will reply 'I don't have the money'. This is the idea. A global elite of multi-billionaires are described as 'greedy' and that is true on one level; but control of money – who has it and who doesn't – is not primarily about greed. It's about control. Sabbatians have seized ever more control of finance and sucked the wealth of the world out of the hands of the population. We talk now, after all, about the 'One-percent' and even then the wealthiest are a lot fewer even than that. This has been made possible by a money scam so outrageous and so vast it could rightly be called the scam of scams founded on creating 'money' out of nothing and 'loaning' that with interest to the population. Money out of nothing is called 'credit'. Sabbatians have asserted control over governments and banking ever more completely through the centuries and secured financial laws that allow banks to lend hugely more than they have on deposit in a confidence trick known as fractional reserve lending. Imagine if you could lend money that doesn't exist and charge the recipient interest for doing so. You would end up in jail. Bankers by contrast end up in mansions, private jets, Malibu and Monaco.

Banks are only required to keep a fraction of their deposits and wealth in their vaults and they are allowed to lend 'money' they don't have called 'credit'. Go into a bank for a loan and if you succeed

the banker will not move any real wealth into your account. They will type into your account the amount of the agreed 'loan' – say £100,000. This is not wealth that really exists; it is non-existent, fresh-air, created-out-of-nothing 'credit' which has never, does not, and will never exist except in theory. Credit is backed by nothing except wind and only has buying power because people think that it has buying power and accept it in return for property, goods and services. I have described this situation as like those cartoon characters you see chasing each other and when they run over the edge of a cliff they keep running forward on fresh air until one of them looks down, realises what's happened, and they all crash into the ravine. The whole foundation of the Sabbatian financial system is to stop people looking down except for periodic moments when they want to crash the system (as in 2008 and 2020 ongoing) and reap the rewards from all the property, businesses and wealth their borrowers had signed over as 'collateral' in return for a 'loan' of fresh air. Most people think that money is somehow created by governments when it comes into existence from the start as a debt through banks 'lending' illusory money called credit. Yes, the very currency of exchange is a *debt* from day one issued as an interest-bearing loan. Why don't governments create money interest-free and lend it to their people interest-free? Governments are controlled by Sabbatians and the financial system is controlled by Sabbatians for whom interest-free money would be a nightmare come true. Sabbatians underpin their financial domination through their global network of central banks, including the privately-owned US Federal Reserve and Britain's Bank of England, and this is orchestrated by a privately-owned central bank coordination body called the Bank for International Settlements in Basle, Switzerland, created by the usual suspects including the Rockefellers and Rothschilds. Central bank chiefs don't answer to governments or the people. They answer to the Bank for International Settlements or, in other words, the Global Cult which is dominated today by Sabbatians.

Built-in disaster

There are so many constituent scams within the overall banking scam. When you take out a loan of thin-air credit only the amount of that loan is theoretically brought into circulation to add to the amount in circulation; but you are paying back the principle plus interest. The additional interest is not created and this means that with every 'loan' there is a shortfall in the money in circulation between what is borrowed and what has to be paid back. There is never even close to enough money in circulation to repay all outstanding public and private debt including interest. Coldly weaved in the very fabric of the system is the certainty that some will lose their homes, businesses and possessions to the banking 'lender'. This is less obvious in times of 'boom' when the amount of money in circulation (and the debt) is expanding through more people wanting and getting loans. When a downturn comes and the money supply contracts it becomes painfully obvious that there is not enough money to service all debt and interest. This is less obvious in times of 'boom' when the amount of money in circulation (and the debt) is expanding through more people wanting and getting loans. When a downturn comes and the money supply contracts and it becomes painfully obvious – as in 2008 and currently – that there is not enough money to service all debt and interest. Sabbatian banksters have been leading the human population through a calculated series of booms (more debt incurred) and busts (when the debt can't be repaid and the banks get the debtor's tangible wealth in exchange for non-existent 'credit'). With each 'bust' Sabbatian bankers have absorbed more of the world's tangible wealth and we end up with the One-percent. Governments are in bankruptcy levels of debt to the same system and are therefore owned by a system they do not control. The Federal Reserve, 'America's central bank', is privately-owned and American presidents only nominally appoint its chairman or woman to maintain the illusion that it's an arm of government. It's not. The 'Fed' is a cartel of private banks which handed billions to its associates and friends after the crash of 2008 and has been Sabbatian-controlled since it was manipulated into being in 1913 through the covert trickery of Rothschild banking agents Jacob Schiff and Paul

Warburg, and the Sabbatian Rockefeller family. Somehow from a Jewish population of two-percent and globally 0.2 percent (Sabbatian interlopers remember are far smaller) ultra-Zionists headed the Federal Reserve for 31 years between 1987 and 2018 in the form of Alan Greenspan, Bernard Bernanke and Janet Yellen (now Biden's Treasury Secretary) with Yellen's deputy chairman a Israeli-American dual citizen and ultra-Zionist Stanley Fischer, a former governor of the Bank of Israel. Ultra-Zionist Fed chiefs spanned the presidencies of Ronald Reagan ('Republican'), Father George Bush ('Republican'), Bill Clinton ('Democrat'), Boy George Bush ('Republican') and Barack Obama ('Democrat'). We should really add the pre-Greenspan chairman, Paul Adolph Volcker, 'appointed' by Jimmy Carter ('Democrat') who ran the Fed between 1979 and 1987 during the Carter and Reagan administrations before Greenspan took over. Volcker was a long-time associate and business partner of the Rothschilds. No matter what the 'party' officially in power the United States economy was directed by the same force. Here are members of the Obama, Trump and Biden administrations and see if you can make out a common theme.

Barack Obama ('Democrat')

Ultra-Zionists Robert Rubin, Larry Summers, and Timothy Geithner ran the US Treasury in the Clinton administration and two of them reappeared with Obama. Ultra-Zionist Fed chairman Alan Greenspan had manipulated the crash of 2008 through deregulation and jumped ship just before the disaster to make way for ultra-Zionist Bernard Bernanke to hand out trillions to Sabbatian 'too big to fail' banks and businesses, including the ubiquitous ultra-Zionist Goldman Sachs which has an ongoing staff revolving door operation between itself and major financial positions in government worldwide. Obama inherited the fallout of the crash when he took office in January, 2009, and fortunately he had the support of his ultra-Zionist White House Chief of Staff Rahm Emmanuel, son of a terrorist who helped to bomb Israel into being in 1948, and his ultra-Zionist senior adviser David Axelrod, chief strategist in Obama's two

successful presidential campaigns. Emmanuel, later mayor of Chicago and former senior fundraiser and strategist for Bill Clinton, is an example of the Sabbatian policy after Israel was established of migrating insider families to America so their children would be born American citizens. 'Obama' chose this financial team throughout his administration to respond to the Sabbatian-instigated crisis:

Timothy Geithner (ultra-Zionist) Treasury Secretary; Jacob J. Lew, Treasury Secretary; Larry Summers (ultra-Zionist), director of the White House National Economic Council; Paul Adolph Volcker (Rothschild business partner), chairman of the Economic Recovery Advisory Board; Peter Orszag (ultra-Zionist), director of the Office of Management and Budget overseeing all government spending; Penny Pritzker (ultra-Zionist), Commerce Secretary; Jared Bernstein (ultra-Zionist), chief economist and economic policy adviser to Vice President Joe Biden; Mary Schapiro (ultra-Zionist), chair of the Securities and Exchange Commission (SEC); Gary Gensler (ultra-Zionist), chairman of the Commodity Futures Trading Commission (CFTC); Sheila Bair (ultra-Zionist), chair of the Federal Deposit Insurance Corporation (FDIC); Karen Mills (ultra-Zionist), head of the Small Business Administration (SBA); Kenneth Feinberg (ultra-Zionist), Special Master for Executive [bail-out] Compensation. Feinberg would be appointed to oversee compensation (with strings) to 9/11 victims and families in a campaign to stop them having their day in court to question the official story. At the same time ultra-Zionist Bernard Bernanke was chairman of the Federal Reserve and these are only some of the ultra-Zionists with allegiance to Sabbatian-controlled Israel in the Obama government. Obama's biggest corporate donor was ultra-Zionist Goldman Sachs which had employed many in his administration.

Donald Trump ('Republican')

Trump claimed to be an outsider (he wasn't) who had come to 'drain the swamp'. He embarked on this goal by immediately appointing ultra-Zionist Steve Mnuchin, a Goldman Sachs employee for 17

years, as his Treasury Secretary. Others included Gary Cohn (ultra-Zionist), chief operating officer of Goldman Sachs, his first Director of the National Economic Council and chief economic adviser, who was later replaced by Larry Kudlow (ultra-Zionist). Trump's senior adviser throughout his four years in the White House was his sinister son-in-law Jared Kushner, a life-long friend of Israel Prime Minister Benjamin Netanyahu. Kushner is the son of a convicted crook who was pardoned by Trump in his last days in office. Other ultra-Zionists in the Trump administration included: Stephen Miller, Senior Policy Adviser; Avrahm Berkowitz, Deputy Adviser to Trump and his Senior Adviser Jared Kushner; Ivanka Trump, Adviser to the President, who converted to Judaism when she married Jared Kushner; David Friedman, Trump lawyer and Ambassador to Israel; Jason Greenblatt, Trump Organization executive vice president and chief legal officer, who was made Special Representative for International Negotiations and the Israeli-Palestinian Conflict; Rod Rosenstein, Deputy Attorney General; Elliot Abrams, Special Representative for Venezuela, then Iran; John Eisenberg, National Security Council Legal Adviser and Deputy Council to the President for National Security Affairs; Anne Neuberger, Deputy National Manager, National Security Agency; Ezra Cohen-Watnick, Acting Under Secretary of Defense for Intelligence; Elan Carr, Special Envoy to monitor and combat anti-Semitism; Len Khodorkovsky, Deputy Special Envoy to monitor and combat anti-Semitism; Reed Cordish, Assistant to the President, Intragovernmental and Technology Initiatives. Trump Vice President Mike Pence and Secretary of State Mike Pompeo, both Christian Zionists, were also vehement supporters of Israel and its goals and ambitions.

Donald 'free-speech believer' Trump pardoned a number of financial and violent criminals while ignoring calls to pardon Julian Assange and Edward Snowden whose crimes are revealing highly relevant information about government manipulation and corruption and the widespread illegal surveillance of the American people by US 'security' agencies. It's so good to know that Trump is on the side of freedom and justice and not mega-criminals with

allegiance to Sabbatian-controlled Israel. These included a pardon for Israeli spy Jonathan Pollard who was jailed for life in 1987 under the Espionage Act. Aviem Sella, the Mossad agent who recruited Pollard, was also pardoned by Trump while Assange sat in jail and Snowden remained in exile in Russia. Sella had 'fled' (was helped to escape) to Israel in 1987 and was never extradited despite being charged under the Espionage Act. A Trump White House statement said that Sella's clemency had been 'supported by Benjamin Netanyahu, Ron Dermer, Israel's US Ambassador, David Friedman, US Ambassador to Israel and Miriam Adelson, wife of leading Trump donor Sheldon Adelson who died shortly before. Other friends of Jared Kushner were pardoned along with Sholom Weiss who was believed to be serving the longest-ever white-collar prison sentence of more than 800 years in 2000. The sentence was commuted of Ponzi-schemer Eliyahu Weinstein who defrauded Jews and others out of \$200 million. I did mention that Assange and Snowden were ignored, right? Trump gave Sabbatians almost everything they asked for in military and political support, moving the US Embassy from Tel Aviv to Jerusalem with its critical symbolic and literal implications for Palestinian statehood, and the 'deal of the Century' designed by Jared Kushner and David Friedman which gave the Sabbatian Israeli government the green light to substantially expand its already widespread program of building illegal Jewish-only settlements in the occupied land of the West Bank. This made a two-state 'solution' impossible by seizing all the land of a potential Palestinian homeland and that had been the plan since 1948 and then 1967 when the Arab-controlled Gaza Strip, West Bank, Sinai Peninsula and Syrian Golan Heights were occupied by Israel. All the talks about talks and road maps and delays have been buying time until the West Bank was physically occupied by Israeli real estate. Trump would have to be a monumentally ill-informed idiot not to see that this was the plan he was helping to complete. The Trump administration was in so many ways the Kushner administration which means the Netanyahu administration which means the Sabbatian administration. I understand why many opposing Cult fascism in all its forms gravitated to Trump, but he

was a crucial part of the Sabbatian plan and I will deal with this in the next chapter.

Joe Biden ('Democrat')

A barely cognitive Joe Biden took over the presidency in January, 2021, along with his fellow empty shell, Vice-President Kamala Harris, as the latest Sabbatian gofers to enter the White House. Names on the door may have changed and the 'party' – the force behind them remained the same as Zionists were appointed to a stream of pivotal areas relating to Sabbatian plans and policy. They included: Janet Yellen, Treasury Secretary, former head of the Federal Reserve, and still another ultra-Zionist running the US Treasury after Mnuchin (Trump), Lew and Geithner (Obama), and Summers and Rubin (Clinton); Anthony Blinken, Secretary of State; Wendy Sherman, Deputy Secretary of State (so that's 'Biden's' Sabbatian foreign policy sorted); Jeff Zients, White House coronavirus coordinator; Rochelle Walensky, head of the Centers for Disease Control; Rachel Levine, transgender deputy health secretary (that's 'Covid' hoax policy under control); Merrick Garland, Attorney General; Alejandro Mayorkas, Secretary of Homeland Security; Cass Sunstein, Homeland Security with responsibility for new immigration laws; Avril Haines, Director of National Intelligence; Anne Neuberger, National Security Agency cybersecurity director (note, cybersecurity); David Cohen, CIA Deputy Director; Ronald Klain, Biden's Chief of Staff (see Rahm Emanuel); Eric Lander, a 'leading geneticist', Office of Science and Technology Policy director (see Smart Grid, synthetic biology agenda); Jessica Rosenworcel, acting head of the Federal Communications Commission (FCC) which controls Smart Grid technology policy and electromagnetic communication systems including 5G. How can it be that so many pivotal positions are held by two-percent of the American population and 0.2 percent of the world population administration after administration no matter who is the president and what is the party? It's a coincidence? Of course it's not and this is why Sabbatians have built their colossal global web of interlocking 'anti-

hate' hate groups to condemn anyone who asks these glaring questions as an 'anti-Semite'. The way that Jewish people horrifically abused in Sabbatian-backed Nazi Germany are exploited to this end is stomach-turning and disgusting beyond words.

Political fusion

Sabbatian manipulation has reversed the roles of Republicans and Democrats and the same has happened in Britain with the Conservative and Labour Parties. Republicans and Conservatives were always labelled the 'right' and Democrats and Labour the 'left', but look at the policy positions now and the Democrat-Labour 'left' has moved further to the 'right' than Republicans and Conservatives under the banner of 'Woke', the Cult-created far-right tyranny. Where once the Democrat-Labour 'left' defended free speech and human rights they now seek to delete them and as I said earlier despite the 'Covid' fascism of the Jackboot Johnson Conservative government in the UK the Labour Party of leader Keir Starmer demanded even more extreme measures. The Labour Party has been very publicly absorbed by Sabbatians after a political and media onslaught against the previous leader, the weak and inept Jeremy Corbyn, over made-up allegations of 'anti-Semitism' both by him and his party. The plan was clear with this 'anti-Semite' propaganda and what was required in response was a swift and decisive 'fuck off' from Corbyn and a statement to expose the Anti-Semitism Industry (Sabbatian) attempt to silence Labour criticism of the Israeli government (Sabbatians) and purge the party of all dissent against the extremes of ultra-Zionism (Sabbatians). Instead Corbyn and his party fell to their knees and appeased the abusers which, by definition, is impossible. Appeasing one demand leads only to a new demand to be appeased until takeover is complete. Like I say – 'fuck off' would have been a much more effective policy and I have used it myself with great effect over the years when Sabbatians are on my case which is most of the time. I consider that fact a great compliment, by the way. The outcome of the Labour Party capitulation is that we now have a Sabbatian-controlled

Conservative Party 'opposed' by a Sabbatian-controlled Labour Party in a one-party Sabbatian state that hurtles towards the extremes of tyranny (the Sabbatian cult agenda). In America the situation is the same. Labour's Keir Starmer spends his days on his knees with his tongue out pointing to Tel Aviv, or I guess now Jerusalem, while Boris Johnson has an 'anti-Semitism czar' in the form of former Labour MP John Mann who keeps Starmer company on his prayer mat.

Sabbatian influence can be seen in Jewish members of the Labour Party who have been ejected for criticism of Israel including those from families that suffered in Nazi Germany. Sabbatians despise real Jewish people and target them even more harshly because it is so much more difficult to dub them 'anti-Semitic' although in their desperation they do try.

CHAPTER THREE

The Pushbacker sting

*Until you realize how easy it is for your mind to be manipulated, you
remain the puppet of someone else's game*

Evita Ochel

I will use the presidencies of Trump and Biden to show how the manipulation of the one-party state plays out behind the illusion of political choice across the world. No two presidencies could – on the face of it – be more different and apparently at odds in terms of direction and policy.

A Renegade Mind sees beyond the obvious and focuses on outcomes and consequences and not image, words and waffle. The Cult embarked on a campaign to divide America between those who blindly support its agenda (the mentality known as 'Woke') and those who are pushing back on where the Cult and its Sabbatians want to go. This presents infinite possibilities for dividing and ruling the population by setting them at war with each other and allows a perceptual ring fence of demonisation to encircle the Pushbackers in a modern version of the Little Big Horn in 1876 when American cavalry led by Lieutenant Colonel George Custer were drawn into a trap, surrounded and killed by Native American tribes defending their land of thousands of years from being seized by the government. In this modern version the roles are reversed and it's those defending themselves from the Sabbatian government who are surrounded and the government that's seeking to destroy them. This trap was set years ago and to explain how we must return to 2016

and the emergence of Donald Trump as a candidate to be President of the United States. He set out to overcome the best part of 20 other candidates in the Republican Party before and during the primaries and was not considered by many in those early stages to have a prayer of living in the White House. The Republican Party was said to have great reservations about Trump and yet somehow he won the nomination. When you know how American politics works – politics in general – there is no way that Trump could have become the party's candidate unless the Sabbatian-controlled 'Neocons' that run the Republican Party wanted that to happen. We saw the proof in emails and documents made public by WikiLeaks that the Democratic Party hierarchy, or Democons, systematically undermined the campaign of Bernie Sanders to make sure that Sabbatian gofer Hillary Clinton won the nomination to be their presidential candidate. If the Democons could do that then the Neocons in the Republican Party could have derailed Trump in the same way. But they didn't and at that stage I began to conclude that Trump could well be the one chosen to be president. If that was the case the 'why' was pretty clear to see – the goal of dividing America between Cult agenda-supporting Wokers and Pushbackers who gravitated to Trump because he was telling them what they wanted to hear. His constituency of support had been increasingly ignored and voiceless for decades and profoundly through the eight years of Sabbatian puppet Barack Obama. Now here was someone speaking their language of pulling back from the incessant globalisation of political and economic power, the exporting of American jobs to China and elsewhere by 'American' (Sabbatian) corporations, the deletion of free speech, and the mass immigration policies that had further devastated job opportunities for the urban working class of all races and the once American heartlands of the Midwest.

Beware the forked tongue

Those people collectively sighed with relief that at last a political leader was apparently on their side, but another trait of the Renegade Mind is that you look even harder at people telling you

what you want to hear than those who are telling you otherwise. Obviously as I said earlier people wish what they want to hear to be true and genuine and they are much more likely to believe that than someone saying what they don't want to hear and don't want to be true. Sales people are taught to be skilled in eliciting by calculated questioning what their customers want to hear and repeating that back to them as their own opinion to get their targets to like and trust them. Assets of the Cult are also sales people in the sense of selling perception. To read Cult manipulation you have to play the long and expanded game and not fall for the Vaudeville show of party politics. Both American parties are vehicles for the Cult and they exploit them in different ways depending on what the agenda requires at that moment. Trump and the Republicans were used to be the focus of dividing America and isolating Pushbackers to open the way for a Biden presidency to become the most extreme in American history by advancing the full-blown Woke (Cult) agenda with the aim of destroying and silencing Pushbackers now labelled Nazi Trump supporters and white supremacists.

Sabbatians wanted Trump in office for the reasons described by ultra-Zionist Saul Alinsky (1909-1972) who was promoting the Woke philosophy through 'community organising' long before anyone had heard of it. In those days it still went by its traditional name of Marxism. The reason for the manipulated Trump phenomenon was laid out in Alinsky's 1971 book, *Rules for Radicals*, which was his blueprint for overthrowing democratic and other regimes and replacing them with Sabbatian Marxism. Not surprisingly his to-do list was evident in the Sabbatian French and Russian 'Revolutions' and that in China which will become very relevant in the next chapter about the 'Covid' hoax. Among Alinsky's followers have been the deeply corrupt Barack Obama, House Speaker Nancy Pelosi and Hillary Clinton who described him as a 'hero'. All three are Sabbatian stooges with Pelosi personifying the arrogant corrupt idiocy that so widely fronts up for the Cult inner core. Predictably as a Sabbatian advocate of the 'light-bringer' Alinsky features Lucifer on the dedication page of his book as the original radical who gained

his own kingdom ('Earth' as we shall see). One of Alinsky's golden radical rules was to pick an individual and focus all attention, hatred and blame on them and not to target faceless bureaucracies and corporations. *Rules for Radicals* is really a Sabbatian handbook with its contents repeatedly employed all over the world for centuries and why wouldn't Sabbatians bring to power their designer-villain to be used as the individual on which all attention, hatred and blame was bestowed? This is what they did and the only question for me is how much Trump knew that and how much he was manipulated. A bit of both, I suspect. This was Alinsky's Trump technique from a man who died in 1972. The technique has spanned history:

Pick the target, freeze it, personalize it, polarize it. Don't try to attack abstract corporations or bureaucracies. Identify a responsible individual. Ignore attempts to shift or spread the blame.

From the moment Trump came to illusory power everything was about him. It wasn't about Republican policy or opinion, but all about Trump. Everything he did was presented in negative, derogatory and abusive terms by the Sabbatian-dominated media led by Cult operations such as CNN, MSNBC, *The New York Times* and the Jeff Bezos-owned *Washington Post* – 'Pick the target, freeze it, personalize it, polarize it.' Trump was turned into a demon to be vilified by those who hated him and a demi-god loved by those who worshipped him. This, in turn, had his supporters, too, presented as equally demonic in preparation for the punchline later down the line when Biden was about to take office. It was here's a Trump, there's a Trump, everywhere a Trump, Trump. Virtually every news story or happening was filtered through the lens of 'The Donald'. You loved him or hated him and which one you chose was said to define you as Satan's spawn or a paragon of virtue. Even supporting some Trump policies or statements and not others was enough for an assault on your character. No shades of grey were or are allowed. Everything is black and white (literally and figuratively). A Californian I knew had her head utterly scrambled by her hatred for Trump while telling people they should love each other. She was so totally consumed by

Trump Derangement Syndrome as it became to be known that this glaring contradiction would never have occurred to her. By definition anyone who criticised Trump or praised his opponents was a hero and this lady described Joe Biden as 'a kind, honest gentleman' when he's a provable liar, mega-crook and vicious piece of work to boot. Sabbatians had indeed divided America using Trump as the fall-guy and all along the clock was ticking on the consequences for his supporters.

In hock to his masters

Trump gave Sabbatians via Israel almost everything they wanted in his four years. Ask and you shall receive was the dynamic between himself and Benjamin Netanyahu orchestrated by Trump's ultra-Zionist son-in-law Jared Kushner, his ultra-Zionist Ambassador to Israel, David Friedman, and ultra-Zionist 'Israel adviser', Jason Greenblatt. The last two were central to the running and protecting from collapse of his business empire, the Trump Organisation, and colossal business failures made him forever beholding to Sabbatian networks that bailed him out. By the start of the 1990s Trump owed \$4 billion to banks that he couldn't pay and almost \$1 billion of that was down to him personally and not his companies. This mega-disaster was the result of building two new casinos in Atlantic City and buying the enormous Taj Mahal operation which led to crippling debt payments. He had borrowed fantastic sums from 72 banks with major Sabbatian connections and although the scale of debt should have had him living in a tent alongside the highway they never foreclosed. A plan was devised to lift Trump from the mire by BT Securities Corporation and Rothschild Inc. and the case was handled by Wilber Ross who had worked for the Rothschilds for 27 years. Ross would be named US Commerce Secretary after Trump's election. Another crucial figure in saving Trump was ultra-Zionist 'investor' Carl Icahn who bought the Taj Mahal casino. Icahn was made special economic adviser on financial regulation in the Trump administration. He didn't stay long but still managed to find time to make a tidy sum of a reported \$31.3 million when he sold his

holdings affected by the price of steel three days before Trump imposed a 235 percent tariff on steel imports. What amazing bits of luck these people have. Trump and Sabbatian operatives have long had a close association and his mentor and legal adviser from the early 1970s until 1986 was the dark and genetically corrupt ultra-Zionist Roy Cohn who was chief counsel to Senator Joseph McCarthy's 'communist' witch-hunt in the 1950s. *Esquire* magazine published an article about Cohn with the headline 'Don't mess with Roy Cohn'. He was described as the most feared lawyer in New York and 'a ruthless master of dirty tricks ... [with] ... more than one Mafia Don on speed dial'. Cohn's influence, contacts, support and protection made Trump a front man for Sabbatians in New York with their connections to one of Cohn's many criminal employers, the 'Russian' Sabbatian Mafia. Israel-centric media mogul Rupert Murdoch was introduced to Trump by Cohn and they started a long friendship. Cohn died in 1986 weeks after being disbarred for unethical conduct by the Appellate Division of the New York State Supreme Court. The wheels of justice do indeed run slow given the length of Cohn's crooked career.

QAnon-sense

We are asked to believe that Donald Trump with his fundamental connections to Sabbatian networks and operatives has been leading the fight to stop the Sabbatian agenda for the fascistic control of America and the world. Sure he has. A man entrapped during his years in the White House by Sabbatian operatives and whose biggest financial donor was casino billionaire Sheldon Adelson who was Sabbatian to his DNA?? Oh, do come on. Trump has been used to divide America and isolate Pushbackers on the Cult agenda under the heading of 'Trump supporters', 'insurrectionists' and 'white supremacists'. The US Intelligence/Mossad Psyop or psychological operation known as QAnon emerged during the Trump years as a central pillar in the Sabbatian campaign to lead Pushbackers into the trap set by those that wished to destroy them. I knew from the start that QAnon was a scam because I had seen the same scenario many

times before over 30 years under different names and I had written about one in particular in the books. 'Not again' was my reaction when QAnon came to the fore. The same script is pulled out every few years and a new name added to the letterhead. The story always takes the same form: 'Insiders' or 'the good guys' in the government-intelligence-military 'Deep State' apparatus were going to instigate mass arrests of the 'bad guys' which would include the Rockefellers, Rothschilds, Barack Obama, Hillary Clinton, George Soros, etc., etc. Dates are given for when the 'good guys' are going to move in, but the dates pass without incident and new dates are given which pass without incident. The central message to Pushbackers in each case is that they don't have to do anything because there is 'a plan' and it is all going to be sorted by the 'good guys' on the inside. 'Trust the plan' was a QAnon mantra when the only plan was to misdirect Pushbackers into putting their trust in a Psyop they believed to be real. Beware, beware, those who tell you what you want to hear and always check it out. Right up to Biden's inauguration QAnon was still claiming that 'the Storm' was coming and Trump would stay on as president when Biden and his cronies were arrested and jailed. It was never going to happen and of course it didn't, but what did happen as a result provided that punchline to the Sabbatian Trump/QAnon Psyop.

On January 6th, 2021, a very big crowd of Trump supporters gathered in the National Mall in Washington DC down from the Capitol Building to protest at what they believed to be widespread corruption and vote fraud that stopped Trump being re-elected for a second term as president in November, 2020. I say as someone that does not support Trump or Biden that the evidence is clear that major vote-fixing went on to favour Biden, a man with cognitive problems so advanced he can often hardly string a sentence together without reading the words written for him on the Teleprompter. Glaring ballot discrepancies included serious questions about electronic voting machines that make vote rigging a comparative cinch and hundreds of thousands of paper votes that suddenly appeared during already advanced vote counts and virtually all of

them for Biden. Early Trump leads in crucial swing states suddenly began to close and disappear. The pandemic hoax was used as the excuse to issue almost limitless numbers of mail-in ballots with no checks to establish that the recipients were still alive or lived at that address. They were sent to streams of people who had not even asked for them. Private organisations were employed to gather these ballots and who knows what they did with them before they turned up at the counts. The American election system has been manipulated over decades to become a sick joke with more holes than a Swiss cheese for the express purpose of dictating the results. Then there was the criminal manipulation of information by Sabbatian tech giants like Facebook, Twitter and Google-owned YouTube which deleted pro-Trump, anti-Biden accounts and posts while everything in support of Biden was left alone. Sabbatians wanted Biden to win because after the dividing of America it was time for full-on Woke and every aspect of the Cult agenda to be unleashed.

Hunter gatherer

Extreme Silicon Valley bias included blocking information by the *New York Post* exposing a Biden scandal that should have ended his bid for president in the final weeks of the campaign. Hunter Biden, his monumentally corrupt son, is reported to have sent a laptop to be repaired at a local store and failed to return for it. Time passed until the laptop became the property of the store for non-payment of the bill. When the owner saw what was on the hard drive he gave a copy to the FBI who did nothing even though it confirmed widespread corruption in which the Joe Biden family were using his political position, especially when he was vice president to Obama, to make multiple millions in countries around the world and most notably Ukraine and China. Hunter Biden's one-time business partner Tony Bobulinski went public when the story broke in the *New York Post* to confirm the corruption he saw and that Joe Biden not only knew what was going on he also profited from the spoils. Millions were handed over by a Chinese company with close

connections – like all major businesses in China – to the Chinese communist party of President Xi Jinping. Joe Biden even boasted at a meeting of the Cult's World Economic Forum that as vice president he had ordered the government of Ukraine to fire a prosecutor. What he didn't mention was that the same man just happened to be investigating an energy company which was part of Hunter Biden's corrupt portfolio. The company was paying him big bucks for no other reason than the influence his father had. Overnight Biden's presidential campaign should have been over given that he had lied publicly about not knowing what his son was doing. Instead almost the entire Sabbatian-owned mainstream media and Sabbatian-owned Silicon Valley suppressed circulation of the story. This alone went a mighty way to rigging the election of 2020. Cult assets like Mark Zuckerberg at Facebook also spent hundreds of millions to be used in support of Biden and vote 'administration'.

The Cult had used Trump as the focus to divide America and was now desperate to bring in moronic, pliable, corrupt Biden to complete the double-whammy. No way were they going to let little things like the will of the people thwart their plan. Silicon Valley widely censored claims that the election was rigged because it *was* rigged. For the same reason anyone claiming it was rigged was denounced as a 'white supremacist' including the pathetically few Republican politicians willing to say so. Right across the media where the claim was mentioned it was described as a 'false claim' even though these excuses for 'journalists' would have done no research into the subject whatsoever. Trump won seven million more votes than any sitting president had ever achieved while somehow a cognitively-challenged soon to be 78-year-old who was hidden away from the public for most of the campaign managed to win more votes than any presidential candidate in history. It makes no sense. You only had to see election rallies for both candidates to witness the enthusiasm for Trump and the apathy for Biden. Tens of thousands would attend Trump events while Biden was speaking in empty car parks with often only television crews attending and framing their shots to hide the fact that no one was there. It was pathetic to see

footage come to light of Biden standing at a podium making speeches only to TV crews and party fixers while reading the words written for him on massive Teleprompter screens. So, yes, those protestors on January 6th had a point about election rigging, but some were about to walk into a trap laid for them in Washington by the Cult Deep State and its QAnon Psyop. This was the Capitol Hill riot ludicrously dubbed an 'insurrection'.

The spider and the fly

Renegade Minds know there are not two 'sides' in politics, only one side, the Cult, working through all 'sides'. It's a stage show, a puppet show, to direct the perceptions of the population into focusing on diversions like parties and candidates while missing the puppeteers with their hands holding all the strings. The Capitol Hill 'insurrection' brings us back to the Little Big Horn. Having created two distinct opposing groupings – Woke and Pushbackers – the trap was about to be sprung. Pushbackers were to be encircled and isolated by associating them all in the public mind with Trump and then labelling Trump as some sort of Confederate leader. I knew immediately that the Capitol riot was a set-up because of two things. One was how easy the rioters got into the building with virtually no credible resistance and secondly I could see – as with the 'Covid' hoax in the West at the start of 2020 – how the Cult could exploit the situation to move its agenda forward with great speed. My experience of Cult techniques and activities over more than 30 years has showed me that while they do exploit situations they haven't themselves created this never happens with events of fundamental agenda significance. Every time major events giving cultists the excuse to rapidly advance their plan you find they are manipulated into being for the specific reason of providing that excuse – Problem-Reaction-Solution. Only a tiny minority of the huge crowd of Washington protestors sought to gain entry to the Capitol by smashing windows and breaching doors. That didn't matter. The whole crowd and all Pushbackers, even if they did not support Trump, were going to be lumped together as dangerous

insurrectionists and conspiracy theorists. The latter term came into widespread use through a CIA memo in the 1960s aimed at discrediting those questioning the nonsensical official story of the Kennedy assassination and it subsequently became widely employed by the media. It's still being used by inept 'journalists' with no idea of its origin to discredit anyone questioning anything that authority claims to be true. When you are perpetrating a conspiracy you need to discredit the very word itself even though the dictionary definition of conspiracy is merely 'the activity of secretly planning with other people to do something bad or illegal' and 'a general agreement to keep silent about a subject for the purpose of keeping it secret'. On that basis there are conspiracies almost wherever you look. For obvious reasons the Cult and its lapdog media have to claim there are no conspiracies even though the word appears in state laws as with conspiracy to defraud, to murder, and to corrupt public morals.

Agent provocateurs are widely used by the Cult Deep State to manipulate genuine people into acting in ways that suit the desired outcome. By genuine in this case I mean protestors genuinely supporting Trump and claims that the election was stolen. In among them, however, were agents of the state wearing the garb of Trump supporters and QAnon to pump-prime the Capital riot which some genuine Trump supporters naively fell for. I described the situation as 'Come into my parlour said the spider to the fly'. Leaflets appeared through the Woke paramilitary arm Antifa, the anti-fascist fascists, calling on supporters to turn up in Washington looking like Trump supporters even though they hated him. Some of those arrested for breaching the Capitol Building were sourced to Antifa and its stable mate Black Lives Matter. Both organisations are funded by Cult billionaires and corporations. One man charged for the riot was according to his lawyer a former FBI agent who had held top secret security clearance for 40 years. Attorney Thomas Plofchan said of his client, 66-year-old Thomas Edward Caldwell:

He has held a Top Secret Security Clearance since 1979 and has undergone multiple Special Background Investigations in support of his clearances. After retiring from the Navy, he

worked as a section chief for the Federal Bureau of Investigation from 2009-2010 as a GS-12 [mid-level employee].

He also formed and operated a consulting firm performing work, often classified, for U.S government customers including the US. Drug Enforcement Agency, Department of Housing and Urban Development, the US Coast Guard, and the US Army Personnel Command.

A judge later released Caldwell pending trial in the absence of evidence about a conspiracy or that he tried to force his way into the building. *The New York Post* reported a 'law enforcement source' as saying that 'at least two known Antifa members were spotted' on camera among Trump supporters during the riot while one of the rioters arrested was John Earle Sullivan, a seriously extreme Black Lives Matter Trump-hater from Utah who was previously arrested and charged in July, 2020, over a BLM-Antifa riot in which drivers were threatened and one was shot. Sullivan is the founder of Utah-based Insurgence USA which is an affiliate of the Cult-created-and-funded Black Lives Matter movement. Footage appeared and was then deleted by Twitter of Trump supporters calling out Antifa infiltrators and a group was filmed changing into pro-Trump clothing before the riot. Security at the building was *pathetic* – as planned. Colonel Leroy Fletcher Prouty, a man with long experience in covert operations working with the US security apparatus, once described the tell-tale sign to identify who is involved in an assassination. He said:

No one has to direct an assassination – it happens. The active role is played secretly by permitting it to happen. This is the greatest single clue. Who has the power to call off or reduce the usual security precautions?

This principle applies to many other situations and certainly to the Capitol riot of January 6th, 2021.

The sting

With such a big and potentially angry crowd known to be gathering near the Capitol the security apparatus would have had a major police detail to defend the building with National Guard troops on

standby given the strength of feeling among people arriving from all over America encouraged by the QAnon Psyop and statements by Donald Trump. Instead Capitol Police 'security' was flimsy, weak, and easily breached. The same number of officers was deployed as on a regular day and that is a blatant red flag. They were not staffed or equipped for a possible riot that had been an obvious possibility in the circumstances. No protective and effective fencing worth the name was put in place and there were no contingency plans. The whole thing was basically a case of standing aside and waving people in. Once inside police mostly backed off apart from one Capitol police officer who ridiculously shot dead unarmed Air Force veteran protestor Ashli Babbitt without a warning as she climbed through a broken window. The 'investigation' refused to name or charge the officer after what must surely be considered a murder in the circumstances. They just lifted a carpet and swept. The story was endlessly repeated about five people dying in the 'armed insurrection' when there was no report of rioters using weapons. Apart from Babbitt the other four died from a heart attack, strokes and apparently a drug overdose. Capitol police officer Brian Sicknick was reported to have died after being bludgeoned with a fire extinguisher when he was alive after the riot was over and died later of what the Washington Medical Examiner's Office said was a stroke. Sicknick had no external injuries. The lies were delivered like rapid fire. There was a narrative to build with incessant repetition of the lie until the lie became the accepted 'everybody knows that' truth. The 'Big Lie' technique of Nazi Propaganda Minister Joseph Goebbels is constantly used by the Cult which was behind the Nazis and is today behind the 'Covid' and 'climate change' hoaxes. Goebbels said:

If you tell a lie big enough and keep repeating it, people will eventually come to believe it. The lie can be maintained only for such time as the State can shield the people from the political, economic and/or military consequences of the lie. It thus becomes vitally important for the State to use all of its powers to repress dissent, for the truth is the mortal enemy of the lie, and thus by extension, the truth is the greatest enemy of the State.

Most protestors had a free run of the Capitol Building. This allowed pictures to be taken of rioters in iconic parts of the building including the Senate chamber which could be used as propaganda images against all Pushbackers. One Congresswoman described the scene as 'the worst kind of non-security anybody could ever imagine'. Well, the first part was true, but someone obviously did imagine it and made sure it happened. Some photographs most widely circulated featured people wearing QAnon symbols and now the Psyop would be used to dub all QAnon followers with the ubiquitous fit-all label of 'white supremacist' and 'insurrectionists'. When a Muslim extremist called Noah Green drove his car at two police officers at the Capitol Building killing one in April, 2021, there was no such political and media hysteria. They were just disappointed he wasn't white.

The witch-hunt

Government prosecutor Michael Sherwin, an aggressive, dark-eyed, professional Rottweiler led the 'investigation' and to call it over the top would be to understate reality a thousand fold. Hundreds were tracked down and arrested for the crime of having the wrong political views and people were jailed who had done nothing more than walk in the building, committed no violence or damage to property, took a few pictures and left. They were labelled a 'threat to the Republic' while Biden sat in the White House signing executive orders written for him that were dismantling 'the Republic'. Even when judges ruled that a mother and son should not be in jail the government kept them there. Some of those arrested have been badly beaten by prison guards in Washington and lawyers for one man said he suffered a fractured skull and was made blind in one eye. Meanwhile a woman is shot dead for no reason by a Capitol Police officer and we are not allowed to know who he is never mind what has happened to him although that will be *nothing*. The Cult's QAnon/Trump sting to identify and isolate Pushbackers and then target them on the road to crushing and deleting them was a resounding success. You would have thought the Russians had

invaded the building at gunpoint and lined up senators for a firing squad to see the political and media reaction. Congresswoman Alexandria Ocasio-Cortez is a child in a woman's body, a terrible-tuos, me, me, me, Woker narcissist of such proportions that words have no meaning. She said she thought she was going to die when 'insurrectionists' banged on her office door. It turned out she wasn't even in the Capitol Building when the riot was happening and the 'banging' was a Capitol Police officer. She referred to herself as a 'survivor' which is an insult to all those true survivors of violent and sexual abuse while she lives her pampered and privileged life talking drivel for a living. Her Woke colleague and fellow mega-narcissist Rashida Tlaib broke down describing the devastating effect on her, too, of *not being* in the building when the rioters were there. Ocasio-Cortez and Tlaib are members of a fully-Woke group of Congresswomen known as 'The Squad' along with Ilhan Omar and Ayanna Pressley. The Squad from what I can see can be identified by its vehement anti-white racism, anti-white men agenda, and, as always in these cases, the absence of brain cells on active duty.

The usual suspects were on the riot case immediately in the form of Democrat ultra-Zionist senators and operatives Chuck Schumer and Adam Schiff demanding that Trump be impeached for 'his part in the insurrection'. The same pair of prats had led the failed impeachment of Trump over the invented 'Russia collusion' nonsense which claimed Russia had helped Trump win the 2016 election. I didn't realise that Tel Aviv had been relocated just outside Moscow. I must find an up-to-date map. The Russia hoax was a Sabbatian operation to keep Trump occupied and impotent and to stop any rapport with Russia which the Cult wants to retain as a perceptual enemy to be pulled out at will. Puppet Biden began attacking Russia when he came to office as the Cult seeks more upheaval, division and war across the world. A two-year stage show 'Russia collusion inquiry' headed by the not-very-bright former 9/11 FBI chief Robert Mueller, with support from 19 lawyers, 40 FBI agents plus intelligence analysts, forensic accountants and other

staff, devoured tens of millions of dollars and found no evidence of Russia collusion which a ten-year-old could have told them on day one. Now the same moronic Schumer and Schiff wanted a second impeachment of Trump over the Capitol 'insurrection' (riot) which the arrested development of Schumer called another 'Pearl Harbor' while others compared it with 9/11 in which 3,000 died and, in the case of CNN, with the Rwandan genocide in the 1990s in which an estimated 500,000 to 600,000 were murdered, between 250, 000 and 500,000 women were raped, and populations of whole towns were hacked to death with machetes. To make those comparisons purely for Cult political reasons is beyond insulting to those that suffered and lost their lives and confirms yet again the callous inhumanity that we are dealing with. Schumer is a monumental idiot and so is Schiff, but they serve the Cult agenda and do whatever they're told so they get looked after. Talking of idiots – another inane man who spanned the Russia and Capitol impeachment attempts was Senator Eric Swalwell who had the nerve to accuse Trump of collusion with the Russians while sleeping with a Chinese spy called Christine Fang or 'Fang Fang' which is straight out of a Bond film no doubt starring Klaus Schwab as the bloke living on a secret island and controlling laser weapons positioned in space and pointing at world capitals. Fang Fang plays the part of Bond's infiltrator girlfriend which I'm sure she would enjoy rather more than sharing a bed with the brainless Swalwell, lying back and thinking of China. The FBI eventually warned Swalwell about Fang Fang which gave her time to escape back to the Chinese dictatorship. How very thoughtful of them. The second Trump impeachment also failed and hardly surprising when an impeachment is supposed to remove a sitting president and by the time it happened Trump was no longer president. These people are running your country America, well, officially anyway. Terrifying isn't it?

Outcomes tell the story - always

The outcome of all this – and it's the *outcome* on which Renegade Minds focus, not the words – was that a vicious, hysterical and

obviously pre-planned assault was launched on Pushbackers to censor, silence and discredit them and even targeted their right to earn a living. They have since been condemned as 'domestic terrorists' that need to be treated like Al-Qaeda and Islamic State. 'Domestic terrorists' is a label the Cult has been trying to make stick since the period of the Oklahoma bombing in 1995 which was blamed on 'far-right domestic terrorists'. If you read *The Trigger* you will see that the bombing was clearly a Problem-Reaction-Solution carried out by the Deep State during a Bill Clinton administration so corrupt that no dictionary definition of the term would even nearly suffice. Nearly 30, 000 troops were deployed from all over America to the empty streets of Washington for Biden's inauguration. Ten thousand of them stayed on with the pretext of protecting the capital from insurrectionists when it was more psychological programming to normalise the use of the military in domestic law enforcement in support of the Cult plan for a police-military state. Biden's fascist administration began a purge of 'wrong-thinkers' in the military which means anyone that is not on board with Woke. The Capitol Building was surrounded by a fence with razor wire and the Land of the Free was further symbolically and literally dismantled. The circle was completed with the installation of Biden and the exploitation of the QAnon Psyop.

America had never been so divided since the civil war of the 19th century, Pushbackers were isolated and dubbed terrorists and now, as was always going to happen, the Cult immediately set about deleting what little was left of freedom and transforming American society through a swish of the hand of the most controlled 'president' in American history leading (officially at least) the most extreme regime since the country was declared an independent state on July 4th, 1776. Biden issued undebated, dictatorial executive orders almost by the hour in his opening days in office across the whole spectrum of the Cult wish-list including diluting controls on the border with Mexico allowing thousands of migrants to illegally enter the United States to transform the demographics of America and import an election-changing number of perceived Democrat

voters. Then there were Biden deportation amnesties for the already illegally resident (estimated to be as high as 20 or even 30 million). A bill before Congress awarded American citizenship to anyone who could prove they had worked in agriculture for just 180 days in the previous two years as 'Big Ag' secured its slave labour long-term. There were the plans to add new states to the union such as Puerto Rico and making Washington DC a state. They are all parts of a plan to ensure that the Cult-owned Woke Democrats would be permanently in power.

Border – what border?

I have exposed in detail in other books how mass immigration into the United States and Europe is the work of Cult networks fuelled by the tens of billions spent to this and other ends by George Soros and his global Open Society (open borders) Foundations. The impact can be seen in America alone where the population has increased by *100 million* in little more than 30 years mostly through immigration. I wrote in *The Answer* that the plan was to have so many people crossing the southern border that the numbers become unstoppable and we are now there under Cult-owned Biden. El Salvador in Central America puts the scale of what is happening into context. A third of the population now lives in the United States, much of it illegally, and many more are on the way. The methodology is to crush Central and South American countries economically and spread violence through machete-wielding psychopathic gangs like MS-13 based in El Salvador and now operating in many American cities. Biden-imposed lax security at the southern border means that it is all but open. He said before his 'election' that he wanted to see a surge towards the border if he became president and that was the green light for people to do just that after election day to create the human disaster that followed for both America and the migrants. When that surge came the imbecilic Alexandria Ocasio-Cortez said it wasn't a 'surge' because they are 'children, not insurgents' and the term 'surge' (used by Biden) was a claim of 'white supremacists'.

This disingenuous lady may one day enter the realm of the most basic intelligence, but it won't be any time soon.

Sabbatians and the Cult are in the process of destroying America by importing violent people and gangs in among the genuine to terrorise American cities and by overwhelming services that cannot cope with the sheer volume of new arrivals. Something similar is happening in Europe as Western society in general is targeted for demographic and cultural transformation and upheaval. The plan demands violence and crime to create an environment of intimidation, fear and division and Soros has been funding the election of district attorneys across America who then stop prosecuting many crimes, reduce sentences for violent crimes and free as many violent criminals as they can. Sabbatians are creating the chaos from which order – their order – can respond in a classic Problem-Reaction-Solution. A Freemasonic moto says 'Ordo Ab Chao' (Order out of Chaos) and this is why the Cult is constantly creating chaos to impose a new 'order'. Here you have the reason the Cult is constantly creating chaos. The 'Covid' hoax can be seen with those entering the United States by plane being forced to take a 'Covid' test while migrants flooding through southern border processing facilities do not. Nothing is put in the way of mass migration and if that means ignoring the government's own 'Covid' rules then so be it. They know it's all bullshit anyway. Any pushback on this is denounced as 'racist' by Wokers and Sabbatian fronts like the ultra-Zionist Anti-Defamation League headed by the appalling Jonathan Greenblatt which at the same time argues that Israel should not give citizenship and voting rights to more Palestinian Arabs or the 'Jewish population' (in truth the Sabbatian network) will lose control of the country.

Society-changing numbers

Biden's masters have declared that countries like El Salvador are so dangerous that their people must be allowed into the United States for humanitarian reasons when there are fewer murders in large parts of many Central American countries than in US cities like

Baltimore. That is not to say Central America cannot be a dangerous place and Cult-controlled American governments have been making it so since way back, along with the dismantling of economies, in a long-term plan to drive people north into the United States. Parts of Central America are very dangerous, but in other areas the story is being greatly exaggerated to justify relaxing immigration criteria. Migrants are being offered free healthcare and education in the United States as another incentive to head for the border and there is no requirement to be financially independent before you can enter to prevent the resources of America being drained. You can't blame migrants for seeking what they believe will be a better life, but they are being played by the Cult for dark and nefarious ends. The numbers since Biden took office are huge. In February, 2021, more than 100,000 people were known to have tried to enter the US illegally through the southern border (it was 34,000 in the same month in 2020) and in March it was 170,000 – a 418 percent increase on March, 2020. These numbers are only known people, not the ones who get in unseen. The true figure for migrants illegally crossing the border in a single month was estimated by one congressman at 250,000 and that number will only rise under Biden's current policy. Gangs of murdering drug-running thugs that control the Mexican side of the border demand money – thousands of dollars – to let migrants cross the Rio Grande into America. At the same time gun battles are breaking out on the border several times a week between rival Mexican drug gangs (which now operate globally) who are equipped with sophisticated military-grade weapons, grenades and armoured vehicles. While the Capitol Building was being 'protected' from a non-existent 'threat' by thousands of troops, and others were still deployed at the time in the Cult Neocon war in Afghanistan, the southern border of America was left to its fate. This is not incompetence, it is cold calculation.

By March, 2021, there were 17,000 unaccompanied children held at border facilities and many of them are ensnared by people traffickers for paedophile rings and raped on their journey north to America. This is not conjecture – this is fact. Many of those designated

children are in reality teenage boys or older. Meanwhile Wokers posture their self-purity for encouraging poor and tragic people to come to America and face this nightmare both on the journey and at the border with the disgusting figure of House Speaker Nancy Pelosi giving disingenuous speeches about caring for migrants. The woman's evil. Wokers condemned Trump for having children in cages at the border (so did Obama, *Shhhh*), but now they are sleeping on the floor without access to a shower with one border facility 729 percent over capacity. The Biden insanity even proposed flying migrants from the southern border to the northern border with Canada for 'processing'. The whole shambles is being overseen by ultra-Zionist Secretary of Homeland Security, the moronic liar Alejandro Mayorkas, who banned news cameras at border facilities to stop Americans seeing what was happening. Mayorkas said there was not a ban on news crews; it was just that they were not allowed to film. Alongside him at Homeland Security is another ultra-Zionist Cass Sunstein appointed by Biden to oversee new immigration laws. Sunstein despises conspiracy researchers to the point where he suggests they should be banned or *taxed* for having such views. The man is not bonkers or anything. He's perfectly well-adjusted, but adjusted to what is the question. Criticise what is happening and you are a 'white supremacist' when earlier non-white immigrants also oppose the numbers which effect their lives and opportunities. Black people in poor areas are particularly damaged by uncontrolled immigration and the increased competition for work opportunities with those who will work for less. They are also losing voting power as Hispanics become more dominant in former black areas. It's a downward spiral for them while the billionaires behind the policy drone on about how much they care about black people and 'racism'. None of this is about compassion for migrants or black people – that's just wind and air. Migrants are instead being mercilessly exploited to transform America while the countries they leave are losing their future and the same is true in Europe. Mass immigration may now be the work of Woke Democrats, but it can be traced back to the 1986 Immigration Reform and Control Act (it

wasn't) signed into law by Republican hero President Ronald Reagan which gave amnesty to millions living in the United States illegally and other incentives for people to head for the southern border. Here we have the one-party state at work again.

Save me syndrome

Almost every aspect of what I have been exposing as the Cult agenda was on display in even the first days of 'Biden' with silencing of Pushbackers at the forefront of everything. A Renegade Mind will view the Trump years and QAnon in a very different light to their supporters and advocates as the dots are connected. The QAnon/Trump Psyop has given the Cult all it was looking for. We may not know how much, or little, that Trump realised he was being used, but that's a side issue. This pincer movement produced the desired outcome of dividing America and having Pushbackers isolated. To turn this around we have to look at new routes to empowerment which do not include handing our power to other people and groups through what I will call the 'Save Me Syndrome' – 'I want someone else to do it so that I don't have to'. We have seen this at work throughout human history and the QAnon/Trump Psyop is only the latest incarnation alongside all the others. Religion is an obvious expression of this when people look to a 'god' or priest to save them or tell them how to be saved and then there are 'save me' politicians like Trump. Politics is a diversion and not a 'saviour'. It is a means to block positive change, not make it possible.

Save Me Syndrome always comes with the same repeating theme of handing your power to whom or what you believe will save you while your real 'saviour' stares back from the mirror every morning. Renegade Minds are constantly vigilant in this regard and always asking the question 'What can I do?' rather than 'What can someone else do for me?' Gandhi was right when he said: 'You must be the change you want to see in the world.' We are indeed the people we have been waiting for. We are presented with a constant raft of reasons to concede that power to others and forget where the real power is. Humanity has the numbers and the Cult does not. It has to

use diversion and division to target the unstoppable power that comes from unity. Religions, governments, politicians, corporations, media, QAnon, are all different manifestations of this power-diversion and dilution. Refusing to give your power to governments and instead handing it to Trump and QAnon is not to take a new direction, but merely to recycle the old one with new names on the posters. I will explore this phenomenon as we proceed and how to break the cycles and recycles that got us here through the mists of repeating perception and so repeating history.

For now we shall turn to the most potent example in the entire human story of the consequences that follow when you give your power away. I am talking, of course, of the 'Covid' hoax.

CHAPTER FOUR

'Covid': Calculated catastrophe

Facts are threatening to those invested in fraud
DaShanne Stokes

We can easily unravel the real reason for the 'Covid pandemic' hoax by employing the Renegade Mind methodology that I have outlined this far. We'll start by comparing the long-planned Cult outcome with the 'Covid pandemic' outcome. Know the outcome and you'll see the journey.

I have highlighted the plan for the Hunger Games Society which has been in my books for so many years with the very few controlling the very many through ongoing dependency. To create this dependency it is essential to destroy independent livelihoods, businesses and employment to make the population reliant on the state (the Cult) for even the basics of life through a guaranteed pittance income. While independence of income remained these Cult ambitions would be thwarted. With this knowledge it was easy to see where the 'pandemic' hoax was going once talk of 'lockdowns' began and the closing of all but perceived 'essential' businesses to 'save' us from an alleged 'deadly virus'. Cult corporations like Amazon and Walmart were naturally considered 'essential' while mom and pop shops and stores had their doors closed by fascist decree. As a result with every new lockdown and new regulation more small and medium, even large businesses not owned by the Cult, went to the wall while Cult giants and their frontmen and women grew financially fatter by the second. Mom and pop were

denied an income and the right to earn a living and the wealth of people like Jeff Bezos (Amazon), Mark Zuckerberg (Facebook) and Sergei Brin and Larry Page (Google/Alphabet) have reached record levels. The Cult was increasing its own power through further dramatic concentrations of wealth while the competition was being destroyed and brought into a state of dependency. Lockdowns have been instigated to secure that very end and were never anything to do with health. My brother Paul spent 45 years building up a bus repair business, but lockdowns meant buses were running at a fraction of normal levels for months on end. Similar stories can be told in their hundreds of millions worldwide. Efforts of a lifetime coldly destroyed by Cult multi-billionaires and their lackeys in government and law enforcement who continued to earn their living from the taxation of the people while denying the right of the same people to earn theirs. How different it would have been if those making and enforcing these decisions had to face the same financial hardships of those they affected, but they never do.

Gates of Hell

Behind it all in the full knowledge of what he is doing and why is the psychopathic figure of Cult operative Bill Gates. His puppet Tedros at the World Health Organization declared 'Covid' a pandemic in March, 2020. The WHO had changed the definition of a 'pandemic' in 2009 just a month before declaring the 'swine flu pandemic' which would not have been so under the previous definition. The same applies to 'Covid'. The definition had included... 'an infection by an infectious agent, occurring simultaneously in different countries, with a significant mortality rate relative to the proportion of the population infected'. The new definition removed the need for 'significant mortality'. The 'pandemic' has been fraudulent even down to the definition, but Gates demanded economy-destroying lockdowns, school closures, social distancing, mandatory masks, a 'vaccination' for every man, woman and child on the planet and severe consequences and restrictions for those that refused. Who gave him this power? The

Cult did which he serves like a little boy in short trousers doing what his daddy tells him. He and his psychopathic missus even smiled when they said that much worse was to come (what they knew was planned to come). Gates responded in the matter-of-fact way of all psychopaths to a question about the effect on the world economy of what he was doing:

Well, it won't go to zero but it will shrink. Global GDP is probably going to take the biggest hit ever [Gates was smiling as he said this] ... in my lifetime this will be the greatest economic hit. But you don't have a choice. People act as if you have a choice. People don't feel like going to the stadium when they might get infected ... People are deeply affected by seeing these stats, by knowing they could be part of the transmission chain, old people, their parents and grandparents, could be affected by this, and so you don't get to say ignore what is going on here.

There will be the ability to open up, particularly in rich countries, if things are done well over the next few months, but for the world at large normalcy only returns when we have largely vaccinated the entire population.

The man has no compassion or empathy. How could he when he's a psychopath like all Cult players? My own view is that even beyond that he is very seriously mentally ill. Look in his eyes and you can see this along with his crazy flailing arms. You don't do what he has done to the world population since the start of 2020 unless you are mentally ill and at the most extreme end of psychopathic. You especially don't do it when to you know, as we shall see, that cases and deaths from 'Covid' are fakery and a product of monumental figure massaging. 'These stats' that Gates referred to are based on a 'test' that's not testing for the 'virus' as he has known all along. He made his fortune with big Cult support as an infamously ruthless software salesman and now buys global control of 'health' (death) policy without the population he affects having any say. It's a breathtaking outrage. Gates talked about people being deeply affected by fear of 'Covid' when that was because of *him* and his global network lying to them minute-by-minute supported by a lying media that he seriously influences and funds to the tune of hundreds of millions. He's handed big sums to media operations including the BBC, NBC, Al Jazeera, Univision, *PBS NewsHour*,

ProPublica, National Journal, The Guardian, The Financial Times, The Atlantic, Texas Tribune, USA Today publisher Gannett, Washington Monthly, Le Monde, Center for Investigative Reporting, Pulitzer Center on Crisis Reporting, National Press Foundation, International Center for Journalists, Solutions Journalism Network, the Poynter Institute for Media Studies, and many more. Gates is everywhere in the 'Covid' hoax and the man must go to prison – or a mental facility – for the rest of his life and his money distributed to those he has taken such enormous psychopathic pleasure in crushing.

The Muscle

The Hunger Games global structure demands a police-military state – a fusion of the two into one force – which viciously imposes the will of the Cult on the population and protects the Cult from public rebellion. In that regard, too, the 'Covid' hoax just keeps on giving. Often unlawful, ridiculous and contradictory 'Covid' rules and regulations have been policed across the world by moronic automatons and psychopaths made faceless by face-nappy masks and acting like the Nazi SS and fascist blackshirts and brownshirts of Hitler and Mussolini. The smallest departure from the rules decreed by the psychos in government and their clueless gofers were jumped upon by the face-nappy fascists. Brutality against public protestors soon became commonplace even on girls, women and old people as the brave men with the batons – the Face-Nappies as I call them – broke up peaceful protests and handed out fines like confetti to people who couldn't earn a living let alone pay hundreds of pounds for what was once an accepted human right. Robot Face-Nappies of Nottingham police in the English East Midlands fined one group £11,000 for attending a child's birthday party. For decades I charted the transformation of law enforcement as genuine, decent officers were replaced with psychopaths and the brain dead who would happily and brutally do whatever their masters told them. Now they were let loose on the public and I would emphasise the point that none of this just happened. The step-by-step change in the dynamic between police and public was orchestrated from the shadows by

those who knew where this was all going and the same with the perceptual reframing of those in all levels of authority and official administration through 'training courses' by organisations such as Common Purpose which was created in the late 1980s and given a massive boost in Blair era Britain until it became a global phenomenon. Supposed public 'servants' began to view the population as the enemy and the same was true of the police. This was the start of the explosion of behaviour manipulation organisations and networks preparing for the all-war on the human psyche unleashed with the dawn of 2020. I will go into more detail about this later in the book because it is a core part of what is happening.

Police desecrated beauty spots to deter people gathering and arrested women for walking in the countryside alone 'too far' from their homes. We had arrogant, clueless sergeants in the Isle of Wight police where I live posting on Facebook what they insisted the population must do or else. A schoolmaster sergeant called Radford looked young enough for me to ask if his mother knew he was out, but he was posting what he *expected* people to do while a Sergeant Wilkinson boasted about fining lads for meeting in a McDonald's car park where they went to get a lockdown takeaway. Wilkinson added that he had even cancelled their order. What a pair of prats these people are and yet they have increasingly become the norm among Jackboot Johnson's Yellowshirts once known as the British police. This was the theme all over the world with police savagery common during lockdown protests in the United States, the Netherlands, and the fascist state of Victoria in Australia under its tyrannical and again moronic premier Daniel Andrews. Amazing how tyrannical and moronic tend to work as a team and the same combination could be seen across America as arrogant, narcissistic Woke governors and mayors such as Gavin Newsom (California), Andrew Cuomo (New York), Gretchen Whitmer (Michigan), Lori Lightfoot (Chicago) and Eric Garcetti (Los Angeles) did their Nazi and Stalin impressions with the full support of the compliant brutality of their enforcers in uniform as they arrested small business owners defying

fascist shutdown orders and took them to jail in ankle shackles and handcuffs. This happened to bistro owner Marlena Pavlos-Hackney in Gretchen Whitmer's fascist state of Michigan when police arrived to enforce an order by a state-owned judge for 'putting the community at risk' at a time when other states like Texas were dropping restrictions and migrants were pouring across the southern border without any 'Covid' questions at all. I'm sure there are many officers appalled by what they are ordered to do, but not nearly enough of them. If they were truly appalled they would not do it. As the months passed every opportunity was taken to have the military involved to make their presence on the streets ever more familiar and 'normal' for the longer-term goal of police-military fusion.

Another crucial element to the Hunger Games enforcement network has been encouraging the public to report neighbours and others for 'breaking the lockdown rules'. The group faced with £11,000 in fines at the child's birthday party would have been dobbed-in by a neighbour with a brain the size of a pea. The technique was most famously employed by the Stasi secret police in communist East Germany who had public informants placed throughout the population. A police chief in the UK says his force doesn't need to carry out 'Covid' patrols when they are flooded with so many calls from the public reporting other people for visiting the beach. Dorset police chief James Vaughan said people were so enthusiastic about snitching on their fellow humans they were now operating as an auxiliary arm of the police: 'We are still getting around 400 reports a week from the public, so we will respond to reports ... We won't need to be doing hotspot patrols because people are very quick to pick the phone up and tell us.' Vaughan didn't say that this is a pillar of all tyrannies of whatever complexion and the means to hugely extend the reach of enforcement while spreading distrust among the people and making them wary of doing anything that might get them reported. Those narcissistic Isle of Wight sergeants Radford and Wilkinson never fail to add a link to their Facebook posts where the public can inform on their fellow slaves.

Neither would be self-aware enough to realise they were imitating the Stasi which they might well never have heard of. Government psychologists that I will expose later laid out a policy to turn communities against each other in the same way.

A coincidence? Yep, and I can knit fog

I knew from the start of the alleged pandemic that this was a Cult operation. It presented limitless potential to rapidly advance the Cult agenda and exploit manipulated fear to demand that every man, woman and child on the planet was 'vaccinated' in a process never used on humans before which infuses self-replicating *synthetic* material into human cells. Remember the plan to transform the human body from a biological to a synthetic biological state. I'll deal with the 'vaccine' (that's not actually a vaccine) when I focus on the genetic agenda. Enough to say here that mass global 'vaccination' justified by this 'new virus' set alarms ringing after 30 years of tracking these people and their methods. The 'Covid' hoax officially beginning in China was also a big red flag for reasons I will be explaining. The agenda potential was so enormous that I could dismiss any idea that the 'virus' appeared naturally. Major happenings with major agenda implications never occur without Cult involvement in making them happen. My questions were twofold in early 2020 as the media began its campaign to induce global fear and hysteria: Was this alleged infectious agent released on purpose by the Cult or did it even exist at all? I then did what I always do in these situations. I sat, observed and waited to see where the evidence and information would take me. By March and early April synchronicity was strongly – and ever more so since then – pointing me in the direction of *there is no 'virus'*. I went public on that with derision even from swathes of the alternative media that voiced a scenario that the Chinese government released the 'virus' in league with Deep State elements in the United States from a top-level bio-lab in Wuhan where the 'virus' is said to have first appeared. I looked at that possibility, but I didn't buy it for several reasons. Deaths from the 'virus' did not in any way match what they

would have been with a 'deadly bioweapon' and it is much more effective if you sell the *illusion* of an infectious agent rather than having a real one unless you can control through injection who has it and who doesn't. Otherwise you lose control of events. A made-up 'virus' gives you a blank sheet of paper on which you can make it do whatever you like and have any symptoms or mutant 'variants' you choose to add while a real infectious agent would limit you to what it actually does. A phantom disease allows you to have endless ludicrous 'studies' on the 'Covid' dollar to widen the perceived impact by inventing ever more 'at risk' groups including one study which said those who walk slowly may be almost four times more likely to die from the 'virus'. People are in psychiatric wards for less.

A real 'deadly bioweapon' can take out people in the hierarchy that are not part of the Cult, but essential to its operation. Obviously they don't want that. Releasing a real disease means you immediately lose control of it. Releasing an illusory one means you don't. Again it's vital that people are extra careful when dealing with what they want to hear. A bioweapon unleashed from a Chinese laboratory in collusion with the American Deep State may fit a conspiracy narrative, but is it true? Would it not be far more effective to use the excuse of a 'virus' to justify the real bioweapon – the 'vaccine'? That way your disease agent does not have to be transmitted and arrives directly through a syringe. I saw a French virologist Luc Montagnier quoted in the alternative media as saying he had discovered that the alleged 'new' severe acute respiratory syndrome coronavirus , or SARS-CoV-2, was made artificially and included elements of the human immunodeficiency 'virus' (HIV) and a parasite that causes malaria. SARS-CoV-2 is alleged to trigger an alleged illness called Covid-19. I remembered Montagnier's name from my research years before into claims that an HIV 'retrovirus' causes AIDs – claims that were demolished by Berkeley virologist Peter Duesberg who showed that no one had ever proved that HIV causes acquired immunodeficiency syndrome or AIDS. Claims that become accepted as fact, publicly and medically, with no proof whatsoever are an ever-recurring story that profoundly applies to

‘Covid’. Nevertheless, despite the lack of proof, Montagnier’s team at the Pasteur Institute in Paris had a long dispute with American researcher Robert Gallo over which of them discovered and isolated the HIV ‘virus’ and with *no evidence* found it to cause AIDS. You will see later that there is also no evidence that any ‘virus’ causes any disease or that there is even such a thing as a ‘virus’ in the way it is said to exist. The claim to have ‘isolated’ the HIV ‘virus’ will be presented in its real context as we come to the shocking story – and it is a story – of SARS-CoV-2 and so will Montagnier’s assertion that he identified the full SARS-CoV-2 genome.

Hoax in the making

We can pick up the ‘Covid’ story in 2010 and the publication by the Rockefeller Foundation of a document called ‘Scenarios for the Future of Technology and International Development’. The inner circle of the Rockefeller family has been serving the Cult since John D. Rockefeller (1839-1937) made his fortune with Standard Oil. It is less well known that the same Rockefeller – the Bill Gates of his day – was responsible for establishing what is now referred to as ‘Big Pharma’, the global network of pharmaceutical companies that make outrageous profits dispensing scalpel and drug ‘medicine’ and are obsessed with pumping vaccines in ever-increasing number into as many human arms and backsides as possible. John D. Rockefeller was the driving force behind the creation of the ‘education’ system in the United States and elsewhere specifically designed to program the perceptions of generations thereafter. The Rockefeller family donated exceptionally valuable land in New York for the United Nations building and were central in establishing the World Health Organization in 1948 as an agency of the UN which was created from the start as a Trojan horse and stalking horse for world government. Now enter Bill Gates. His family and the Rockefellers have long been extremely close and I have seen genealogy which claims that if you go back far enough the two families fuse into the same bloodline. Gates has said that the Bill and Melinda Gates Foundation was inspired by the Rockefeller Foundation and why not

when both are serving the same Cult? Major tax-exempt foundations are overwhelmingly criminal enterprises in which Cult assets fund the Cult agenda in the guise of 'philanthropy' while avoiding tax in the process. Cult operatives can become mega-rich in their role of front men and women for the psychopaths at the inner core and they, too, have to be psychopaths to knowingly serve such evil. Part of the deal is that a big percentage of the wealth gleaned from representing the Cult has to be spent advancing the ambitions of the Cult and hence you have the Rockefeller Foundation, Bill and Melinda Gates Foundation (and *so* many more) and people like George Soros with his global Open Society Foundations spending their billions in pursuit of global Cult control. Gates is a global public face of the Cult with his interventions in world affairs including Big Tech influence; a central role in the 'Covid' and 'vaccine' scam; promotion of the climate change shakedown; manipulation of education; geoengineering of the skies; and his food-control agenda as the biggest owner of farmland in America, his GMO promotion and through other means. As one writer said: 'Gates monopolizes or wields disproportionate influence over the tech industry, global health and vaccines, agriculture and food policy (including biopiracy and fake food), weather modification and other climate technologies, surveillance, education and media.' The almost limitless wealth secured through Microsoft and other not-allowed-to-fail ventures (including vaccines) has been ploughed into a long, long list of Cult projects designed to enslave the entire human race. Gates and the Rockefellers have been working as one unit with the Rockefeller-established World Health Organization leading global 'Covid' policy controlled by Gates through his mouth-piece Tedros. Gates became the WHO's biggest funder when Trump announced that the American government would cease its donations, but Biden immediately said he would restore the money when he took office in January, 2021. The Gates Foundation (the Cult) owns through limitless funding the world health system and the major players across the globe in the 'Covid' hoax.

Okay, with that background we return to that Rockefeller Foundation document of 2010 headed 'Scenarios for the Future of Technology and International Development' and its 'imaginary' epidemic of a virulent and deadly influenza strain which infected 20 percent of the global population and killed eight million in seven months. The Rockefeller scenario was that the epidemic destroyed economies, closed shops, offices and other businesses and led to governments imposing fierce rules and restrictions that included mandatory wearing of face masks and body-temperature checks to enter communal spaces like railway stations and supermarkets. The document predicted that even after the height of the Rockefeller-envisaged epidemic the authoritarian rule would continue to deal with further pandemics, transnational terrorism, environmental crises and rising poverty. Now you may think that the Rockefellers are our modern-day seers or alternatively, and rather more likely, that they well knew what was planned a few years further on. Fascism had to be imposed, you see, to 'protect citizens from risk and exposure'. The Rockefeller scenario document said:

During the pandemic, national leaders around the world flexed their authority and imposed airtight rules and restrictions, from the mandatory wearing of face masks to body-temperature checks at the entries to communal spaces like train stations and supermarkets. Even after the pandemic faded, this more authoritarian control and oversight of citizens and their activities stuck and even intensified. In order to protect themselves from the spread of increasingly global problems – from pandemics and transnational terrorism to environmental crises and rising poverty – leaders around the world took a firmer grip on power.

At first, the notion of a more controlled world gained wide acceptance and approval. Citizens willingly gave up some of their sovereignty – and their privacy – to more paternalistic states in exchange for greater safety and stability. Citizens were more tolerant, and even eager, for top-down direction and oversight, and national leaders had more latitude to impose order in the ways they saw fit.

In developed countries, this heightened oversight took many forms: biometric IDs for all citizens, for example, and tighter regulation of key industries whose stability was deemed vital to national interests. In many developed countries, enforced cooperation with a suite of new regulations and agreements slowly but steadily restored both order and, importantly, economic growth.

There we have the prophetic Rockefellers in 2010 and three years later came their paper for the Global Health Summit in Beijing, China, when government representatives, the private sector, international organisations and groups met to discuss the next 100 years of 'global health'. The Rockefeller Foundation-funded paper was called 'Dreaming the Future of Health for the Next 100 Years and more prophecy ensued as it described a dystopian future: 'The abundance of data, digitally tracking and linking people may mean the 'death of privacy' and may replace physical interaction with transient, virtual connection, generating isolation and raising questions of how values are shaped in virtual networks.' Next in the 'Covid' hoax preparation sequence came a 'table top' simulation in 2018 for another 'imaginary' pandemic of a disease called Clade X which was said to kill 900 million people. The exercise was organised by the Gates-funded Johns Hopkins University's Center for Health Security in the United States and this is the very same university that has been compiling the disgustingly and systematically erroneous global figures for 'Covid' cases and deaths. Similar Johns Hopkins health crisis scenarios have included the Dark Winter exercise in 2001 and Atlantic Storm in 2005.

Nostradamus 201

For sheer predictive genius look no further prophecy-watchers than the Bill Gates-funded Event 201 held only six weeks before the 'coronavirus pandemic' is supposed to have broken out in China and Event 201 was based on a scenario of a global 'coronavirus pandemic'. Melinda Gates, the great man's missus, told the BBC that he had 'prepared for years' for a coronavirus pandemic which told us what we already knew. Nostradamugates had predicted in a TED talk in 2015 that a pandemic was coming that would kill a lot of people and demolish the world economy. My god, the man is a machine – possibly even literally. Now here he was only weeks before the real thing funding just such a simulated scenario and involving his friends and associates at Johns Hopkins, the World Economic Forum Cult-front of Klaus Schwab, the United Nations,

Johnson & Johnson, major banks, and officials from China and the Centers for Disease Control in the United States. What synchronicity – Johns Hopkins would go on to compile the fraudulent ‘Covid’ figures, the World Economic Forum and Schwab would push the ‘Great Reset’ in response to ‘Covid’, the Centers for Disease Control would be at the forefront of ‘Covid’ policy in the United States, Johnson & Johnson would produce a ‘Covid vaccine’, and everything would officially start just weeks later in China. Spooky, eh? They were even accurate in creating a simulation of a ‘virus’ pandemic because the ‘real thing’ would also be a simulation. Event 201 was not an exercise preparing for something that might happen; it was a rehearsal for what those in control knew was *going* to happen and very shortly. Hours of this simulation were posted on the Internet and the various themes and responses mirrored what would soon be imposed to transform human society. News stories were inserted and what they said would be commonplace a few weeks later with still more prophecy perfection. Much discussion focused on the need to deal with misinformation and the ‘anti-vax movement’ which is exactly what happened when the ‘virus’ arrived – was said to have arrived – in the West.

Cult-owned social media banned criticism and exposure of the official ‘virus’ narrative and when I said there *was* no ‘virus’ in early April, 2020, I was banned by one platform after another including YouTube, Facebook and later Twitter. The mainstream broadcast media in Britain was in effect banned from interviewing me by the Tony-Blair-created government broadcasting censor Ofcom headed by career government bureaucrat Melanie Dawes who was appointed just as the ‘virus’ hoax was about to play out in January, 2020. At the same time the Ickonic media platform was using Vimeo, another ultra-Zionist-owned operation, while our own player was being created and they deleted in an instant hundreds of videos, documentaries, series and shows to confirm their unbelievable vindictiveness. We had copies, of course, and they had to be restored one by one when our player was ready. These people have no class. Sabbatian Facebook promised free advertisements for the Gates-

controlled World Health Organization narrative while deleting ‘false claims and conspiracy theories’ to stop ‘misinformation’ about the alleged coronavirus. All these responses could be seen just a short while earlier in the scenarios of Event 201. Extreme censorship was absolutely crucial for the Cult because the official story was so ridiculous and unsupportable by the evidence that it could never survive open debate and the free-flow of information and opinion. If you can’t win a debate then don’t have one is the Cult’s approach throughout history. Facebook’s little boy front man – front boy – Mark Zuckerberg equated ‘credible and accurate information’ with official sources and exposing their lies with ‘misinformation’.

Silencing those that can see

The censorship dynamic of Event 201 is now the norm with an army of narrative-supporting ‘fact-checker’ organisations whose entire reason for being is to tell the public that official narratives are true and those exposing them are lying. One of the most appalling of these ‘fact-checkers’ is called NewsGuard founded by ultra-Zionist Americans Gordon Crovitz and Steven Brill. Crovitz is a former publisher of *The Wall Street Journal*, former Executive Vice President of Dow Jones, a member of the Council on Foreign Relations (CFR), and on the board of the American Association of Rhodes Scholars. The CFR and Rhodes Scholarships, named after Rothschild agent Cecil Rhodes who plundered the gold and diamonds of South Africa for his masters and the Cult, have featured widely in my books. NewsGuard don’t seem to like me for some reason – I really can’t think why – and they have done all they can to have me censored and discredited which is, to quote an old British politician, like being savaged by a dead sheep. They are, however, like all in the censorship network, very well connected and funded by organisations themselves funded by, or connected to, Bill Gates. As you would expect with anything associated with Gates NewsGuard has an offshoot called HealthGuard which ‘fights online health care hoaxes’. How very kind. Somehow the NewsGuard European Managing Director Anna-Sophie Harling, a remarkably young-

looking woman with no broadcasting experience and little hands-on work in journalism, has somehow secured a position on the 'Content Board' of UK government broadcast censor Ofcom. An executive of an organisation seeking to discredit dissidents of the official narratives is making decisions for the government broadcast 'regulator' about content?? Another appalling 'fact-checker' is Full Fact funded by George Soros and global censors Google and Facebook.

It's amazing how many activists in the 'fact-checking', 'anti-hate', arena turn up in government-related positions – people like UK Labour Party activist Imran Ahmed who heads the Center for Countering Digital Hate founded by people like Morgan McSweeney, now chief of staff to the Labour Party's hapless and useless 'leader' Keir Starmer. Digital Hate – which is what it really is – uses the American spelling of Center to betray its connection to a transatlantic network of similar organisations which in 2020 shapeshifted from attacking people for 'hate' to attacking them for questioning the 'Covid' hoax and the dangers of the 'Covid vaccine'. It's just a coincidence, you understand. This is one of Imran Ahmed's hysterical statements: 'I would go beyond calling anti-vaxxers conspiracy theorists to say they are an extremist group that pose a national security risk.' No one could ever accuse this prat of understatement and he's including in that those parents who are now against vaccines after their children were damaged for life or killed by them. He's such a nice man. Ahmed does the rounds of the Woke media getting soft-ball questions from spineless 'journalists' who never ask what right he has to campaign to destroy the freedom of speech of others while he demands it for himself. There also seems to be an overrepresentation in Ofcom of people connected to the narrative-worshipping BBC. This incredible global network of narrative-support was super-vital when the 'Covid' hoax was played in the light of the mega-whopper lies that have to be defended from the spotlight cast by the most basic intelligence.

Setting the scene

The Cult plays the long game and proceeds step-by-step ensuring that everything is in place before major cards are played and they don't come any bigger than the 'Covid' hoax. The psychopaths can't handle events where the outcome isn't certain and as little as possible – preferably nothing – is left to chance. Politicians, government and medical officials who would follow direction were brought to illusory power in advance by the Cult web whether on the national stage or others like state governors and mayors of America. For decades the dynamic between officialdom, law enforcement and the public was changed from one of service to one of control and dictatorship. Behaviour manipulation networks established within government were waiting to impose the coming 'Covid' rules and regulations specifically designed to subdue and rewire the psyche of the people in the guise of protecting health. These included in the UK the Behavioural Insights Team part-owned by the British government Cabinet Office; the Scientific Pandemic Insights Group on Behaviours (SPI-B); and a whole web of intelligence and military groups seeking to direct the conversation on social media and control the narrative. Among them are the cyberwarfare (on the people) 77th Brigade of the British military which is also coordinated through the Cabinet Office as civilian and military leadership continues to combine in what they call the Fusion Doctrine. The 77th Brigade is a British equivalent of the infamous Israeli (Sabbatian) military cyberwarfare and Internet manipulation operation Unit 8200 which I expose at length in *The Trigger*. Also carefully in place were the medical and science advisers to government – many on the payroll past or present of Bill Gates – and a whole alternative structure of unelected government stood by to take control when elected parliaments were effectively closed down once the 'Covid' card was slammed on the table. The structure I have described here and so much more was installed in every major country through the Cult networks. The top-down control hierarchy looks like this: The Cult – Cult-owned Gates – the World Health Organization and Tedros – Gates-funded or controlled chief medical officers and science 'advisers' (dictators) in each country –

political 'leaders' – law enforcement – The People. Through this simple global communication and enforcement structure the policy of the Cult could be imposed on virtually the entire human population so long as they acquiesced to the fascism. With everything in place it was time for the button to be pressed in late 2019/early 2020.

These were the prime goals the Cult had to secure for its will to prevail:

- 1) Locking down economies, closing all but designated 'essential' businesses (Cult-owned corporations were 'essential'), and putting the population under house arrest was an imperative to destroy independent income and employment and ensure dependency on the Cult-controlled state in the Hunger Games Society. Lockdowns had to be established as the global blueprint from the start to respond to the 'virus' and followed by pretty much the entire world.
- 2) The global population had to be terrified into believing in a deadly 'virus' that didn't actually exist so they would unquestioningly obey authority in the belief that authority must know how best to protect them and their families. Software salesman Gates would suddenly morph into the world's health expert and be promoted as such by the Cult-owned media.
- 3) A method of testing that wasn't testing for the 'virus', but was only claimed to be, had to be in place to provide the illusion of 'cases' and subsequent 'deaths' that had a very different cause to the 'Covid-19' that would be scribbled on the death certificate.
- 4) Because there was no 'virus' and the great majority testing positive with a test not testing for the 'virus' would have no symptoms of anything the lie had to be sold that people without symptoms (without the 'virus') could still pass it on to others. This was crucial to justify for the first time quarantining – house arresting – healthy people. Without this the economy-destroying lockdown of *everybody* could not have been credibly sold.
- 5) The 'saviour' had to be seen as a vaccine which beyond evil drug companies were working like angels of mercy to develop as quickly as possible, with all corners cut, to save the day. The public must absolutely not know that the 'vaccine' had nothing to do with a 'virus' or that the contents were ready and waiting with a very different motive long before the 'Covid' card was even lifted from the pack.

I said in March, 2020, that the 'vaccine' would have been created way ahead of the 'Covid' hoax which justified its use and the following December an article in the New York *Intelligencer* magazine said the Moderna 'vaccine' had been 'designed' by

January, 2020. This was 'before China had even acknowledged that the disease could be transmitted from human to human, more than a week before the first confirmed coronavirus case in the United States'. The article said that by the time the first American death was announced a month later 'the vaccine had already been manufactured and shipped to the National Institutes of Health for the beginning of its Phase I clinical trial'. The 'vaccine' was actually 'designed' long before that although even with this timescale you would expect the article to ask how on earth it could have been done that quickly. Instead it asked why the 'vaccine' had not been rolled out then and not months later. Journalism in the mainstream is truly dead. I am going to detail in the next chapter why the 'virus' has never existed and how a hoax on that scale was possible, but first the foundation on which the Big Lie of 'Covid' was built.

The test that doesn't test

Fraudulent 'testing' is the bottom line of the whole 'Covid' hoax and was the means by which a 'virus' that did not exist *appeared* to exist. They could only achieve this magic trick by using a test not testing for the 'virus'. To use a test that *was* testing for the 'virus' would mean that every test would come back negative given there was no 'virus'. They chose to exploit something called the RT-PCR test invented by American biochemist Kary Mullis in the 1980s who said publicly that his PCR test ... *cannot detect infectious disease*. Yes, the 'test' used worldwide to detect infectious 'Covid' to produce all the illusory 'cases' and 'deaths' compiled by Johns Hopkins and others *cannot detect infectious disease*. This fact came from the mouth of the man who invented PCR and was awarded the Nobel Prize in Chemistry in 1993 for doing so. Sadly, and incredibly conveniently for the Cult, Mullis died in August, 2019, at the age of 74 just before his test would be fraudulently used to unleash fascism on the world. He was said to have died from pneumonia which was an irony in itself. A few months later he would have had 'Covid-19' on his death certificate. I say the timing of his death was convenient because had he lived Mullis, a brilliant, honest and decent man, would have been

vociferously speaking out against the use of his test to detect 'Covid' when it was never designed, or able, to do that. I know that to be true given that Mullis made the same point when his test was used to 'detect' – not detect – HIV. He had been seriously critical of the Gallo/Montagnier claim to have isolated the HIV 'virus' and shown it to cause AIDS for which Mullis said there was no evidence. AIDS is actually not a disease but a series of diseases from which people die all the time. When they die from those *same diseases* after a positive 'test' for HIV then AIDS goes on their death certificate. I think I've heard that before somewhere. Countries instigated a policy with 'Covid' that anyone who tested positive with a test not testing for the 'virus' and died of any other cause within 28 days and even longer 'Covid-19' had to go on the death certificate. Cases have come from the test that can't test for infectious disease and the deaths are those who have died of *anything* after testing positive with a test not testing for the 'virus'. I'll have much more later about the death certificate scandal.

Mullis was deeply dismissive of the now US 'Covid' star Anthony Fauci who he said was a liar who didn't know anything about anything – 'and I would say that to his face – nothing.' He said of Fauci: 'The man thinks he can take a blood sample, put it in an electron microscope and if it's got a virus in there you'll know it – he doesn't understand electron microscopy and he doesn't understand medicine and shouldn't be in a position like he's in.' That position, terrifyingly, has made him the decider of 'Covid' fascism policy on behalf of the Cult in his role as director since 1984 of the National Institute of Allergy and Infectious Diseases (NIAID) while his record of being wrong is laughable; but being wrong, so long as it's the *right kind* of wrong, is why the Cult loves him. He'll say anything the Cult tells him to say. Fauci was made Chief Medical Adviser to the President immediately Biden took office. Biden was installed in the White House by Cult manipulation and one of his first decisions was to elevate Fauci to a position of even more control. This is a coincidence? Yes, and I identify as a flamenco dancer called Lola. How does such an incompetent criminal like Fauci remain in that

pivotal position in American health since *the 1980s*? When you serve the Cult it looks after you until you are surplus to requirements. Kary Mullis said prophetically of Fauci and his like: 'Those guys have an agenda and it's not an agenda we would like them to have ... they make their own rules, they change them when they want to, and Tony Fauci does not mind going on television in front of the people who pay his salary and lie directly into the camera.' Fauci has done that almost daily since the 'Covid' hoax began. Lying is in Fauci's DNA. To make the situation crystal clear about the PCR test this is a direct quote from its inventor Kary Mullis:

It [the PCR test] doesn't tell you that you're sick and doesn't tell you that the thing you ended up with was really going to hurt you ...'

Ask yourself why governments and medical systems the world over have been using this very test to decide who is 'infected' with the SARS-CoV-2 'virus' and the alleged disease it allegedly causes, 'Covid-19'. The answer to that question will tell you what has been going on. By the way, here's a little show-stopper – the 'new' SARS-CoV-2 'virus' was 'identified' as such right from the start using ... *the PCR test not testing for the 'virus'*. If you are new to this and find that shocking then stick around. I have hardly started yet. Even worse, other 'tests', like the 'Lateral Flow Device' (LFD), are considered so useless that they have to be *confirmed* by the PCR test! Leaked emails written by Ben Dyson, adviser to UK 'Health' Secretary Matt Hancock, said they were 'dangerously unreliable'. Dyson, executive director of strategy at the Department of Health, wrote: 'As of today, someone who gets a positive LFD result in (say) London has at best a 25 per cent chance of it being a true positive, but if it is a self-reported test potentially as low as 10 per cent (on an optimistic assumption about specificity) or as low as 2 per cent (on a more pessimistic assumption).' These are the 'tests' that schoolchildren and the public are being urged to have twice a week or more and have to isolate if they get a positive. Each fake positive goes in the statistics as a 'case' no matter how ludicrously inaccurate and the

'cases' drive lockdown, masks and the pressure to 'vaccinate'. The government said in response to the email leak that the 'tests' were accurate which confirmed yet again what shocking bloody liars they are. The real false positive rate is *100 percent* as we'll see. In another 'you couldn't make it up' the UK government agreed to pay £2.8 billion to California's Innova Medical Group to supply the irrelevant lateral flow tests. The company's primary test-making centre is in China. Innova Medical Group, established in March, 2020, is owned by Pasaca Capital Inc, chaired by Chinese-American millionaire Charles Huang who was born in Wuhan.

How it works – and how it doesn't

The RT-PCR test, known by its full title of Polymerase chain reaction, is used across the world to make millions, even billions, of copies of a DNA/RNA genetic information sample. The process is called 'amplification' and means that a tiny sample of genetic material is amplified to bring out the detailed content. I stress that it is not testing for an infectious disease. It is simply amplifying a sample of genetic material. In the words of Kary Mullis: 'PCR is ... just a process that's used to make a whole lot of something out of something.' To emphasise the point companies that make the PCR tests circulated around the world to 'test' for 'Covid' warn on the box that it can't be used to detect 'Covid' or infectious disease and is for research purposes only. It's okay, rest for a minute and you'll be fine. This is the test that produces the 'cases' and 'deaths' that have been used to destroy human society. All those global and national medical and scientific 'experts' demanding this destruction to 'save us' *KNOW* that the test is not testing for the 'virus' and the cases and deaths they claim to be real are an almost unimaginable fraud. Every one of them and so many others including politicians and psychopaths like Gates and Tedros must be brought before Nuremburg-type trials and jailed for the rest of their lives. The more the genetic sample is amplified by PCR the more elements of that material become sensitive to the test and by that I don't mean sensitive for a 'virus' but for elements of the genetic material which

is *naturally* in the body or relates to remnants of old conditions of various kinds lying dormant and causing no disease. Once the amplification of the PCR reaches a certain level *everyone* will test positive. So much of the material has been made sensitive to the test that everyone will have some part of it in their body. Even lying criminals like Fauci have said that once PCR amplifications pass 35 cycles everything will be a false positive that cannot be trusted for the reasons I have described. I say, like many proper doctors and scientists, that 100 percent of the 'positives' are false, but let's just go with Fauci for a moment.

He says that any amplification over 35 cycles will produce false positives and yet the US Centers for Disease Control (CDC) and Food and Drug Administration (FDA) have recommended up to 40 *cycles* and the National Health Service (NHS) in Britain admitted in an internal document for staff that it was using 45 *cycles* of amplification. A long list of other countries has been doing the same and at least one 'testing' laboratory has been using 50 *cycles*. Have you ever heard a doctor, medical 'expert' or the media ask what level of amplification has been used to claim a 'positive'. The 'test' comes back 'positive' and so you have the 'virus', end of story. Now we can see how the government in Tanzania could send off samples from a goat and a pawpaw fruit under human names and both came back positive for 'Covid-19'. Tanzania president John Magufuli mocked the 'Covid' hysteria, the PCR test and masks and refused to import the DNA-manipulating 'vaccine'. The Cult hated him and an article sponsored by the Bill Gates Foundation appeared in the London *Guardian* in February, 2021, headed 'It's time for Africa to rein in Tanzania's anti-vaxxer president'. Well, 'reined in' he shortly was. Magufuli appeared in good health, but then, in March, 2021, he was dead at 61 from 'heart failure'. He was replaced by Samia Hassan Suhulu who is connected to Klaus Schwab's World Economic Forum and she immediately reversed Magufuli's 'Covid' policy. A sample of cola tested positive for 'Covid' with the PCR test in Germany while American actress and singer-songwriter Erykah Badu tested positive in one nostril and negative in the other. Footballer Ronaldo called

the PCR test 'bullshit' after testing positive three times and being forced to quarantine and miss matches when there was nothing wrong with him. The mantra from Tedros at the World Health Organization and national governments (same thing) has been test, test, test. They know that the more tests they can generate the more fake 'cases' they have which go on to become 'deaths' in ways I am coming to. The UK government has its Operation Moonshot planned to test multiple millions every day in workplaces and schools with free tests for everyone to use twice a week at home in line with the Cult plan from the start to make testing part of life. A government advertisement for an 'Interim Head of Asymptomatic Testing Communication' said the job included responsibility for delivering a 'communications strategy' (propaganda) 'to support the expansion of asymptomatic testing that *'normalises testing as part of everyday life'*'. More tests means more fake 'cases', 'deaths' and fascism. I have heard of, and from, many people who booked a test, couldn't turn up, and yet got a positive result through the post for a test they'd never even had. The whole thing is crazy, but for the Cult there's method in the madness. Controlling and manipulating the level of amplification of the test means the authorities can control whenever they want the number of apparent 'cases' and 'deaths'. If they want to justify more fascist lockdown and destruction of livelihoods they keep the amplification high. If they want to give the illusion that lockdowns and the 'vaccine' are working then they lower the amplification and 'cases' and 'deaths' will appear to fall. In January, 2021, the Cult-owned World Health Organization suddenly warned laboratories about over-amplification of the test and to lower the threshold. Suddenly headlines began appearing such as: 'Why ARE "Covid" cases plummeting?' This was just when the vaccine rollout was underway and I had predicted months before they would make cases appear to fall through amplification tampering when the 'vaccine' came. These people are so predictable.

Cow vaccines?

The question must be asked of what is on the test swabs being poked far up the nose of the population to the base of the brain? A nasal swab punctured one woman's brain and caused it to leak fluid. Most of these procedures are being done by people with little training or medical knowledge. Dr Lorraine Day, former orthopaedic trauma surgeon and Chief of Orthopaedic Surgery at San Francisco General Hospital, says the tests are really a '*vaccine*'. Cows have long been vaccinated this way. She points out that masks have to cover the nose and the mouth where it is claimed the '*virus*' exists in saliva. Why then don't they take saliva from the mouth as they do with a DNA test instead of pushing a long swab up the nose towards the brain? The ethmoid bone separates the nasal cavity from the brain and within that bone is the cribriform plate. Dr Day says that when the swab is pushed up against this plate and twisted the procedure is '*depositing things back there*'. She claims that among these '*things*' are nanoparticles that can enter the brain. Researchers have noted that a team at the Gates-funded Johns Hopkins have designed tiny, star-shaped micro-devices that can latch onto intestinal mucosa and release drugs into the body. Mucosa is the thin skin that covers the inside surface of parts of the body such as *the nose* and mouth and produces mucus to protect them. The Johns Hopkins micro-devices are called '*theragrippers*' and were '*inspired*' by a parasitic worm that digs its sharp teeth into a host's intestines. Nasal swabs are also coated in the sterilisation agent ethylene oxide. The US National Cancer Institute posts this explanation on its website:

At room temperature, ethylene oxide is a flammable colorless gas with a sweet odor. It is used primarily to produce other chemicals, including antifreeze. In smaller amounts, ethylene oxide is used as a pesticide and a sterilizing agent. The ability of ethylene oxide to damage DNA makes it an effective sterilizing agent but also accounts for its cancer-causing activity.

The Institute mentions lymphoma and leukaemia as cancers most frequently reported to be associated with occupational exposure to ethylene oxide along with stomach and breast cancers. How does anyone think this is going to work out with the constant testing

regime being inflicted on adults and children at home and at school that will accumulate in the body anything that's on the swab?

Doctors know best

It is vital for people to realise that 'hero' doctors 'know' only what the Big Pharma-dominated medical authorities tell them to 'know' and if they refuse to 'know' what they are told to 'know' they are out the door. They are mostly not physicians or healers, but repeaters of the official narrative – or else. I have seen alleged professional doctors on British television make shocking statements that we are supposed to take seriously. One called 'Dr' Amir Khan, who is actually telling patients how to respond to illness, said that men could take the birth pill to 'help slow down the effects of Covid-19'. In March, 2021, another ridiculous 'Covid study' by an American doctor proposed injecting men with the female sex hormone progesterone as a 'Covid' treatment. British doctor Nighat Arif told the BBC that face coverings were now going to be part of ongoing normal. Yes, the vaccine protects you, she said (evidence?) ... but the way to deal with viruses in the community was always going to come down to hand washing, face covering and keeping a physical distance. That's not what we were told before the 'vaccine' was circulating. Arif said she couldn't imagine ever again going on the underground or in a lift without a mask. I was just thanking my good luck that she was not my doctor when she said – in March, 2021 – that if 'we are *behaving* and we are doing all the right things' she thought we could 'have our nearest and dearest around us at home ... around *Christmas* and *New Year*! Her patronising delivery was the usual school teacher talking to six-year-olds as she repeated every government talking point and probably believed them all. If we have learned anything from the 'Covid' experience surely it must be that humanity's perception of doctors needs a fundamental rethink. NHS 'doctor' Sara Kayat told her television audience that the 'Covid vaccine' would '100 percent prevent hospitalisation and death'. Not even Big Pharma claimed that. We have to stop taking 'experts' at their word without question when so many of them are

clueless and only repeating the party line on which their careers depend. That is not to say there are not brilliant doctors – there are and I have spoken to many of them since all this began – but you won't see them in the mainstream media or quoted by the psychopaths and yes-people in government.

Remember the name – Christian Drosten

German virologist Christian Drosten, Director of Charité Institute of Virology in Berlin, became a national star after the pandemic hoax began. He was feted on television and advised the German government on 'Covid' policy. Most importantly to the wider world Drosten led a group that produced the 'Covid' testing protocol for the PCR test. What a remarkable feat given the PCR cannot test for infectious disease and even more so when you think that Drosten said that his method of testing for SARS-CoV-2 was developed 'without having virus material available'. *He developed a test for a 'virus' that he didn't have and had never seen.* Let that sink in as you survey the global devastation that came from what he did. The whole catastrophe of Drosten's 'test' was based on the alleged genetic sequence published by Chinese scientists on the Internet. We will see in the next chapter that this alleged 'genetic sequence' has never been produced by China or anyone and cannot be when there *is no* SARS-CoV-2. Drosten, however, doesn't seem to let little details like that get in the way. He was the lead author with Victor Corman from the same Charité Hospital of the paper 'Detection of 2019 novel coronavirus (2019-nCoV) by real-time PCR' published in a magazine called *Eurosurveillance*. This became known as the Corman-Drosten paper. In November, 2020, with human society devastated by the effects of the Corman-Drosten test baloney, the protocol was publicly challenged by 22 international scientists and independent researchers from Europe, the United States, and Japan. Among them were senior molecular geneticists, biochemists, immunologists, and microbiologists. They produced a document headed 'External peer review of the RTPCR test to detect SARS-Cov-2 Reveals 10 Major Flaws At The Molecular and Methodological Level: Consequences

For False-Positive Results'. The flaws in the Corman-Drosten test included the following:

- The test is non-specific because of erroneous design
- Results are enormously variable
- The test is unable to discriminate between the whole 'virus' and viral fragments
- It doesn't have positive or negative controls
- The test lacks a standard operating procedure
- It is unsupported by proper peer view

The scientists said the PCR 'Covid' testing protocol was not founded on science and they demanded the Corman-Drosten paper be retracted by *Eurosurveillance*. They said all present and previous Covid deaths, cases, and 'infection rates' should be subject to a massive retroactive inquiry. Lockdowns and travel restrictions should be reviewed and relaxed and those diagnosed through PCR to have 'Covid-19' should not be forced to isolate. Dr Kevin Corbett, a health researcher and nurse educator with a long academic career producing a stream of peer-reviewed publications at many UK universities, made the same point about the PCR test debacle. He said of the scientists' conclusions: 'Every scientific rationale for the development of that test has been totally destroyed by this paper. It's like Hiroshima/Nagasaki to the Covid test.' He said that China hadn't given them an isolated 'virus' when Drosten developed the test. Instead they had developed the test from *a sequence in a gene bank*.' Put another way ... *they made it up!* The scientists were supported in this contention by a Portuguese appeals court which ruled in November, 2020, that PCR tests are unreliable and it is unlawful to quarantine people based solely on a PCR test. The point about China not providing an isolated virus must be true when the 'virus' has never been isolated to this day and the consequences of that will become clear. Drosten and company produced this useless 'protocol' right on cue in January, 2020, just as the 'virus' was said to

be moving westward and it somehow managed to successfully pass a peer-review in 24 hours. In other words there was no peer-review for a test that would be used to decide who had 'Covid' and who didn't across the world. The Cult-created, Gates-controlled World Health Organization immediately recommended all its nearly 200 member countries to use the Drosten PCR protocol to detect 'cases' and 'deaths'. The sting was underway and it continues to this day.

So who is this Christian Drosten that produced the means through which death, destruction and economic catastrophe would be justified? His education background, including his doctoral thesis, would appear to be somewhat shrouded in mystery and his track record is dire as with another essential player in the 'Covid' hoax, the Gates-funded Professor Neil Ferguson at the Gates-funded Imperial College in London of whom more shortly. Drosten predicted in 2003 that the alleged original SARS 'virus' (SARS-1) was an epidemic that could have serious effects on economies and an effective vaccine would take at least two years to produce. Drosten's answer to every alleged 'outbreak' is a vaccine which you won't be shocked to know. What followed were just 774 official deaths worldwide and none in Germany where there were only nine cases. That is even if you believe there ever was a SARS 'virus' when the evidence is zilch and I will expand on this in the next chapter. Drosten claims to be co-discoverer of 'SARS-1' and developed a test for it in 2003. He was screaming warnings about 'swine flu' in 2009 and how it was a widespread infection far more severe than any dangers from a vaccine could be and people should get vaccinated. It would be helpful for Drosten's vocal chords if he simply recorded the words 'the virus is deadly and you need to get vaccinated' and copies could be handed out whenever the latest made-up threat comes along. Drosten's swine flu epidemic never happened, but Big Pharma didn't mind with governments spending hundreds of millions on vaccines that hardly anyone bothered to use and many who did wished they hadn't. A study in 2010 revealed that the risk of dying from swine flu, or H1N1, was no higher than that of the annual seasonal flu which is what at least most of 'it' really was as in

the case of 'Covid-19'. A media investigation into Drosten asked how with such a record of inaccuracy he could be *the* government adviser on these issues. The answer to that question is the same with Drosten, Ferguson and Fauci – they keep on giving the authorities the 'conclusions' and 'advice' they want to hear. Drosten certainly produced the goods for them in January, 2020, with his PCR protocol garbage and provided the foundation of what German internal medicine specialist Dr Claus Köhnlein, co-author of *Virus Mania*, called the 'test pandemic'. The 22 scientists in the *Eurosurveillance* challenge called out conflicts of interest within the Drosten 'protocol' group and with good reason. Olfert Landt, a regular co-author of Drosten 'studies', owns the biotech company TIB Molbiol Syntheselabor GmbH in Berlin which manufactures and sells the tests that Drosten and his mates come up with. They have done this with SARS, Enterotoxigenic E. coli (ETEC), MERS, Zika 'virus', yellow fever, and now 'Covid'. Landt told the *Berliner Zeitung* newspaper:

The testing, design and development came from the Charité [Drosten and Corman]. We simply implemented it immediately in the form of a kit. And if we don't have the virus, which originally only existed in Wuhan, we can make a synthetic gene to simulate the genome of the virus. That's what we did very quickly.

This is more confirmation that the Drosten test was designed without access to the 'virus' and only a synthetic simulation which is what SARS-CoV-2 really is – a computer-generated synthetic fiction. It's quite an enterprise they have going here. A Drosten team decides what the test for something should be and Landt's biotech company flogs it to governments and medical systems across the world. His company must have made an absolute fortune since the 'Covid' hoax began. Dr Reiner Fuellmich, a prominent German consumer protection trial lawyer in Germany and California, is on Drosten's case and that of Tedros at the World Health Organization for crimes against humanity with a class-action lawsuit being prepared in the United States and other legal action in Germany.

Why China?

Scamming the world with a 'virus' that doesn't exist would seem impossible on the face of it, but not if you have control of the relatively few people that make policy decisions and the great majority of the global media. Remember it's not about changing 'real' reality it's about controlling *perception* of reality. You don't have to make something happen you only have to make people *believe* that it's happening. Renegade Minds understand this and are therefore much harder to swindle. 'Covid-19' is not a 'real' 'virus'. It's a mind virus, like a computer virus, which has infected the minds, not the bodies, of billions. It all started, publically at least, in China and that alone is of central significance. The Cult was behind the revolution led by its asset Mao Zedong, or Chairman Mao, which established the People's Republic of China on October 1st, 1949. It should have been called The Cult's Republic of China, but the name had to reflect the recurring illusion that vicious dictatorships are run by and for the people (see all the 'Democratic Republics' controlled by tyrants). In the same way we have the 'Biden' Democratic Republic of America officially ruled by a puppet tyrant (at least temporarily) on behalf of Cult tyrants. The creation of Mao's merciless communist/fascist dictatorship was part of a frenzy of activity by the Cult at the conclusion of World War Two which, like the First World War, it had instigated through its assets in Germany, Britain, France, the United States and elsewhere. Israel was formed in 1948; the Soviet Union expanded its 'Iron Curtain' control, influence and military power with the Warsaw Pact communist alliance in 1955; the United Nations was formed in 1945 as a Cult precursor to world government; and a long list of world bodies would be established including the World Health Organization (1948), World Trade Organization (1948 under another name until 1995), International Monetary Fund (1945) and World Bank (1944). Human society was redrawn and hugely centralised in the global Problem-Reaction-Solution that was World War Two. All these changes were significant. Israel would become the headquarters of the Sabbatians

and the revolution in China would prepare the ground and control system for the events of 2019/2020.

Renegade Minds know there are no borders except for public consumption. The Cult is a seamless, borderless global entity and to understand the game we need to put aside labels like borders, nations, countries, communism, fascism and democracy. These delude the population into believing that countries are ruled within their borders by a government of whatever shade when these are mere agencies of a global power. America's illusion of democracy and China's communism/fascism are subsidiaries – vehicles – for the same agenda. We may hear about conflict and competition between America and China and on the lower levels that will be true; but at the Cult level they are branches of the same company in the way of the McDonald's example I gave earlier. I have tracked in the books over the years support by US governments of both parties for Chinese Communist Party infiltration of American society through allowing the sale of land, even military facilities, and the acquisition of American business and university influence. All this is underpinned by the infamous stealing of intellectual property and technological know-how. Cult-owned Silicon Valley corporations waive their fraudulent 'morality' to do business with human-rights-free China; Cult-controlled Disney has become China's PR department; and China in effect owns 'American' sports such as basketball which depends for much of its income on Chinese audiences. As a result any sports player, coach or official speaking out against China's horrific human rights record is immediately condemned or fired by the China-worshipping National Basketball Association. One of the first acts of China-controlled Biden was to issue an executive order telling federal agencies to stop making references to the 'virus' by the 'geographic location of its origin'. Long-time Congressman Jerry Nadler warned that criticising China, America's biggest rival, leads to hate crimes against Asian people in the United States. So shut up you bigot. China is fast closing in on Israel as a country that must not be criticised which is apt, really, given that Sabbatians control them both. The two countries have

developed close economic, military, technological and strategic ties which include involvement in China's 'Silk Road' transport and economic initiative to connect China with Europe. Israel was the first country in the Middle East to recognise the establishment of Mao's tyranny in 1950 months after it was established.

Project Wuhan – the 'Covid' Psyop

I emphasise again that the Cult plays the long game and what is happening to the world today is the result of centuries of calculated manipulation following a script to take control step-by-step of every aspect of human society. I will discuss later the common force behind all this that has spanned those centuries and thousands of years if the truth be told. Instigating the Mao revolution in China in 1949 with a 2020 'pandemic' in mind is not only how they work – the 71 years between them is really quite short by the Cult's standards of manipulation preparation. The reason for the Cult's Chinese revolution was to create a fiercely-controlled environment within which an extreme structure for human control could be incubated to eventually be unleashed across the world. We have seen this happen since the 'pandemic' emerged from China with the Chinese control-structure founded on AI technology and tyrannical enforcement sweep across the West. Until the moment when the Cult went for broke in the West and put its fascism on public display Western governments had to pay some lip-service to freedom and democracy to not alert too many people to the tyranny-in-the-making. Freedoms were more subtly eroded and power centralised with covert government structures put in place waiting for the arrival of 2020 when that smokescreen of 'freedom' could be dispensed with. The West was not able to move towards tyranny before 2020 anything like as fast as China which was created as a tyranny and had no limits on how fast it could construct the Cult's blueprint for global control. When the time came to impose that structure on the world it was the same Cult-owned Chinese communist/fascist government that provided the excuse – the 'Covid pandemic'. It was absolutely crucial to the Cult plan for the Chinese response to the 'pandemic' –

draconian lockdowns of the entire population – to become the blueprint that Western countries would follow to destroy the livelihoods and freedom of their people. This is why the Cult-owned, Gates-owned, WHO Director-General Tedros said early on:

The Chinese government is to be congratulated for the extraordinary measures it has taken to contain the outbreak. China is actually setting a new standard for outbreak response and it is not an exaggeration.

Forbes magazine said of China: ‘... those measures protected untold millions from getting the disease’. The Rockefeller Foundation ‘epidemic scenario’ document in 2010 said ‘prophetically’:

However, a few countries did fare better – China in particular. The Chinese government’s quick imposition and enforcement of mandatory quarantine for all citizens, as well as its instant and near-hermetic sealing off of all borders, saved millions of lives, stopping the spread of the virus far earlier than in other countries and enabling a swifter post-pandemic recovery.

Once again – *spooky*.

The first official story was the ‘bat theory’ or rather the bat diversion. The source of the ‘virus outbreak’ we were told was a ‘wet market’ in Wuhan where bats and other animals are bought and eaten in horrifically unhygienic conditions. Then another story emerged through the alternative media that the ‘virus’ had been released on purpose or by accident from a BSL-4 (biosafety level 4) laboratory in Wuhan not far from the wet market. The lab was reported to create and work with lethal concoctions and bioweapons. Biosafety level 4 is the highest in the World Health Organization system of safety and containment. Renegade Minds are aware of what I call designer manipulation. The ideal for the Cult is for people to buy its prime narrative which in the opening salvos of the ‘pandemic’ was the wet market story. It knows, however, that there is now a considerable worldwide alternative media of researchers sceptical of anything governments say and they are often given a version of events in a form they can perceive as credible while misdirecting them from the real truth. In this case let them

think that the conspiracy involved is a 'bioweapon virus' released from the Wuhan lab to keep them from the real conspiracy – *there is no 'virus'*. The WHO's current position on the source of the outbreak at the time of writing appears to be: 'We haven't got a clue, mate.' This is a good position to maintain mystery and bewilderment. The inner circle will know where the 'virus' came from – *nowhere*. The bottom line was to ensure the public believed there *was* a 'virus' and it didn't much matter if they thought it was natural or had been released from a lab. The belief that there was a 'deadly virus' was all that was needed to trigger global panic and fear. The population was terrified into handing their power to authority and doing what they were told. They had to or they were 'all gonna die'.

In March, 2020, information began to come my way from real doctors and scientists and my own additional research which had my intuition screaming: 'Yes, that's it! *There is no virus.*' The 'bioweapon' was not the 'virus'; it was the '*vaccine*' already being talked about that would be the bioweapon. My conclusion was further enhanced by happenings in Wuhan. The 'virus' was said to be sweeping the city and news footage circulated of people collapsing in the street (which they've never done in the West with the same 'virus'). The Chinese government was building 'new hospitals' in a matter of ten days to 'cope with demand' such was the virulent nature of the 'virus'. Yet in what seemed like no time the 'new hospitals' closed – even if they even opened – and China declared itself 'virus-free'. It was back to business as usual. This was more propaganda to promote the Chinese draconian lockdowns in the West as the way to 'beat the virus'. Trouble was that we subsequently had lockdown after lockdown, but never business as usual. As the people of the West and most of the rest of the world were caught in an ever-worsening spiral of lockdown, social distancing, masks, isolated old people, families forced apart, and livelihood destruction, it was party-time in Wuhan. Pictures emerged of thousands of people enjoying pool parties and concerts. It made no sense until you realised there never was a 'virus' and the

whole thing was a Cult set-up to transform human society out of one of its major global strongholds – China.

How is it possible to deceive virtually the entire world population into believing there is a deadly virus when there is not even a 'virus' let alone a deadly one? It's nothing like as difficult as you would think and that's clearly true because it happened.

Postscript: See end of book Postscript for more on the 'Wuhan lab virus release' story which the authorities and media were pushing heavily in the summer of 2021 to divert attention from the truth that the 'Covid virus' is pure invention.

CHAPTER FIVE

There is no 'virus'

You can fool some of the people all of the time, and all of the people some of the time, but you cannot fool all of the people all of the time
Abraham Lincoln

The greatest form of mind control is repetition. The more you repeat the same mantra of alleged 'facts' the more will accept them to be true. It becomes an 'everyone knows that, mate'. If you can also censor any other version or alternative to your alleged 'facts' you are pretty much home and cooking.

By the start of 2020 the Cult owned the global mainstream media almost in its entirety to spew out its 'Covid' propaganda and ignore or discredit any other information and view. Cult-owned social media platforms in Cult-owned Silicon Valley were poised and ready to unleash a campaign of ferocious censorship to obliterate all but the official narrative. To complete the circle many demands for censorship by Silicon Valley were led by the mainstream media as 'journalists' became full-out enforcers for the Cult both as propagandists and censors. Part of this has been the influx of young people straight out of university who have become 'journalists' in significant positions. They have no experience and a headful of programmed perceptions from their years at school and university at a time when today's young are the most perceptually-targeted generations in known human history given the insidious impact of technology. They enter the media perceptually prepared and ready to repeat the narratives of the system that programmed them to

repeat its narratives. The BBC has a truly pathetic 'specialist disinformation reporter' called Marianna Spring who fits this bill perfectly. She is clueless about the world, how it works and what is really going on. Her role is to discredit anyone doing the job that a proper journalist would do and system-serving hacks like Spring wouldn't dare to do or even see the need to do. They are too busy licking the arse of authority which can never be wrong and, in the case of the BBC propaganda programme, *Panorama*, contacting payments systems such as PayPal to have a donations page taken down for a film company making documentaries questioning vaccines. Even the BBC soap opera *EastEnders* included a disgracefully biased scene in which an inarticulate white working class woman was made to look foolish for questioning the 'vaccine' while a well-spoken black man and Asian woman promoted the government narrative. It ticked every BBC box and the fact that the black and minority community was resisting the 'vaccine' had nothing to do with the way the scene was written. The BBC has become a disgusting tyrannical propaganda and censorship operation that should be defunded and disbanded and a free media take its place with a brief to stop censorship instead of demanding it. A BBC 'interview' with Gates goes something like: 'Mr Gates, sir, if I can call you sir, would you like to tell our audience why you are such a great man, a wonderful humanitarian philanthropist, and why you should absolutely be allowed as a software salesman to decide health policy for approaching eight billion people? Thank you, sir, please sir.' Propaganda programming has been incessant and merciless and when all you hear is the same story from the media, repeated by those around you who have only heard the same story, is it any wonder that people on a grand scale believe absolute mendacious garbage to be true? You are about to see, too, why this level of information control is necessary when the official 'Covid' narrative is so nonsensical and unsupportable by the evidence.

Structure of Deceit

The pyramid structure through which the 'Covid' hoax has been manifested is very simple and has to be to work. As few people as possible have to be involved with full knowledge of what they are doing – and why – or the real story would get out. At the top of the pyramid are the inner core of the Cult which controls Bill Gates who, in turn, controls the World Health Organization through his pivotal funding and his puppet Director-General mouthpiece, Tedros. Before he was appointed Tedros was chair of the Gates-founded Global Fund to 'fight against AIDS, tuberculosis and malaria', a board member of the Gates-funded 'vaccine alliance' GAVI, and on the board of another Gates-funded organisation. Gates owns him and picked him for a specific reason – Tedros is a crook and worse. 'Dr' Tedros (he's not a medical doctor, the first WHO chief not to be) was a member of the tyrannical Marxist government of Ethiopia for decades with all its human rights abuses. He has faced allegations of corruption and misappropriation of funds and was exposed three times for covering up cholera epidemics while Ethiopia's health minister. Tedros appointed the mass-murdering genocidal Zimbabwe dictator Robert Mugabe as a WHO goodwill ambassador for public health which, as with Tedros, is like appointing a psychopath to run a peace and love campaign. The move was so ridiculous that he had to drop Mugabe in the face of widespread condemnation. American economist David Steinman, a Nobel peace prize nominee, lodged a complaint with the International Criminal Court in The Hague over alleged genocide by Tedros when he was Ethiopia's foreign minister. Steinman says Tedros was a 'crucial decision maker' who directed the actions of Ethiopia's security forces from 2013 to 2015 and one of three officials in charge when those security services embarked on the 'killing' and 'torturing' of Ethiopians. You can see where Tedros is coming from and it's sobering to think that he has been the vehicle for Gates and the Cult to direct the global response to 'Covid'. Think about that. A psychopathic Cult dictates to psychopath Gates who dictates to psychopath Tedros who dictates how countries of the world must respond to a 'Covid virus' never scientifically shown to exist. At the same time psychopathic Cult-owned Silicon Valley information

giants like Google, YouTube, Facebook and Twitter announced very early on that they would give the Cult/Gates/Tedros/WHO version of the narrative free advertising and censor those who challenged their intelligence-insulting, mendacious story.

The next layer in the global 'medical' structure below the Cult, Gates and Tedros are the chief medical officers and science 'advisers' in each of the WHO member countries which means virtually all of them. Medical officers and arbiters of science (they're not) then take the WHO policy and recommended responses and impose them on their country's population while the political 'leaders' say they are deciding policy (they're clearly not) by 'following the science' on the advice of the 'experts' – the same medical officers and science 'advisers' (dictators). In this way with the rarest of exceptions the entire world followed the same policy of lockdown, people distancing, masks and 'vaccines' dictated by the psychopathic Cult, psychopathic Gates and psychopathic Tedros who we are supposed to believe give a damn about the health of the world population they are seeking to enslave. That, amazingly, is all there is to it in terms of crucial decision-making. Medical staff in each country then follow like sheep the dictates of the shepherds at the top of the national medical hierarchies – chief medical officers and science 'advisers' who themselves follow like sheep the shepherds of the World Health Organization and the Cult. Shepherds at the national level often have major funding and other connections to Gates and his Bill and Melinda Gates Foundation which carefully hands out money like confetti at a wedding to control the entire global medical system from the WHO down.

Follow the money

Christopher Whitty, Chief Medical Adviser to the UK Government at the centre of 'virus' policy, a senior adviser to the government's Scientific Advisory Group for Emergencies (SAGE), and Executive Board member of the World Health Organization, was gifted a grant of \$40 million by the Bill and Melinda Gates Foundation for malaria research in Africa. The BBC described the unelected Whitty as 'the

official who will probably have the greatest impact on our everyday lives of any individual policymaker in modern times' and so it turned out. What Gates and Tedros have said Whitty has done like his equivalents around the world. Patrick Vallance, co-chair of SAGE and the government's Chief Scientific Adviser, is a former executive of Big Pharma giant GlaxoSmithKline with its fundamental financial and business connections to Bill Gates. In September, 2020, it was revealed that Vallance owned a deferred bonus of shares in GlaxoSmithKline worth £600,000 while the company was 'developing' a 'Covid vaccine'. Move along now – nothing to see here – what could possibly be wrong with that? Imperial College in London, a major player in 'Covid' policy in Britain and elsewhere with its 'Covid-19' Response Team, is funded by Gates and has big connections to China while the now infamous Professor Neil Ferguson, the useless 'computer modeller' at Imperial College is also funded by Gates. Ferguson delivered the dramatically inaccurate excuse for the first lockdowns (much more in the next chapter). The Institute for Health Metrics and Evaluation (IHME) in the United States, another source of outrageously false 'Covid' computer models to justify lockdowns, is bankrolled by Gates who is a vehement promotor of lockdowns. America's version of Whitty and Vallance, the again now infamous Anthony Fauci, has connections to 'Covid vaccine' maker Moderna as does Bill Gates through funding from the Bill and Melinda Gates Foundation. Fauci is director of the National Institute of Allergy and Infectious Diseases (NIAID), a major recipient of Gates money, and they are very close. Deborah Birx who was appointed White House Coronavirus Response Coordinator in February, 2020, is yet another with ties to Gates. Everywhere you look at the different elements around the world behind the coordination and decision making of the 'Covid' hoax there is Bill Gates and his money. They include the World Health Organization; Centers for Disease Control (CDC) in the United States; National Institutes of Health (NIH) of Anthony Fauci; Imperial College and Neil Ferguson; the London School of Hygiene where Chris Whitty worked; Regulatory agencies like the UK Medicines & Healthcare products Regulatory Agency (MHRA)

which gave emergency approval for 'Covid vaccines'; Wellcome Trust; GAVI, the Vaccine Alliance; the Coalition for Epidemic Preparedness Innovations (CEPI); Johns Hopkins University which has compiled the false 'Covid' figures; and the World Economic Forum. A [Nationalfile.com](https://www.nationalfile.com) article said:

Gates has a lot of pull in the medical world, he has a multi-million dollar relationship with Dr. Fauci, and Fauci originally took the Gates line supporting vaccines and casting doubt on [the drug hydroxychloroquine]. Coronavirus response team member Dr. Deborah Birx, appointed by former president Obama to serve as United States Global AIDS Coordinator, also sits on the board of a group that has received billions from Gates' foundation, and Birx reportedly used a disputed Bill Gates-funded model for the White House's Coronavirus effort. Gates is a big proponent for a population lockdown scenario for the Coronavirus outbreak.

Another funder of Moderna is the Defense Advanced Research Projects Agency (DARPA), the technology-development arm of the Pentagon and one of the most sinister organisations on earth. DARPA had a major role with the CIA covert technology-funding operation In-Q-Tel in the development of Google and social media which is now at the centre of global censorship. Fauci and Gates are extremely close and openly admit to talking regularly about 'Covid' policy, but then why wouldn't Gates have a seat at every national 'Covid' table after his Foundation committed \$1.75 billion to the 'fight against Covid-19'. When passed through our Orwellian Translation Unit this means that he has bought and paid for the Cult-driven 'Covid' response worldwide. Research the major 'Covid' response personnel in your own country and you will find the same Gates funding and other connections again and again. Medical and science chiefs following World Health Organization 'policy' sit atop a medical hierarchy in their country of administrators, doctors and nursing staff. These 'subordinates' are told they must work and behave in accordance with the policy delivered from the 'top' of the national 'health' pyramid which is largely the policy delivered by the WHO which is the policy delivered by Gates and the Cult. The whole 'Covid' narrative has been imposed on medical staff by a climate of fear although great numbers don't even need that to comply. They do so through breathtaking levels of ignorance and

include doctors who go through life simply repeating what Big Pharma and their hierarchical masters tell them to say and believe. No wonder Big Pharma 'medicine' is one of the biggest killers on Planet Earth.

The same top-down system of intimidation operates with regard to the Cult Big Pharma cartel which also dictates policy through national and global medical systems in this way. The Cult and Big Pharma agendas are the same because the former controls and owns the latter. 'Health' administrators, doctors, and nursing staff are told to support and parrot the dictated policy or they will face consequences which can include being fired. How sad it's been to see medical staff meekly repeating and imposing Cult policy without question and most of those who can see through the deceit are only willing to speak anonymously off the record. They know what will happen if their identity is known. This has left the courageous few to expose the lies about the 'virus', face masks, overwhelmed hospitals that aren't, and the dangers of the 'vaccine' that isn't a vaccine. When these medical professionals and scientists, some renowned in their field, have taken to the Internet to expose the truth their articles, comments and videos have been deleted by Cult-owned Facebook, Twitter and YouTube. What a real head-shaker to see YouTube videos with leading world scientists and highly qualified medical specialists with an added link underneath to the notorious Cult propaganda website *Wikipedia* to find the 'facts' about the same subject.

HIV – the 'Covid' trial-run

I'll give you an example of the consequences for health and truth that come from censorship and unquestioning belief in official narratives. The story was told by PCR inventor Kary Mullis in his book *Dancing Naked in the Mind Field*. He said that in 1984 he accepted as just another scientific fact that Luc Montagnier of France's Pasteur Institute and Robert Gallo of America's National Institutes of Health had independently discovered that a 'retrovirus' dubbed HIV (human immunodeficiency virus) caused AIDS. They

were, after all, Mullis writes, specialists in retroviruses. This is how the medical and science pyramids work. Something is announced or *assumed* and then becomes an everybody-knows-that purely through repetition of the assumption as if it is fact. Complete crap becomes accepted truth with no supporting evidence and only repetition of the crap. This is how a 'virus' that doesn't exist became the 'virus' that changed the world. The HIV-AIDS fairy story became a multi-billion pound industry and the media poured out propaganda terrifying the world about the deadly HIV 'virus' that caused the lethal AIDS. By then Mullis was working at a lab in Santa Monica, California, to detect retroviruses with his PCR test in blood donations received by the Red Cross. In doing so he asked a virologist where he could find a reference for HIV being the cause of AIDS. 'You don't need a reference,' the virologist said ... '*Everybody knows it.*' Mullis said he wanted to quote a reference in the report he was doing and he said he felt a little funny about not knowing the source of such an important discovery when everyone else seemed to. The virologist suggested he cite a report by the Centers for Disease Control and Prevention (CDC) on morbidity and mortality. Mullis read the report, but it only said that an organism had been identified and did not say how. The report did not identify the original scientific work. Physicians, however, *assumed* (key recurring theme) that if the CDC was convinced that HIV caused AIDS then proof must exist. Mullis continues:

I did computer searches. Neither Montagnier, Gallo, nor anyone else had published papers describing experiments which led to the conclusion that HIV probably caused AIDS. I read the papers in *Science* for which they had become well known as AIDS doctors, but all they had said there was that they had found evidence of a past infection by something which was probably HIV in some AIDS patients.

They found antibodies. Antibodies to viruses had always been considered evidence of past disease, not present disease. Antibodies signaled that the virus had been defeated. The patient had saved himself. There was no indication in these papers that this virus caused a disease. They didn't show that everybody with the antibodies had the disease. In fact they found some healthy people with antibodies.

Mullis asked why their work had been published if Montagnier and Gallo hadn't really found this evidence, and why had they been fighting so hard to get credit for the discovery? He says he was hesitant to write 'HIV is the probable cause of AIDS' until he found published evidence to support that. 'Tens of thousands of scientists and researchers were spending billions of dollars a year doing research based on this idea,' Mullis writes. 'The reason had to be there somewhere; otherwise these people would not have allowed their research to settle into one narrow channel of investigation.' He said he lectured about PCR at numerous meetings where people were always talking about HIV and he asked them how they knew that HIV was the cause of AIDS:

Everyone said something. Everyone had the answer at home, in the office, in some drawer. They all knew, and they would send me the papers as soon as they got back. But I never got any papers. Nobody ever sent me the news about how AIDS was caused by HIV.

Eventually Mullis was able to ask Montagnier himself about the reference proof when he lectured in San Diego at the grand opening of the University of California AIDS Research Center. Mullis says this was the last time he would ask his question without showing anger. Montagnier said he should reference the CDC report. 'I read it', Mullis said, and it didn't answer the question. 'If Montagnier didn't know the answer who the hell did?' Then one night Mullis was driving when an interview came on National Public Radio with Peter Duesberg, a prominent virologist at Berkeley and a California Scientist of the Year. Mullis says he finally understood why he could not find references that connected HIV to AIDS – *there weren't any!* No one had ever proved that HIV causes AIDS even though it had spawned a multi-billion pound global industry and the media was repeating this as fact every day in their articles and broadcasts terrifying the shit out of people about AIDS and giving the impression that a positive test for HIV (see 'Covid') was a death sentence. Duesberg was a threat to the AIDS gravy train and the agenda that underpinned it. He was therefore abused and castigated after he told the Proceedings of the National Academy of Sciences

there was no good evidence implicating the new 'virus'. Editors rejected his manuscripts and his research funds were deleted. Mullis points out that the CDC has defined AIDS as one of more than 30 diseases *if accompanied* by a positive result on a test that detects antibodies to HIV; but those same diseases are not defined as AIDS cases when antibodies are not detected:

If an HIV-positive woman develops uterine cancer, for example, she is considered to have AIDS. If she is not HIV positive, she simply has uterine cancer. An HIV-positive man with tuberculosis has AIDS; if he tests negative he simply has tuberculosis. If he lives in Kenya or Colombia, where the test for HIV antibodies is too expensive, he is simply presumed to have the antibodies and therefore AIDS, and therefore he can be treated in the World Health Organization's clinic. It's the only medical help available in some places. And it's free, because the countries that support WHO are worried about AIDS.

Mullis accuses the CDC of continually adding new diseases (see ever more 'Covid symptoms') to the grand AIDS definition and of virtually doctoring the books to make it appear as if the disease continued to spread. He cites how in 1993 the CDC enormously broadened its AIDS definition and county health authorities were delighted because they received \$2,500 per year from the Federal government for every reported AIDS case. Ladies and gentlemen, I have just described, via Kary Mullis, the 'Covid pandemic' of 2020 and beyond. Every element is the same and it's been pulled off in the same way by the same networks.

The 'Covid virus' exists? Okay – prove it. Er ... still waiting

What Kary Mullis described with regard to 'HIV' has been repeated with 'Covid'. A claim is made that a new, or 'novel', infection has been found and the entire medical system of the world repeats that as fact exactly as they did with HIV and AIDS. No one in the mainstream asks rather relevant questions such as 'How do you know?' and 'Where is your proof?' The SARS-Cov-2 'virus' and the 'Covid-19 disease' became an overnight 'everybody-knows-that'. The origin could be debated and mulled over, but what you could not suggest was that 'SARS-Cov-2' didn't exist. That would be

ridiculous. 'Everybody knows' the 'virus' exists. Well, I didn't for one along with American proper doctors like Andrew Kaufman and Tom Cowan and long-time American proper journalist Jon Rappaport. We dared to pursue the obvious and simple question: 'Where's the evidence?' The overwhelming majority in medicine, journalism and the general public did not think to ask that. After all, *everyone knew* there was a new 'virus'. Everyone was saying so and I heard it on the BBC. Some would eventually argue that the 'deadly virus' was nothing like as deadly as claimed, but few would venture into the realms of its very existence. Had they done so they would have found that the evidence for that claim had gone AWOL as with HIV causes AIDS. In fact, not even that. For something to go AWOL it has to exist in the first place and scientific proof for a 'SARS-Cov-2' can be filed under nothing, nowhere and zilch.

Dr Andrew Kaufman is a board-certified forensic psychiatrist in New York State, a Doctor of Medicine and former Assistant Professor and Medical Director of Psychiatry at SUNY Upstate Medical University, and Medical Instructor of Hematology and Oncology at the Medical School of South Carolina. He also studied biology at the Massachusetts Institute of Technology (MIT) and trained in Psychiatry at Duke University. Kaufman is retired from allopathic medicine, but remains a consultant and educator on natural healing. I saw a video of his very early on in the 'Covid' hoax in which he questioned claims about the 'virus' in the absence of any supporting evidence and with plenty pointing the other way. I did everything I could to circulate his work which I felt was asking the pivotal questions that needed an answer. I can recommend an excellent pull-together interview he did with the website The Last Vagabond entitled *Dr Andrew Kaufman: Virus Isolation, Terrain Theory and Covid-19* and his website is andrewkaufmanmd.com. Kaufman is not only a forensic psychiatrist; he is forensic in all that he does. He always reads original scientific papers, experiments and studies instead of second-third-fourth-hand reports about the 'virus' in the media which are repeating the repeated repetition of the narrative. When he did so with the original Chinese 'virus' papers Kaufman

realised that there was no evidence of a 'SARS-Cov-2'. They had never – from the start – shown it to exist and every repeat of this claim worldwide was based on the accepted existence of proof that was nowhere to be found – see Kary Mullis and HIV. Here we go again.

Let's postulate

Kaufman discovered that the Chinese authorities immediately concluded that the cause of an illness that broke out among about 200 initial patients in Wuhan was a 'new virus' when there were no grounds to make that conclusion. The alleged 'virus' was not isolated from other genetic material in their samples and then shown through a system known as Koch's postulates to be the causative agent of the illness. The world was told that the SARS-Cov-2 'virus' caused a disease they called 'Covid-19' which had 'flu-like' symptoms and could lead to respiratory problems and pneumonia. If it wasn't so tragic it would almost be funny. *'Flu-like' symptoms? Pneumonia? Respiratory disease?* What in CHINA and particularly in Wuhan, one of the most polluted cities in the world with a resulting epidemic of respiratory disease?? Three hundred thousand people get pneumonia in China every year and there are nearly a billion cases worldwide of 'flu-like symptoms'. These have a whole range of causes – including pollution in Wuhan – but no other possibility was credibly considered in late 2019 when the world was told there was a new and deadly 'virus'. The global prevalence of pneumonia and 'flu-like systems' gave the Cult networks unlimited potential to re-diagnose these other causes as the mythical 'Covid-19' and that is what they did from the very start. Kaufman revealed how Chinese medical and science authorities (all subordinates to the Cult-owned communist government) took genetic material from the lungs of only a few of the first patients. The material contained their own cells, bacteria, fungi and other microorganisms living in their bodies. The only way you could prove the existence of the 'virus' and its responsibility for the alleged 'Covid-19' was to isolate the virus from all the other material – a process also known as 'purification' – and

then follow the postulates sequence developed in the late 19th century by German physician and bacteriologist Robert Koch which became the 'gold standard' for connecting an alleged causation agent to a disease:

1. The microorganism (bacteria, fungus, virus, etc.) must be present in every case of the disease and all patients must have the same symptoms. It must also *not be present in healthy individuals*.
2. The microorganism must be isolated from the host with the disease. If the microorganism is a bacteria or fungus it must be grown in a pure culture. If it is a virus, it must be purified (i.e. containing no other material except the virus particles) from a clinical sample.
3. The specific disease, with all of its characteristics, must be reproduced when the infectious agent (the purified virus or a pure culture of bacteria or fungi) is inoculated into a healthy, susceptible host.
4. The microorganism must be recoverable from the experimentally infected host as in step 2.

Not one of these criteria has been met in the case of 'SARS-Cov-2' and 'Covid-19'. Not ONE. EVER. Robert Koch refers to bacteria and not viruses. What are called 'viral particles' are so minute (hence masks are useless by any definition) that they could only be seen after the invention of the electron microscope in the 1930s and can still only be observed through that means. American bacteriologist and virologist Thomas Milton Rivers, the so-called 'Father of Modern Virology' who was very significantly director of the Rockefeller Institute for Medical Research in the 1930s, developed a less stringent version of Koch's postulates to identify 'virus' causation known as 'Rivers criteria'. 'Covid' did not pass that process either. Some even doubt whether any 'virus' can be isolated from other particles containing genetic material in the Koch method. Freedom of Information requests in many countries asking for scientific proof that the 'Covid virus' has been purified and isolated and shown to exist have all come back with a 'we don't have that' and when this happened with a request to the UK Department of Health they added this comment:

However, outside of the scope of the [Freedom of Information Act] and on a discretionary basis, the following information has been advised to us, which may be of interest. Most infectious diseases are caused by viruses, bacteria or fungi. Some bacteria or fungi have the capacity to grow on their own in isolation, for example in colonies on a petri dish. Viruses are different in that they are what we call 'obligate pathogens' – that is, they cannot survive or reproduce without infecting a host ...

... For some diseases, it is possible to establish causation between a microorganism and a disease by isolating the pathogen from a patient, growing it in pure culture and reintroducing it to a healthy organism. These are known as 'Koch's postulates' and were developed in 1882. However, as our understanding of disease and different disease-causing agents has advanced, these are no longer the method for determining causation [Andrew Kaufman asks why in that case are there two published articles falsely claiming to satisfy Koch's postulates].

It has long been known that viral diseases cannot be identified in this way as viruses cannot be grown in 'pure culture'. When a patient is tested for a viral illness, this is normally done by looking for the presence of antigens, or viral genetic code in a host with molecular biology techniques [Kaufman asks how you could know the origin of these chemicals without having a pure culture for comparison].

For the record 'antigens' are defined so:

Invading microorganisms have antigens on their surface that the human body can recognise as being foreign – meaning not belonging to it. When the body recognises a foreign antigen, lymphocytes (white blood cells) produce antibodies, which are complementary in shape to the antigen.

Notwithstanding that this is open to question in relation to 'SARS-Cov-2' the presence of 'antibodies' can have many causes and they are found in people that are perfectly well. Kary Mullis said: 'Antibodies ... had always been considered evidence of past disease, not present disease.'

'Covid' really is a *computer* 'virus'

Where the UK Department of Health statement says 'viruses' are now 'diagnosed' through a 'viral genetic code in a host with molecular biology techniques', they mean ... *the PCR test* which its inventor said cannot test for infectious disease. They have no credible method of connecting a 'virus' to a disease and we will see that there is no scientific proof that any 'virus' causes any disease or there is any such thing as a 'virus' in the way that it is described. Tenacious Canadian researcher Christine Massey and her team made

some 40 Freedom of Information requests to national public health agencies in different countries asking for proof that SARS-CoV-2 has been isolated and not one of them could supply that information. Massey said of her request in Canada: 'Freedom of Information reveals Public Health Agency of Canada has no record of 'SARS-COV-2' isolation performed by anyone, anywhere, ever.' If you accept the comment from the UK Department of Health it's because they can't isolate a 'virus'. Even so many 'science' papers claimed to have isolated the 'Covid virus' until they were questioned and had to admit they hadn't. A reply from the Robert Koch Institute in Germany was typical: 'I am not aware of a paper which purified isolated SARS-CoV-2.' So what the hell was Christian Drosten and his gang using to design the 'Covid' testing protocol that has produced all the illusory Covid' cases and 'Covid' deaths when the head of the Chinese version of the CDC admitted there was a problem right from the start in that the 'virus' had never been isolated/purified? Breathe deeply: What they are calling 'Covid' is actually created by a *computer program* i.e. *they made it up* – er, that's it. They took lung fluid, with many sources of genetic material, from one single person alleged to be infected with Covid-19 by a PCR test which they *claimed*, without clear evidence, contained a 'virus'. They used several computer programs to create a model of a theoretical virus genome sequence from more than fifty-six million small sequences of RNA, each of an unknown source, assembling them like a puzzle with no known solution. The computer filled in the gaps with sequences from bits in the gene bank to make it look like a bat SARS-like coronavirus! A wave of the magic wand and poof, an *in silico* (computer-generated) genome, a scientific fantasy, was created. UK health researcher Dr Kevin Corbett made the same point with this analogy:

... It's like giving you a few bones and saying that's your fish. It could be any fish. Not even a skeleton. Here's a few fragments of bones. That's your fish ... It's all from gene bank and the bits of the virus sequence that weren't there they made up.

They synthetically created them to fill in the blanks. That's what genetics is; it's a code. So it's ABBCCDDDD and you're missing some what you think is EEE so you put it in. It's all

synthetic. You just manufacture the bits that are missing. This is the end result of the geneticization of virology. This is basically a computer virus.

Further confirmation came in an email exchange between British citizen journalist Frances Leader and the government's Medicines & Healthcare Products Regulatory Agency (the Gates-funded MHRA) which gave emergency permission for untested 'Covid vaccines' to be used. The agency admitted that the 'vaccine' is not based on an isolated 'virus', but comes from a *computer-generated model*. Frances Leader was naturally banned from Cult-owned fascist Twitter for making this exchange public. The process of creating computer-generated alleged 'viruses' is called 'in silico' or 'in silicon' – computer chips – and the term 'in silico' is believed to originate with biological experiments using only a computer in 1989. 'Vaccines' involved with 'Covid' are also produced 'in silico' or by computer not a natural process. If the original 'virus' is nothing more than a made-up computer model how can there be 'new variants' of something that never existed in the first place? They are not new 'variants'; they are new *computer models* only minutely different to the original program and designed to further terrify the population into having the 'vaccine' and submitting to fascism. You want a 'new variant'? Click, click, enter – there you go. Tell the medical profession that you have discovered a 'South African variant', 'UK variants' or a 'Brazilian variant' and in the usual HIV-causes-AIDS manner they will unquestioningly repeat it with no evidence whatsoever to support these claims. They will go on television and warn about the dangers of 'new variants' while doing nothing more than repeating what they have been told to be true and knowing that any deviation from that would be career suicide. Big-time insiders will know it's a hoax, but much of the medical community is clueless about the way they are being played and themselves play the public without even being aware they are doing so. What an interesting 'coincidence' that AstraZeneca and Oxford University were conducting 'Covid vaccine trials' in the three countries – the UK, South Africa and Brazil – where the first three 'variants' were claimed to have 'broken out'.

Here's your 'virus' – it's a unicorn

Dr Andrew Kaufman presented a brilliant analysis describing how the 'virus' was imagined into fake existence when he dissected an article published by *Nature* and written by 19 authors detailing *alleged* 'sequencing of a complete viral genome' of the 'new SARS-CoV-2 virus'. This computer-modelled *in silico* genome was used as a template for all subsequent genome sequencing experiments that resulted in the so-called variants which he said now number more than 6,000. The fake genome was constructed from more than 56 million individual short strands of RNA. Those little pieces were assembled into longer pieces by finding areas of overlapping sequences. The computer programs created over two million possible combinations from which the authors simply chose the longest one. They then compared this to a 'bat virus' and the computer 'alignment' rearranged the sequence and filled in the gaps! They called this computer-generated abomination the 'complete genome'. Dr Tom Cowan, a fellow medical author and collaborator with Kaufman, said such computer-generation constitutes scientific fraud and he makes this superb analogy:

Here is an equivalency: A group of researchers claim to have found a unicorn because they found a piece of a hoof, a hair from a tail, and a snippet of a horn. They then add that information into a computer and program it to re-create the unicorn, and they then claim this computer re-creation is the real unicorn. Of course, they had never actually seen a unicorn so could not possibly have examined its genetic makeup to compare their samples with the actual unicorn's hair, hooves and horn.

The researchers claim they decided which is the real genome of SARS-CoV-2 by 'consensus', sort of like a vote. Again, different computer programs will come up with different versions of the imaginary 'unicorn', so they come together as a group and decide which is the real imaginary unicorn.

This is how the 'virus' that has transformed the world was brought into fraudulent 'existence'. Extraordinary, yes, but as the Nazis said the bigger the lie the more will believe it. Cowan, however, wasn't finished and he went on to identify what he called the real blockbuster in the paper. He quotes this section from a paper written

by virologists and published by the CDC and then explains what it means:

Therefore, we examined the capacity of SARS-CoV-2 to infect and replicate in several common primate and human cell lines, including human adenocarcinoma cells (A549), human liver cells (HUH 7.0), and human embryonic kidney cells (HEK-293T). In addition to Vero E6 and Vero CCL81 cells. ... Each cell line was inoculated at high multiplicity of infection and examined 24h post-infection.

No CPE was observed in any of the cell lines except in Vero cells, which grew to greater than 10 to the 7th power at 24 h post-infection. In contrast, HUH 7.0 and 293T showed only modest viral replication, and A549 cells were incompatible with SARS CoV-2 infection.

Cowan explains that when virologists attempt to prove infection they have three possible 'hosts' or models on which they can test. The first was humans. Exposure to humans was generally not done for ethical reasons and has never been done with SARS-CoV-2 or any coronavirus. The second possible host was animals. Cowan said that forgetting for a moment that they never actually use purified virus when exposing animals they do use solutions that they *claim* contain the virus. Exposure to animals has been done with SARS-CoV-2 in an experiment involving mice and this is what they found: *None of the wild (normal) mice got sick*. In a group of genetically-modified mice, a statistically insignificant number lost weight and had slightly bristled fur, but they experienced nothing like the illness called 'Covid-19'. Cowan said the third method – the one they mostly rely on – is to inoculate solutions they *say* contain the virus onto a variety of tissue cultures. This process had never been shown to kill tissue *unless* the sample material was starved of nutrients and poisoned as *part of the process*. Yes, incredibly, in tissue experiments designed to show the 'virus' is responsible for killing the tissue they starve the tissue of nutrients and add toxic drugs including antibiotics and they do not have control studies to see if it's the starvation and poisoning that is degrading the tissue rather than the 'virus' they allege to be in there somewhere. You want me to pinch you? Yep, I understand. Tom Cowan said this about the whole nonsensical farce as he explains what that quote from the CDC paper really means:

The shocking thing about the above quote is that using their own methods, the virologists found that solutions containing SARS-CoV-2 – even in high amounts – were NOT, I repeat NOT, infective to any of the three human tissue cultures they tested. In plain English, this means they proved, on their terms, that this ‘new coronavirus’ is not infectious to human beings. It is ONLY infective to monkey kidney cells, and only then when you add two potent drugs (gentamicin and amphotericin), known to be toxic to kidneys, to the mix.

My friends, read this again and again. These virologists, published by the CDC, performed a clear proof, on their terms, showing that the SARS-CoV-2 virus is harmless to human beings. That is the only possible conclusion, but, unfortunately, this result is not even mentioned in their conclusion. They simply say they can provide virus stocks cultured only on monkey Vero cells, thanks for coming.

Cowan concluded: ‘If people really understood how this “science” was done, I would hope they would storm the gates and demand honesty, transparency and truth.’ Dr Michael Yeadon, former Vice President and Chief Scientific Adviser at drug giant Pfizer has been a vocal critic of the ‘Covid vaccine’ and its potential for multiple harm. He said in an interview in April, 2021, that ‘not one [vaccine] has the virus. He was asked why vaccines normally using a ‘dead’ version of a disease to activate the immune system were not used for ‘Covid’ and instead we had the synthetic methods of the ‘mRNA Covid vaccine’. Yeadon said that to do the former ‘you’d have to have some of [the virus] wouldn’t you?’ He added: ‘No-one’s got any – seriously.’ Yeadon said that surely they couldn’t have fooled the whole world for a year without having a virus, ‘but oddly enough ask around – no one’s got it’. He didn’t know why with all the ‘great labs’ around the world that the virus had not been isolated – ‘Maybe they’ve been too busy running bad PCR tests and vaccines that people don’t need.’ What is today called ‘science’ is not ‘science’ at all. Science is no longer what is, but whatever people can be manipulated to *believe* that it is. Real science has been hijacked by the Cult to dispense and produce the ‘expert scientists’ and contentions that suit the agenda of the Cult. How big-time this has happened with the ‘Covid’ hoax which is entirely based on fake science delivered by fake ‘scientists’ and fake ‘doctors’. The human-caused climate change hoax is also entirely based on fake science delivered by fake ‘scientists’ and fake ‘climate experts’. In both cases real

scientists, climate experts and doctors have their views suppressed and deleted by the Cult-owned science establishment, media and Silicon Valley. This is the 'science' that politicians claim to be 'following' and a common denominator of 'Covid' and climate are Cult psychopaths Bill Gates and his mate Klaus Schwab at the Gates-funded World Economic Forum. But, don't worry, it's all just a coincidence and absolutely nothing to worry about. Zzzzzzzzz.

What is a 'virus' REALLY?

Dr Tom Cowan is one of many contesting the very existence of viruses let alone that they cause disease. This is understandable when there is no scientific evidence for a disease-causing 'virus'. German virologist Dr Stefan Lanka won a landmark case in 2017 in the German Supreme Court over his contention that there is no such thing as a measles virus. He had offered a big prize for anyone who could prove there is and Lanka won his case when someone sought to claim the money. There is currently a prize of more than 225,000 euros on offer from an Isolate Truth Fund for anyone who can prove the isolation of SARS-CoV-2 and its genetic substance. Lanka wrote in an article headed 'The Misconception Called Virus' that scientists think a 'virus' is causing tissue to become diseased and degraded when in fact it is the *processes they are using* which do that – not a 'virus'. Lanka has done an important job in making this point clear as Cowan did in his analysis of the CDC paper. Lanka says that all claims about viruses as disease-causing pathogens are wrong and based on 'easily recognisable, understandable and verifiable misinterpretations.' Scientists believed they were working with 'viruses' in their laboratories when they were really working with 'typical particles of specific dying tissues or cells ...' Lanka said that the tissue decaying process claimed to be caused by a 'virus' still happens when no alleged 'virus' is involved. It's the *process* that does the damage and not a 'virus'. The genetic sample is deprived of nutrients, removed from its energy supply through removal from the body and then doused in toxic antibiotics to remove any bacteria. He confirms again that establishment scientists do not (pinch me)

conduct control experiments to see if this is the case and if they did they would see the claims that 'viruses' are doing the damage is nonsense. He adds that during the measles 'virus' court case he commissioned an independent laboratory to perform just such a control experiment and the result was that the tissues and cells died in the exact same way as with alleged 'infected' material. This is supported by a gathering number of scientists, doctors and researchers who reject what is called 'germ theory' or the belief in the body being infected by contagious sources emitted by other people. Researchers Dawn Lester and David Parker take the same stance in their highly-detailed and sourced book *What Really Makes You Ill – Why everything you thought you knew about disease is wrong* which was recommended to me by a number of medical professionals genuinely seeking the truth. Lester and Parker say there is no provable scientific evidence to show that a 'virus' can be transmitted between people or people and animals or animals and people:

The definition also claims that viruses are the cause of many diseases, as if this has been definitively proven. But this is not the case; there is no original scientific evidence that definitively demonstrates that any virus is the cause of any disease. The burden of proof for any theory lies with those who proposed it; but none of the existing documents provides 'proof' that supports the claim that 'viruses' are pathogens.

Dr Tom Cowan employs one of his clever analogies to describe the process by which a 'virus' is named as the culprit for a disease when what is called a 'virus' is only material released by cells detoxing themselves from infiltration by chemical or radiation poisoning. The tidal wave of technologically-generated radiation in the 'smart' modern world plus all the toxic food and drink are causing this to happen more than ever. Deluded 'scientists' misread this as a gathering impact of what they wrongly label 'viruses'.

Paper can infect houses

Cowan said in an article for davidicke.com – with his tongue only mildly in his cheek – that he believed he had made a tremendous

discovery that may revolutionise science. He had discovered that small bits of paper are alive, 'well alive-ish', can 'infect' houses, and then reproduce themselves inside the house. The result was that this explosion of growth in the paper inside the house causes the house to explode, blowing it to smithereens. His evidence for this new theory is that in the past months he had carefully examined many of the houses in his neighbourhood and found almost no scraps of paper on the lawns and surrounds of the house. There was an occasional stray label, but nothing more. Then he would return to these same houses a week or so later and with a few, not all of them, particularly the old and decrepit ones, he found to his shock and surprise they were littered with stray bits of paper. He knew then that the paper had infected these houses, made copies of itself, and blew up the house. A young boy on a bicycle at one of the sites told him he had seen a demolition crew using dynamite to explode the house the previous week, but Cowan dismissed this as the idle thoughts of silly boys because 'I was on to something big'. He was on to how 'scientists' mistake genetic material in the detoxifying process for something they call a 'virus'. Cowan said of his house and paper story:

If this sounds crazy to you, it's because it should. This scenario is obviously nuts. But consider this admittedly embellished, for effect, current viral theory that all scientists, medical doctors and virologists currently believe.

He takes the example of the 'novel SARS-Cov2' virus to prove the point. First they take someone with an undefined illness called 'Covid-19' and don't even attempt to find any virus in their sputum. Never mind the scientists still describe how this 'virus', which they have not located attaches to a cell receptor, injects its genetic material, in 'Covid's' case, RNA, into the cell. The RNA once inserted exploits the cell to reproduce itself and makes 'thousands, nay millions, of copies of itself ... Then it emerges victorious to claim its next victim':

If you were to look in the scientific literature for proof, actual scientific proof, that uniform SARS-CoV2 viruses have been properly isolated from the sputum of a sick person, that actual spike proteins could be seen protruding from the virus (which has not been found), you would find that such evidence doesn't exist.

If you go looking in the published scientific literature for actual pictures, proof, that these spike proteins or any viral proteins are ever attached to any receptor embedded in any cell membrane, you would also find that no such evidence exists. If you were to look for a video or documented evidence of the intact virus injecting its genetic material into the body of the cell, reproducing itself and then emerging victorious by budding off the cell membrane, you would find that no such evidence exists.

The closest thing you would find is electron micrograph pictures of cellular particles, possibly attached to cell debris, both of which to be seen were stained by heavy metals, a process that completely distorts their architecture within the living organism. This is like finding bits of paper stuck to the blown-up bricks, thereby proving the paper emerged by taking pieces of the bricks on its way out.

The Enders baloney

Cowan describes the 'Covid' story as being just as make-believe as his paper story and he charts back this fantasy to a Nobel Prize winner called John Enders (1897-1985), an American biomedical scientist who has been dubbed 'The Father of Modern Vaccines'. Enders is claimed to have 'discovered' the process of the viral culture which 'proved' that a 'virus' caused measles. Cowan explains how Enders did this 'by using the EXACT same procedure that has been followed by every virologist to find and characterize every new virus since 1954'. Enders took throat swabs from children with measles and immersed them in 2ml of milk. Penicillin (100u/ml) and the antibiotic streptomycin (50,g/ml) were added and the whole mix was centrifuged – rotated at high speed to separate large cellular debris from small particles and molecules as with milk and cream, for example. Cowan says that if the aim is to find little particles of genetic material ('viruses') in the snot from children with measles it would seem that the last thing you would do is mix the snot with other material – milk –that also has genetic material. 'How are you ever going to know whether whatever you found came from the snot or the milk?' He points out that streptomycin is a 'nephrotoxic' or poisonous-to-the-kidney drug. You will see the relevance of that

shortly. Cowan says that it gets worse, much worse, when Enders describes the culture medium upon which the virus 'grows': 'The culture medium consisted of bovine amniotic fluid (90%), beef embryo extract (5%), horse serum (5%), antibiotics and phenol red as an indicator of cell metabolism.' Cowan asks incredulously: 'Did he just say that the culture medium also contained fluids and tissues that are themselves rich sources of genetic material?' The genetic cocktail, or 'medium', is inoculated onto tissue and cells from rhesus monkey *kidney* tissue. This is where the importance of streptomycin comes in and currently-used antimicrobials and other drugs that are *poisonous to kidneys* and used in ALL modern viral cultures (e.g. gentamicin, streptomycin, and amphotericin). Cowan asks: 'How are you ever going to know from this witch's brew where any genetic material comes from as we now have five different sources of rich genetic material in our mix?' Remember, he says, that all genetic material, whether from monkey kidney tissues, bovine serum, milk, etc., is made from the exact same components. The same central question returns: 'How are you possibly going to know that it was the virus that killed the kidney tissue and not the toxic antibiotic and starvation rations on which you are growing the tissue?' John Enders answered the question himself – *you can't*:

A second agent was obtained from an uninoculated culture of monkey kidney cells. The cytopathic changes [death of the cells] it induced in the unstained preparations could not be distinguished with confidence from the viruses isolated from measles.

The death of the cells ('cytopathic changes') happened in exactly the same manner, whether they inoculated the kidney tissue with the measles snot or not, Cowan says. 'This is evidence that the destruction of the tissue, the very proof of viral causation of illness, was not caused by anything in the snot because they saw the same destructive effect when the snot was not even used ... the cytopathic, i.e., cell-killing, changes come from the process of the culture itself, not from any virus in any snot, period.' Enders quotes in his 1957 paper a virologist called Ruckle as reporting similar findings 'and in addition has isolated an agent from monkey kidney tissue that is so

far indistinguishable from human measles virus'. In other words, Cowan says, these particles called 'measles viruses' are simply and clearly breakdown products of the starved and poisoned tissue. For measles 'virus' see all 'viruses' including the so-called 'Covid virus'. Enders, the 'Father of Modern Vaccines', also said:

There is a potential risk in employing cultures of primate cells for the production of vaccines composed of attenuated virus, since the presence of other agents possibly latent in primate tissues cannot be definitely excluded by any known method.

Cowan further quotes from a paper published in the journal *Viruses* in May, 2020, while the 'Covid pandemic' was well underway in the media if not in reality. 'EVs' here refers to particles of genetic debris from our own tissues, such as exosomes of which more in a moment: 'The remarkable resemblance between EVs and viruses has caused quite a few problems in the studies focused on the analysis of EVs released during viral infections.' Later the paper adds that to date a reliable method that can actually guarantee a complete separation (of EVs from viruses) DOES NOT EXIST. This was published at a time when a fairy tale 'virus' was claimed in total certainty to be causing a fairy tale 'viral disease' called 'Covid-19' – a fairy tale that was already well on the way to transforming human society in the image that the Cult has worked to achieve for so long. Cowan concludes his article:

To summarize, there is no scientific evidence that pathogenic viruses exist. What we think of as 'viruses' are simply the normal breakdown products of dead and dying tissues and cells. When we are well, we make fewer of these particles; when we are starved, poisoned, suffocated by wearing masks, or afraid, we make more.

There is no engineered virus circulating and making people sick. People in laboratories all over the world are making genetically modified products to make people sick. These are called vaccines. There is no virome, no 'ecosystem' of viruses, viruses are not 8%, 50% or 100 % of our genetic material. These are all simply erroneous ideas based on the misconception called a virus.

What is 'Covid'? Load of bollocks

The background described here by Cowan and Lanka was emphasised in the first video presentation that I saw by Dr Andrew Kaufman when he asked whether the 'Covid virus' was in truth a natural defence mechanism of the body called 'exosomes'. These are released by cells when in states of toxicity – see the same themes returning over and over. They are released ever more profusely as chemical and radiation toxicity increases and think of the potential effect therefore of 5G alone as its destructive frequencies infest the human energetic information field with a gathering pace (5G went online in Wuhan in 2019 as the 'virus' emerged). I'll have more about this later. Exosomes transmit a warning to the rest of the body that 'Houston, we have a problem'. Kaufman presented images of exosomes and compared them with 'Covid' under an electron microscope and the similarity was remarkable. They both attach to the same cell receptors (*claimed* in the case of 'Covid'), contain the same genetic material in the form of RNA or ribonucleic acid, and both are found in 'viral cell cultures' with damaged or dying cells. James Hildreth MD, President and Chief Executive Officer of the Meharry Medical College at Johns Hopkins, said: 'The virus is fully an exosome in every sense of the word.' Kaufman's conclusion was that there is no 'virus': 'This entire pandemic is a completely manufactured crisis ... there is no evidence of anyone dying from [this] illness.' Dr Tom Cowan and Sally Fallon Morell, authors of *The Contagion Myth*, published a statement with Dr Kaufman in February, 2021, explaining why the 'virus' does not exist and you can read it that in full in the Appendix.

'Virus' theory can be traced to the 'cell theory' in 1858 of German physician Rudolf Virchow (1821-1920) who contended that disease originates from a single cell infiltrated by a 'virus'. Dr Stefan Lanka said that findings and insights with respect to the structure, function and central importance of tissues in the creation of life, which were already known in 1858, comprehensively refute the cell theory. Virchow ignored them. We have seen the part later played by John Enders in the 1950s and Lanka notes that infection theories were only established as a global dogma through the policies and

eugenics of the Third Reich in Nazi Germany (creation of the same Sabbatian cult behind the 'Covid' hoax). Lanka said: 'Before 1933, scientists dared to contradict this theory; after 1933, these critical scientists were silenced'. Dr Tom Cowan's view is that ill-health is caused by too much of something, too little of something, or toxification from chemicals and radiation – not contagion. We must also highlight as a major source of the 'virus' theology a man still called the 'Father of Modern Virology' – Thomas Milton Rivers (1888-1962). There is no way given the Cult's long game policy that it was a coincidence for the 'Father of Modern Virology' to be director of the Rockefeller Institute for Medical Research from 1937 to 1956 when he is credited with making the Rockefeller Institute a leader in 'viral research'. Cult Rockefellerers were the force behind the creation of Big Pharma 'medicine', established the World Health Organisation in 1948, and have long and close associations with the Gates family that now runs the WHO during the pandemic hoax through mega-rich Cult gofer and psychopath Bill Gates.

Only a Renegade Mind can see through all this bullshit by asking the questions that need to be answered, not taking 'no' or prevarication for an answer, and certainly not hiding from the truth in fear of speaking it. Renegade Minds have always changed the world for the better and they will change this one no matter how bleak it may currently appear to be.

CHAPTER SIX

Sequence of deceit

If you tell the truth, you don't have to remember anything
Mark Twain

Against the background that I have laid out this far the sequence that took us from an invented 'virus' in Cult-owned China in late 2019 to the fascist transformation of human society can be seen and understood in a whole new context.

We were told that a deadly disease had broken out in Wuhan and the world media began its campaign (coordinated by behavioural psychologists as we shall see) to terrify the population into unquestioning compliance. We were shown images of Chinese people collapsing in the street which never happened in the West with what was supposed to be the same condition. In the earliest days when alleged cases and deaths were few the fear register was hysterical in many areas of the media and this would expand into the common media narrative across the world. The real story was rather different, but we were never told that. The Chinese government, one of the Cult's biggest centres of global operation, said they had discovered a new illness with flu-like and pneumonia-type symptoms in a city with such toxic air that it is overwhelmed with flu-like symptoms, pneumonia and respiratory disease. Chinese scientists said it was a new – 'novel' – coronavirus which they called Sars-Cov-2 and that it caused a disease they labelled 'Covid-19'. There was no evidence for this and the 'virus' has never to this day been isolated, purified and its genetic code established from that. It

was from the beginning a computer-generated fiction. Stories of Chinese whistleblowers saying the number of deaths was being suppressed or that the 'new disease' was related to the Wuhan bio-lab misdirected mainstream and alternative media into cul-de-sacs to obscure the real truth – there was no 'virus'.

Chinese scientists took genetic material from the lung fluid of just a few people and said they had found a 'new' disease when this material had a wide range of content. There was no evidence for a 'virus' for the very reasons explained in the last two chapters. The 'virus' has never been shown to (a) exist and (b) cause any disease. People were diagnosed on symptoms that are so widespread in Wuhan and polluted China and with a PCR test that can't detect infectious disease. On this farce the whole global scam was sold to the rest of the world which would also diagnose respiratory disease as 'Covid-19' from symptoms alone or with a PCR test not testing for a 'virus'. Flu miraculously disappeared *worldwide* in 2020 and into 2021 as it was redesignated 'Covid-19'. It was really the same old flu with its 'flu-like' symptoms attributed to 'flu-like' 'Covid-19'. At the same time with very few exceptions the Chinese response of draconian lockdown and fascism was the chosen weapon to respond across the West as recommended by the Cult-owned Tedros at the Cult-owned World Health Organization run by the Cult-owned Gates. All was going according to plan. Chinese scientists – everything in China is controlled by the Cult-owned government – compared their contaminated RNA lung-fluid material with other RNA sequences and said it appeared to be just under 80 percent identical to the SARS-CoV-1 'virus' claimed to be the cause of the SARS (severe acute respiratory syndrome) 'outbreak' in 2003. They decreed that because of this the 'new virus' had to be related and they called it SARS-CoV-2. There are some serious problems with this assumption and *assumption* was all it was. Most 'factual' science turns out to be assumptions repeated into everyone-knows-that. A match of under 80-percent is meaningless. Dr Kaufman makes the point that there's a 96 percent genetic correlation between humans and chimpanzees, but 'no one would say our genetic material is part

of the chimpanzee family'. Yet the Chinese authorities were claiming that a much lower percentage, less than 80 percent, proved the existence of a new 'coronavirus'. For goodness sake human DNA is 60 percent similar to a *banana*.

You are feeling sleepy

The entire 'Covid' hoax is a global Psyop, a psychological operation to program the human mind into believing and fearing a complete fantasy. A crucial aspect of this was what *appeared* to happen in Italy. It was all very well streaming out daily images of an alleged catastrophe in Wuhan, but to the Western mind it was still on the other side of the world in a very different culture and setting. A reaction of 'this could happen to me and my family' was still nothing like as intense enough for the mind-doctors. The Cult needed a Western example to push people over that edge and it chose Italy, one of its major global locations going back to the Roman Empire. An Italian 'Covid' crisis was manufactured in a particular area called Lombardy which just happens to be notorious for its toxic air and therefore respiratory disease. Wuhan, China, *déjà vu*. An hysterical media told horror stories of Italians dying from 'Covid' in their droves and how Lombardy hospitals were being overrun by a tidal wave of desperately ill people needing treatment after being struck down by the 'deadly virus'. Here was the psychological turning point the Cult had planned. Wow, if this is happening in Italy, the Western mind concluded, this indeed could happen to me and my family. Another point is that Italian authorities responded by following the Chinese blueprint so vehemently recommended by the Cult-owned World Health Organization. They imposed fascistic lockdowns on the whole country viciously policed with the help of surveillance drones sweeping through the streets seeking out anyone who escaped from mass house arrest. Livelihoods were destroyed and psychology unravelled in the way we have witnessed since in all lockdown countries. Crucial to the plan was that Italy responded in this way to set the precedent of suspending freedom and imposing fascism in a 'Western liberal democracy'. I emphasised in an

animated video explanation on davidicke.com posted in the summer of 2020 how important it was to the Cult to expand the Chinese lockdown model across the West. Without this, and the bare-faced lie that non-symptomatic people could still transmit a 'disease' they didn't have, there was no way locking down the whole population, sick and not sick, could be pulled off. At just the right time and with no evidence Cult operatives and gofers claimed that people without symptoms could pass on the 'disease'. In the name of protecting the 'vulnerable' like elderly people, who lockdowns would kill by the tens of thousands, we had for the first time healthy people told to isolate as well as the sick. The great majority of people who tested positive had no symptoms because there was nothing wrong with them. It was just a trick made possible by a test not testing for the 'virus'.

Months after my animated video the Gates-funded Professor Neil Ferguson at the Gates-funded Imperial College confirmed that I was right. He didn't say it in those terms, naturally, but he did say it. Ferguson will enter the story shortly for his outrageously crazy 'computer models' that led to Britain, the United States and many other countries following the Chinese and now Italian methods of response. Put another way, following the Cult script. Ferguson said that SAGE, the UK government's scientific advisory group which has controlled 'Covid' policy from the start, wanted to follow the Chinese lockdown model (while they all continued to work and be paid), but they wondered if they could possibly, in Ferguson's words, 'get away with it in Europe'. 'Get away with it'? Who the hell do these moronic, arrogant people think they are? This appalling man Ferguson said that once Italy went into national lockdown they realised they, too, could mimic China:

It's a communist one-party state, we said. We couldn't get away with it in Europe, we thought ... and then Italy did it. And we realised we could. Behind this garbage from Ferguson is a simple fact: Doing the same as China in every country was the plan from the start and Ferguson's 'models' would play a central role in achieving that. It's just a coincidence, of course, and absolutely nothing to worry your little head about.

Oops, sorry, our mistake

Once the Italian segment of the Psyop had done the job it was designed to do a very different story emerged. Italian authorities revealed that 99 percent of those who had 'died from Covid-19' in Italy had one, two, three, or more 'co-morbidities' or illnesses and health problems that could have ended their life. The US Centers for Disease Control and Prevention (CDC) published a figure of 94 percent for Americans dying of 'Covid' while having other serious medical conditions – on average two to three (some five or six) other potential causes of death. In terms of death from an unproven 'virus' I say it is 100 percent. The other one percent in Italy and six percent in the US would presumably have died from 'Covid's' flu-like symptoms with a range of other possible causes in conjunction with a test not testing for the 'virus'. Fox News reported that even more startling figures had emerged in one US county in which 410 of 422 deaths attributed to 'Covid-19' had other potentially deadly health conditions. The Italian National Health Institute said later that the average age of people dying with a 'Covid-19' diagnosis in Italy was about 81. Ninety percent were over 70 with ten percent over 90. In terms of other reasons to die some 80 percent had two or more chronic diseases with half having three or more including cardiovascular problems, diabetes, respiratory problems and cancer. Why is the phantom 'Covid-19' said to kill overwhelmingly old people and hardly affect the young? Old people continually die of many causes and especially respiratory disease which you can re-diagnose 'Covid-19' while young people die in tiny numbers by comparison and rarely of respiratory disease. Old people 'die of Covid' because they die of other things that can be redesignated 'Covid' and it really is that simple.

Flu has flown

The blueprint was in place. Get your illusory 'cases' from a test not testing for the 'virus' and redesignate other causes of death as 'Covid-19'. You have an instant 'pandemic' from something that is nothing more than a computer-generated fiction. With near-on a

billion people having 'flu-like' symptoms every year the potential was limitless and we can see why flu quickly and apparently miraculously disappeared *worldwide* by being diagnosed 'Covid-19'. The painfully bloody obvious was explained away by the childlike media in headlines like this in the UK '*Independent*': 'Not a single case of flu detected by Public Health England this year as Covid restrictions suppress virus'. I kid you not. The masking, social distancing and house arrest that did not make the 'Covid virus' disappear somehow did so with the 'flu virus'. Even worse the article, by a bloke called Samuel Lovett, suggested that maybe the masking, sanitising and other 'Covid' measures should continue to keep the flu away. With a ridiculousness that disturbs your breathing (it's 'Covid-19') the said Lovett wrote: 'With widespread social distancing and mask-wearing measures in place throughout the UK, the usual routes of transmission for influenza have been blocked.' He had absolutely no evidence to support that statement, but look at the consequences of him acknowledging the obvious. With flu not disappearing at all and only being relabelled 'Covid-19' he would have to contemplate that 'Covid' was a hoax on a scale that is hard to imagine. You need guts and commitment to truth to even go there and that's clearly something Samuel Lovett does not have in abundance. He would never have got it through the editors anyway.

Tens of thousands die in the United States alone every winter from flu including many with pneumonia complications. CDC figures record *45 million* Americans diagnosed with flu in 2017-2018 of which 61,000 died and some reports claim 80,000. Where was the same hysteria then that we have seen with 'Covid-19'? Some 250,000 Americans are admitted to hospital with pneumonia every year with about 50,000 cases proving fatal. About 65 million suffer respiratory disease every year and three million deaths makes this the third biggest cause of death worldwide. You only have to redesignate a portion of all these people 'Covid-19' and you have an instant global pandemic or the *appearance* of one. Why would doctors do this? They are told to do this and all but a few dare not refuse those who must be obeyed. Doctors in general are not researching their own

knowledge and instead take it direct and unquestioned from the authorities that own them and their careers. The authorities say they must now diagnose these symptoms 'Covid-19' and not flu, or whatever, and they do it. Dark suits say put 'Covid-19' on death certificates no matter what the cause of death and the doctors do it. Renegade Minds don't fall for the illusion that doctors and medical staff are all highly-intelligent, highly-principled, seekers of medical truth. *Some are*, but not the majority. They are repeaters, gofers, and yes sir, no sir, purveyors of what the system demands they purvey. The 'Covid' con is not merely confined to diseases of the lungs. Instructions to doctors to put 'Covid-19' on death certificates for anyone dying of *anything* within 28 days (or much more) of a positive test not testing for the 'virus' opened the floodgates. The term dying *with* 'Covid' and not *of* 'Covid' was coined to cover the truth. Whether it was a *with* or an *of* they were all added to the death numbers attributed to the 'deadly virus' compiled by national governments and globally by the Gates-funded Johns Hopkins operation in the United States that was so involved in those 'pandemic' simulations. Fraudulent deaths were added to the ever-growing list of fraudulent 'cases' from false positives from a false test. No wonder Professor Walter Ricciardi, scientific advisor to the Italian minister of health, said after the Lombardy hysteria had done its job that 'Covid' death rates were due to Italy having the second oldest population in the world and to *how hospitals record deaths*:

The way in which we code deaths in our country is very generous in the sense that all the people who die in hospitals with the coronavirus are deemed to be dying of the coronavirus. On re-evaluation by the National Institute of Health, only 12 per cent of death certificates have shown a direct causality from coronavirus, while 88 per cent of patients who have died have at least one pre-morbidity – many had two or three.

This is extraordinary enough when you consider the propaganda campaign to use Italy to terrify the world, but how can they even say twelve percent were genuine when the 'virus' has not been shown to exist, its 'code' is a computer program, and diagnosis comes from a test not testing for it? As in China, and soon the world, 'Covid-19' in

Italy was a redesignation of diagnosis. Lies and corruption were to become the real 'pandemic' fuelled by a pathetically-compliant medical system taking its orders from the tiny few at the top of their national hierarchy who answered to the World Health Organization which answers to Gates and the Cult. Doctors were told – ordered – to diagnose a particular set of symptoms 'Covid-19' and put that on the death certificate for any cause of death if the patient had tested positive with a test not testing for the virus or had 'Covid' symptoms like the flu. The United States even introduced big financial incentives to manipulate the figures with hospitals receiving £4,600 from the Medicare system for diagnosing someone with regular pneumonia, \$13,000 if they made the diagnosis from the same symptoms 'Covid-19' pneumonia, and \$39,000 if they put a 'Covid' diagnosed patient on a ventilator that would almost certainly kill them. A few – painfully and pathetically few – medical whistleblowers revealed (before Cult-owned YouTube deleted their videos) that they had been instructed to 'let the patient crash' and put them straight on a ventilator instead of going through a series of far less intrusive and dangerous methods as they would have done before the pandemic hoax began and the financial incentives kicked in. We are talking cold-blooded murder given that ventilators are so damaging to respiratory systems they are usually the last step before heaven awaits. Renegade Minds never fall for the belief that people in white coats are all angels of mercy and cannot be full-on psychopaths. I have explained in detail in *The Answer* how what I am describing here played out across the world coordinated by the World Health Organization through the medical hierarchies in almost every country.

Medical scientist calls it

Information about the non-existence of the 'virus' began to emerge for me in late March, 2020, and mushroomed after that. I was sent an email by Sir Julian Rose, a writer, researcher, and organic farming promotor, from a medical scientist friend of his in the United States. Even at that early stage in March the scientist was able to explain

how the 'Covid' hoax was being manipulated. He said there were no reliable tests for a specific 'Covid-19 virus' and nor were there any reliable agencies or media outlets for reporting numbers of actual 'Covid-19' cases. We have seen in the long period since then that he was absolutely right. 'Every action and reaction to Covid-19 is based on totally flawed data and we simply cannot make accurate assessments,' he said. Most people diagnosed with 'Covid-19' were showing nothing more than cold and flu-like symptoms 'because most coronavirus strains *are* nothing more than cold/flu-like symptoms'. We had farcical situations like an 84-year-old German man testing positive for 'Covid-19' and his nursing home ordered to quarantine only for him to be found to have a common cold. The scientist described back then why PCR tests and what he called the 'Mickey Mouse test kits' were useless for what they were claimed to be identifying. 'The idea these kits can isolate a specific virus like Covid-19 is nonsense,' he said. Significantly, he pointed out that 'if you want to create a totally false panic about a totally false pandemic – pick a coronavirus'. This is exactly what the Cult-owned Gates, World Economic Forum and Johns Hopkins University did with their Event 201 'simulation' followed by their real-life simulation called the 'pandemic'. The scientist said that all you had to do was select the sickest of people with respiratory-type diseases in a single location – 'say Wuhan' – and administer PCR tests to them. You can then claim that anyone showing 'viral sequences' similar to a coronavirus 'which will inevitably be quite a few' is suffering from a 'new' disease:

Since you already selected the sickest flu cases a fairly high proportion of your sample will go on to die. You can then say this 'new' virus has a CFR [case fatality rate] higher than the flu and use this to infuse more concern and do more tests which will of course produce more 'cases', which expands the testing, which produces yet more 'cases' and so on and so on. Before long you have your 'pandemic', and all you have done is use a simple test kit trick to convert the worst flu and pneumonia cases into something new that doesn't ACTUALLY EXIST [my emphasis].

He said that you then 'just run the same scam in other countries' and make sure to keep the fear message running high 'so that people

will feel panicky and less able to think critically'. The only problem to overcome was the fact *there is no* actual new deadly pathogen and only regular sick people. This meant that deaths from the 'new deadly pathogen' were going to be way too low for a real new deadly virus pandemic, but he said this could be overcome in the following ways – all of which would go on to happen:

1. You can claim this is just the beginning and more deaths are imminent [you underpin this with fantasy 'computer projections']. Use this as an excuse to quarantine everyone and then claim the quarantine prevented the expected millions of dead.
2. You can [say that people] 'minimizing' the dangers are irresponsible and bully them into not talking about numbers.
3. You can talk crap about made up numbers hoping to blind people with pseudoscience.
4. You can start testing well people (who, of course, will also likely have shreds of coronavirus [RNA] in them) and thus inflate your 'case figures' with 'asymptomatic carriers' (you will of course have to spin that to sound deadly even though any virologist knows the more symptom-less cases you have the less deadly is your pathogen).

The scientist said that if you take these simple steps 'you can have your own entirely manufactured pandemic up and running in weeks'. His analysis made so early in the hoax was brilliantly prophetic of what would actually unfold. Pulling all the information together in these recent chapters we have this is simple 1, 2, 3, of how you can delude virtually the entire human population into believing in a 'virus' that doesn't exist:

- A 'Covid case' is someone who tests positive with a test not testing for the 'virus'.
- A 'Covid death' is someone who dies of *any cause* within 28 days (or much longer) of testing positive with a test not testing for the 'virus'.
- Asymptomatic means there is nothing wrong with you, but they claim you can pass on what you don't have to justify locking

down (quarantining) healthy people in totality.

The foundations of the hoax are that simple. A study involving ten million people in Wuhan, published in November, 2020, demolished the whole lie about those without symptoms passing on the 'virus'. They found '300 asymptomatic cases' and traced their contacts to find that not one of them was detected with the 'virus'.

'Asymptomatic' patients and their contacts were isolated for no less than two weeks and nothing changed. I know it's all crap, but if you are going to claim that those without symptoms can transmit 'the virus' then you must produce evidence for that and they never have. Even World Health Organization official Dr Maria Van Kerkhove, head of the emerging diseases and zoonosis unit, said as early as June, 2020, that she doubted the validity of asymptomatic transmission. She said that 'from the data we have, it still seems to be rare that an asymptomatic person actually transmits onward to a secondary individual' and by 'rare' she meant that she couldn't cite any case of asymptomatic transmission.

The Ferguson factor

The problem for the Cult as it headed into March, 2020, when the script had lockdown due to start, was that despite all the manipulation of the case and death figures they still did not have enough people alleged to have died from 'Covid' to justify mass house arrest. This was overcome in the way the scientist described: 'You can claim this is just the beginning and more deaths are imminent ... Use this as an excuse to quarantine everyone and then claim the quarantine prevented the expected millions of dead.' Enter one Professor Neil Ferguson, the Gates-funded 'epidemiologist' at the Gates-funded Imperial College in London. Ferguson is Britain's Christian Drosten in that he has a dire record of predicting health outcomes, but is still called upon to advise government on the next health outcome when another 'crisis' comes along. This may seem to be a strange and ridiculous thing to do. Why would you keep turning for policy guidance to people who have a history of being

monumentally wrong? Ah, but it makes sense from the Cult point of view. These 'experts' keep on producing predictions that suit the Cult agenda for societal transformation and so it was with Neil Ferguson as he revealed his horrific (and clearly insane) computer model predictions that allowed lockdowns to be imposed in Britain, the United States and many other countries. Ferguson does not have even an A-level in biology and would appear to have no formal training in computer modelling, medicine or epidemiology, according to Derek Winton, an MSc in Computational Intelligence. He wrote an article somewhat aghast at what Ferguson did which included taking no account of respiratory disease 'seasonality' which means it is far worse in the winter months. Who would have thought that respiratory disease could be worse in the winter? Well, certainly not Ferguson.

The massively China-connected Imperial College and its bizarre professor provided the excuse for the long-incubated Chinese model of human control to travel westward at lightning speed. Imperial College confirms on its website that it collaborates with the Chinese Research Institute; publishes more than 600 research papers every year with Chinese research institutions; has 225 Chinese staff; 2,600 Chinese students – the biggest international group; 7,000 former students living in China which is the largest group outside the UK; and was selected for a tour by China's President Xi Jinping during his state visit to the UK in 2015. The college takes major donations from China and describes itself as the UK's number one university collaborator with Chinese research institutions. The China communist/fascist government did not appear phased by the woeful predictions of Ferguson and Imperial when during the lockdown that Ferguson induced the college signed a five-year collaboration deal with China tech giant Huawei that will have Huawei's indoor 5G network equipment installed at the college's West London tech campus along with an 'AI cloud platform'. The deal includes Chinese sponsorship of Imperial's Venture Catalyst entrepreneurship competition. Imperial is an example of the enormous influence the Chinese government has within British and North American

universities and research centres – and further afield. Up to 200 academics from more than a dozen UK universities are being investigated on suspicion of ‘unintentionally’ helping the Chinese government build weapons of mass destruction by ‘transferring world-leading research in advanced military technology such as aircraft, missile designs and cyberweapons’. Similar scandals have broken in the United States, but it’s all a coincidence. Imperial College serves the agenda in many other ways including the promotion of every aspect of the United Nations Agenda 21/2030 (the Great Reset) and produced computer models to show that human-caused ‘climate change’ is happening when in the real world it isn’t. Imperial College is driving the climate agenda as it drives the ‘Covid’ agenda (both Cult hoaxes) while Patrick Vallance, the UK government’s Chief Scientific Adviser on ‘Covid’, was named Chief Scientific Adviser to the UN ‘climate change’ conference known as COP26 hosted by the government in Glasgow, Scotland. ‘Covid’ and ‘climate’ are fundamentally connected.

Professor Woeful

From Imperial’s bosom came Neil Ferguson still advising government despite his previous disasters and it was announced early on that he and other key people like UK Chief Medical Adviser Chris Whitty had caught the ‘virus’ as the propaganda story was being sold. Somehow they managed to survive and we had Prime Minister Boris Johnson admitted to hospital with what was said to be a severe version of the ‘virus’ in this same period. His whole policy and demeanour changed when he returned to Downing Street. It’s a small world with these government advisors – especially in their communal connections to Gates – and Ferguson had partnered with Whitty to write a paper called ‘Infectious disease: Tough choices to reduce Ebola transmission’ which involved another scare-story that didn’t happen. Ferguson’s ‘models’ predicted that up to 150,000 could die from ‘mad cow disease’, or BSE, and its version in sheep if it was transmitted to humans. BSE was not transmitted and instead triggered by an organophosphate pesticide used to treat a pest on

cows. Fewer than 200 deaths followed from the human form. Models by Ferguson and his fellow incompetents led to the unnecessary culling of millions of pigs, cattle and sheep in the foot and mouth outbreak in 2001 which destroyed the lives and livelihoods of farmers and their families who had often spent decades building their herds and flocks. Vast numbers of these animals did not have foot and mouth and had no contact with the infection. Another 'expert' behind the cull was Professor Roy Anderson, a computer modeller at Imperial College specialising in the epidemiology of *human*, not animal, disease. Anderson has served on the Bill and Melinda Gates Grand Challenges in Global Health advisory board and chairs another Gates-funded organisation. Gates is everywhere.

In a precursor to the 'Covid' script Ferguson backed closing schools 'for prolonged periods' over the swine flu 'pandemic' in 2009 and said it would affect a third of the world population if it continued to spread at the speed he claimed to be happening. His mates at Imperial College said much the same and a news report said: 'One of the authors, the epidemiologist and disease modeller Neil Ferguson, who sits on the World Health Organisation's emergency committee for the outbreak, said the virus had "full pandemic potential".' Professor Liam Donaldson, the Chris Whitty of his day as Chief Medical Officer, said the worst case could see 30 percent of the British people infected by swine flu with 65,000 dying. Ferguson and Donaldson were indeed proved correct when at the end of the year the number of deaths attributed to swine flu was 392. The term 'expert' is rather liberally applied unfortunately, not least to complete idiots. Swine flu 'projections' were great for GlaxoSmithKline (GSK) as millions rolled in for its Pandemrix influenza vaccine which led to brain damage with children most affected. The British government (taxpayers) paid out more than £60 million in compensation after GSK was given immunity from prosecution. Yet another 'Covid' déjà vu. Swine flu was supposed to have broken out in Mexico, but Dr Wolfgang Wodarg, a German doctor, former member of parliament and critic of the 'Covid' hoax, observed 'the spread of swine flu' in Mexico City at the time. He

said: 'What we experienced in Mexico City was a very mild flu which did not kill more than usual – which killed even fewer people than usual.' Hyping the fear against all the facts is not unique to 'Covid' and has happened many times before. Ferguson is reported to have over-estimated the projected death toll of bird flu (H5N1) by some three million-fold, but bird flu vaccine makers again made a killing from the scare. This is some of the background to the Neil Ferguson who produced the perfectly-timed computer models in early 2020 predicting that half a million people would die in Britain without draconian lockdown and 2.2 million in the United States. Politicians panicked, people panicked, and lockdowns of alleged short duration were instigated to 'flatten the curve' of cases gleaned from a test not testing for the 'virus'. I said at the time that the public could forget the 'short duration' bit. This was an agenda to destroy the livelihoods of the population and force them into mass control through dependency and there was going to be nothing 'short' about it. American researcher Daniel Horowitz described the consequences of the 'models' spewed out by Gates-funded Ferguson and Imperial College:

What led our government and the governments of many other countries into panic was a single Imperial College of UK study, funded by global warming activists, that predicted 2.2 million deaths if we didn't lock down the country. In addition, the reported 8-9% death rate in Italy scared us into thinking there was some other mutation of this virus that they got, which might have come here.

Together with the fact that we were finally testing and had the ability to actually report new cases, we thought we were headed for a death spiral. But again ... we can't flatten a curve if we don't know when the curve started.

How about it *never* started?

Giving them what they want

An investigation by German news outlet *Welt Am Sonntag* (*World on Sunday*) revealed how in March, 2020, the German government gathered together 'leading scientists from several research institutes and universities' and 'together, they were to produce a [modelling]

paper that would serve as legitimization for further tough political measures'. The Cult agenda was justified by computer modelling not based on evidence or reality; it was specifically constructed to justify the Cult demand for lockdowns all over the world to destroy the independent livelihoods of the global population. All these modellers and everyone responsible for the 'Covid' hoax have a date with a trial like those in Nuremberg after World War Two when Nazis faced the consequences of their war crimes. These corrupt-beyond-belief 'modellers' wrote the paper according to government instructions and it said that if lockdown measures were lifted then up to one million Germans would die from 'Covid-19' adding that some would die 'agonizingly at home, gasping for breath' unable to be treated by hospitals that couldn't cope. All lies. No matter – it gave the Cult all that it wanted. What did long-time government 'modeller' Neil Ferguson say? If the UK and the United States didn't lockdown half a million would die in Britain and 2.2 million Americans. Anyone see a theme here? 'Modellers' are such a crucial part of the lockdown strategy that we should look into their background and follow the money. Researcher Rosemary Frei produced an excellent article headlined 'The Modelling-paper Mafiosi'. She highlights a guy called John Edmunds, a British epidemiologist, and professor in the Faculty of Epidemiology and Population Health at the London School of Hygiene & Tropical Medicine. He studied at Imperial College. Edmunds is a member of government 'Covid' advisory bodies which have been dictating policy, the New and Emerging Respiratory Virus Threats Advisory Group (NERVTAG) and the Scientific Advisory Group for Emergencies (SAGE).

Ferguson, another member of NERVTAG and SAGE, led the way with the original 'virus' and Edmunds has followed in the 'variant' stage and especially the so-called UK or Kent variant known as the 'Variant of Concern' (VOC) B.1.1.7. He said in a co-written report for the Centre for Mathematical modelling of Infectious Diseases at the London School of Hygiene and Tropical Medicine, with input from the Centre's 'Covid-19' Working Group, that there was 'a realistic

possibility that VOC B.1.1.7 is associated with an increased risk of death compared to non-VOC viruses'. Fear, fear, fear, get the vaccine, fear, fear, fear, get the vaccine. Rosemary Frei reveals that almost all the paper's authors and members of the modelling centre's 'Covid-19' Working Group receive funding from the Bill and Melinda Gates Foundation and/or the associated Gates-funded Wellcome Trust. The paper was published by e-journal *Medrx* which only publishes papers not peer-reviewed and the journal was established by an organisation headed by Facebook's Mark Zuckerberg and his missus. What a small world it is. Frei discovered that Edmunds is on the Scientific Advisory Board of the Coalition for Epidemic Preparedness Innovations (CEPI) which was established by the Bill and Melinda Gates Foundation, Klaus Schwab's Davos World Economic Forum and Big Pharma giant Wellcome. CEPI was 'launched in Davos [in 2017] to develop vaccines to stop future epidemics', according to its website. 'Our mission is to accelerate the development of vaccines against emerging infectious diseases and enable equitable access to these vaccines for people during outbreaks.' What kind people they are. Rosemary Frei reveals that Public Health England (PHE) director Susan Hopkins is an author of her organisation's non-peer-reviewed reports on 'new variants'. Hopkins is a professor of infectious diseases at London's Imperial College which is gifted tens of millions of dollars a year by the Bill and Melinda Gates Foundation. Gates-funded modelling disaster Neil Ferguson also co-authors Public Health England reports and he spoke in December, 2020, about the potential danger of the B.1.1.7. 'UK variant' promoted by Gates-funded modeller John Edmunds. When I come to the 'Covid vaccines' the 'new variants' will be shown for what they are – bollocks.

Connections, connections

All these people and modellers are lockdown-obsessed or, put another way, they demand what the Cult demands. Edmunds said in January, 2021, that to ease lockdowns too soon would be a disaster and they had to 'vaccinate much, much, much more widely than the

elderly'. Rosemary Frei highlights that Edmunds is married to Jeanne Pimenta who is described in a LinkedIn profile as director of epidemiology at GlaxoSmithKline (GSK) and she held shares in the company. Patrick Vallance, co-chair of SAGE and the government's Chief Scientific Adviser, is a former executive of GSK and has a deferred bonus of shares in the company worth £600,000. GSK has serious business connections with Bill Gates and is collaborating with mRNA-'vaccine' company CureVac to make 'vaccines' for the new variants that Edmunds is talking about. GSK is planning a 'Covid vaccine' with drug giant Sanofi. Puppets Prime Minister Boris Johnson announced in the spring of 2021 that up to 60 million vaccine doses were to be made at the GSK facility at Barnard Castle in the English North East. Barnard Castle, with a population of just 6,000, was famously visited in breach of lockdown rules in April, 2020, by Johnson aide Dominic Cummings who said that he drove there 'to test his eyesight' before driving back to London. Cummings would be better advised to test his integrity – not that it would take long. The GSK facility had nothing to do with his visit then although I'm sure Patrick Vallance would have been happy to arrange an introduction and some tea and biscuits. Ruthless psychopath Gates has made yet another fortune from vaccines in collaboration with Big Pharma companies and gushes at the phenomenal profits to be made from vaccines – more than a 20-to-1 return as he told one interviewer. Gates also tweeted in December, 2019, with the foreknowledge of what was coming: 'What's next for our foundation? I'm particularly excited about what the next year could mean for one of the best buys in global health: vaccines.'

Modeller John Edmunds is a big promotor of vaccines as all these people appear to be. He's the dean of the London School of Hygiene & Tropical Medicine's Faculty of Epidemiology and Population Health which is primarily funded by the Bill and Melinda Gates Foundation and the Gates-established and funded GAVI vaccine alliance which is the Gates vehicle to vaccinate the world. The organisation Doctors Without Borders has described GAVI as being 'aimed more at supporting drug-industry desires to promote new

products than at finding the most efficient and sustainable means for fighting the diseases of poverty'. But then that's why the psychopath Gates created it. John Edmunds said in a video that the London School of Hygiene & Tropical Medicine is involved in every aspect of vaccine development including large-scale clinical trials. He contends that mathematical modelling can show that vaccines protect individuals and society. That's on the basis of shit in and shit out, I take it. Edmunds serves on the UK Vaccine Network as does Ferguson and the government's foremost 'Covid' adviser, the grim-faced, dark-eyed Chris Whitty. The Vaccine Network says it works 'to support the government to identify and shortlist targeted investment opportunities for the most promising vaccines and vaccine technologies that will help combat infectious diseases with epidemic potential, and to address structural issues related to the UK's broader vaccine infrastructure'. Ferguson is acting Director of the Imperial College Vaccine Impact Modelling Consortium which has funding from the Bill and Melina Gates Foundation and the Gates-created GAVI 'vaccine alliance'. Anyone wonder why these characters see vaccines as the answer to every problem? Ferguson is wildly enthusiastic in his support for GAVI's campaign to vaccinate children en masse in poor countries. You would expect someone like Gates who has constantly talked about the need to reduce the population to want to fund vaccines to keep more people alive. I'm sure that's why he does it. The John Edmunds London School of Hygiene & Tropical Medicine (LSHTM) has a Vaccines Manufacturing Innovation Centre which develops, tests and commercialises vaccines. Rosemary Frei writes:

The vaccines centre also performs affiliated activities like combating 'vaccine hesitancy'. The latter includes the Vaccine Confidence Project. The project's stated purpose is, among other things, 'to provide analysis and guidance for early response and engagement with the public to ensure sustained confidence in vaccines and immunisation'. The Vaccine Confidence Project's director is LSHTM professor Heidi Larson. For more than a decade she's been researching how to combat vaccine hesitancy.

How the bloody hell can blokes like John Edmunds and Neil Ferguson with those connections and financial ties model 'virus' case

and death projections for the government and especially in a way that gives their paymasters like Gates exactly what they want? It's insane, but this is what you find throughout the world.

'Covid' is not dangerous, oops, wait, yes it is

Only days before Ferguson's nightmare scenario made Jackboot Johnson take Britain into a China-style lockdown to save us from a deadly 'virus' the UK government website gov.uk was reporting something very different to Ferguson on a page of official government guidance for 'high consequence infectious diseases (HCID)'. It said this about 'Covid-19':

As of 19 March 2020, COVID-19 is no longer considered to be a high consequence infectious diseases (HCID) in the UK [my emphasis]. The 4 nations public health HCID group made an interim recommendation in January 2020 to classify COVID-19 as an HCID. This was based on consideration of the UK HCID criteria about the virus and the disease with information available during the early stages of the outbreak.

Now that more is known about COVID-19, the public health bodies in the UK have reviewed the most up to date information about COVID-19 against the UK HCID criteria. They have determined that several features have now changed; in particular, more information is available about mortality rates (low overall), and there is now greater clinical awareness and a specific and sensitive laboratory test, the availability of which continues to increase. The Advisory Committee on Dangerous Pathogens (ACDP) is also of the opinion that COVID-19 should no longer be classified as an HCID.

Soon after the government had been exposed for downgrading the risk they upgraded it again and everyone was back to singing from the same Cult hymn book. Ferguson and his fellow Gates clones indicated that lockdowns and restrictions would have to continue until a Gates-funded vaccine was developed. Gates said the same because Ferguson and his like were repeating the Gates script which is the Cult script. 'Flatten the curve' became an ongoing nightmare of continuing lockdowns with periods in between of severe restrictions in pursuit of destroying independent incomes and had nothing to do with protecting health about which the Cult gives not a shit. Why wouldn't Ferguson be pushing a vaccine 'solution' when he's owned by vaccine-obsessive Gates who makes a fortune from them and

when Ferguson heads the Vaccine Impact Modelling Consortium at Imperial College funded by the Gates Foundation and GAVI, the 'vaccine alliance', created by Gates as his personal vaccine promotion operation? To compound the human catastrophe that Ferguson's 'models' did so much to create he was later exposed for breaking his own lockdown rules by having sexual liaisons with his married girlfriend Antonia Staats at his home while she was living at another location with her husband and children. Staats was a 'climate' activist and senior campaigner at the Soros-funded Avaaz which I wouldn't trust to tell me that grass is green. Ferguson had to resign as a government advisor over this hypocrisy in May, 2020, but after a period of quiet he was back being quoted by the ridiculous media on the need for more lockdowns and a vaccine rollout. Other government-advising 'scientists' from Imperial College held the fort in his absence and said lockdown could be indefinite until a vaccine was found. The Cult script was being sung by the payrolled choir. I said there was no intention of going back to 'normal' when the 'vaccine' came because the 'vaccine' is part of a very different agenda that I will discuss in Human 2.0. Why would the Cult want to let the world go back to normal when destroying that normal forever was the whole point of what was happening? House arrest, closing businesses and schools through lockdown, (un)social distancing and masks all followed the Ferguson fantasy models. Again as I predicted (these people are so predictable) when the 'vaccine' arrived we were told that house arrest, lockdown, (un)social distancing and masks would still have to continue. I will deal with the masks in the next chapter because they are of fundamental importance.

Where's the 'pandemic'?

Any mildly in-depth assessment of the figures revealed what was really going on. Cult-funded and controlled organisations still have genuine people working within them such is the number involved. So it is with Genevieve Briand, assistant program director of the Applied Economics master's degree program at Johns Hopkins

University. She analysed the impact that 'Covid-19' had on deaths from *all* causes in the United States using official data from the CDC for the period from early February to early September, 2020. She found that allegedly 'Covid' *related*-deaths exceeded those from heart disease which she found strange with heart disease always the biggest cause of fatalities. Her research became even more significant when she noted the sudden decline in 2020 of *all* non-'Covid' deaths: 'This trend is completely contrary to the pattern observed in all previous years ... the total decrease in deaths by other causes almost exactly equals the increase in deaths by Covid-19.' This was such a game, set and match in terms of what was happening that Johns Hopkins University deleted the article on the grounds that it 'was being used to support false and dangerous inaccuracies about the impact of the pandemic'. No – because it exposed the scam from official CDC figures and this was confirmed when those figures were published in January, 2021. Here we can see the effect of people dying from heart attacks, cancer, road accidents and gunshot wounds – *anything* – having 'Covid-19' on the death certificate along with those diagnosed from 'symptoms' who had even not tested positive with a test not testing for the 'virus'. I am not kidding with the gunshot wounds, by the way. Brenda Bock, coroner in Grand County, Colorado, revealed that two gunshot victims tested positive for the 'virus' within the previous 30 days and were therefore classified as 'Covid deaths'. Bock said: 'These two people had tested positive for Covid, but that's not what killed them. A gunshot wound is what killed them.' She said she had not even finished her investigation when the state listed the gunshot victims as deaths due to the 'virus'. The death and case figures for 'Covid-19' are an absolute joke and yet they are repeated like parrots by the media, politicians and alleged medical 'experts'. The official Cult narrative is the only show in town.

Genevieve Briand found that deaths from all causes were not exceptional in 2020 compared with previous years and a Spanish magazine published figures that said the same about Spain which was a 'Covid' propaganda hotspot at one point. *Discovery Salud*, a

health and medicine magazine, quoted government figures which showed how 17,000 *fewer* people died in Spain in 2020 than in 2019 and more than 26,000 fewer than in 2018. The age-standardised mortality rate for England and Wales when age distribution is taken into account was significantly lower in 2020 than the 1970s, 80s and 90s, and was only the ninth highest since 2000. Where is the 'pandemic'?

Post mortems and autopsies virtually disappeared for 'Covid' deaths amid claims that 'virus-infected' bodily fluids posed a risk to those carrying out the autopsy. This was rejected by renowned German pathologist and forensic doctor Klaus Püschel who said that he and his staff had by then done 150 autopsies on 'Covid' patients with no problems at all. He said they were needed to know why some 'Covid' patients suffered blood clots and not severe respiratory infections. The 'virus' is, after all, called SARS or 'severe acute respiratory syndrome'. I highlighted in the spring of 2020 this phenomenon and quoted New York intensive care doctor Cameron Kyle-Sidell who posted a soon deleted YouTube video to say that they had been told to prepare to treat an infectious disease called 'Covid-19', but that was not what they were dealing with. Instead he likened the lung condition of the most severely ill patients to what you would expect with cabin depressurisation in a plane at 30,000 feet or someone dropped on the top of Everest without oxygen or acclimatisation. I have never said this is not happening to a small minority of alleged 'Covid' patients – I am saying this is not caused by a phantom 'contagious virus'. Indeed Kyle-Sidell said that 'Covid-19' was not the disease they were told was coming their way. 'We are operating under a medical paradigm that is untrue,' he said, and he believed they were treating the wrong disease: 'These people are being slowly starved of oxygen.' Patients would take off their oxygen masks in a state of fear and stress and while they were blue in the face on the brink of death. They did not look like patients dying of pneumonia. You can see why they don't want autopsies when their virus doesn't exist and there is another condition in some people that they don't wish to be uncovered. I should add here that

the 5G system of millimetre waves was being rapidly introduced around the world in 2020 and even more so now as they fire 5G at the Earth from satellites. At 60 gigahertz within the 5G range that frequency interacts with the oxygen molecule and stops people breathing in sufficient oxygen to be absorbed into the bloodstream. They are installing 5G in schools and hospitals. The world is not mad or anything. 5G can cause major changes to the lungs and blood as I detail in *The Answer* and these consequences are labelled 'Covid-19', the alleged symptoms of which can be caused by 5G and other electromagnetic frequencies as cells respond to radiation poisoning.

The 'Covid death' scam

Dr Scott Jensen, a Minnesota state senator and medical doctor, exposed 'Covid' Medicare payment incentives to hospitals and death certificate manipulation. He said he was sent a seven-page document by the US Department of Health 'coaching' him on how to fill out death certificates which had never happened before. The document said that he didn't need to have a laboratory test for 'Covid-19' to put that on the death certificate and that shocked him when death certificates are supposed to be about facts. Jensen described how doctors had been 'encouraged, if not pressured' to make a diagnosis of 'Covid-19' if they thought it was probable or '*presumed*'. No positive test was necessary – not that this would have mattered anyway. He said doctors were told to diagnose 'Covid' by symptoms when these were the same as colds, allergies, other respiratory problems, and certainly with influenza which 'disappeared' in the 'Covid' era. A common sniffle was enough to get the dreaded verdict. Ontario authorities decreed that a single care home resident with *one* symptom from a long list must lead to the isolation of the entire home. Other courageous doctors like Jensen made the same point about death figure manipulation and how deaths by other causes were falling while 'Covid-19 deaths' were rising at the same rate due to re-diagnosis. Their videos rarely survive long on YouTube with its Cult-supporting algorithms courtesy of CEO Susan Wojcicki and her bosses at Google. Figure-tampering was so glaring

and ubiquitous that even officials were letting it slip or outright saying it. UK chief scientific adviser Patrick Vallance said on one occasion that 'Covid' on the death certificate doesn't mean 'Covid' was the cause of death (so why the hell is it there?) and we had the rare sight of a BBC reporter telling the truth when she said: 'Someone could be successfully treated for Covid, in say April, discharged, and then in June, get run over by a bus and die ... That person would still be counted as a Covid death in England.' Yet the BBC and the rest of the world media went on repeating the case and death figures as if they were real. Illinois Public Health Director Dr Ngozi Ezike revealed the deceit while her bosses must have been clenching their buttocks:

If you were in a hospice and given a few weeks to live and you were then found to have Covid that would be counted as a Covid death. [There might be] a clear alternate cause, but it is still listed as a Covid death. So everyone listed as a Covid death doesn't mean that was the cause of the death, but that they had Covid at the time of death.

Yes, a 'Covid virus' never shown to exist and tested for with a test not testing for the 'virus'. In the first period of the pandemic hoax through the spring of 2020 the process began of designating almost everything a 'Covid' death and this has continued ever since. I sat in a restaurant one night listening to a loud conversation on the next table where a family was discussing in bewilderment how a relative who had no symptoms of 'Covid', and had died of a long-term problem, could have been diagnosed a death by the 'virus'. I could understand their bewilderment. If they read this book they will know why this medical fraud has been perpetrated the world over.

Some media truth shock

The media ignored the evidence of death certificate fraud until eventually one columnist did speak out when she saw it first-hand. Bel Mooney is a long-time national newspaper journalist in Britain currently working for the *Daily Mail*. Her article on February 19th, 2021, carried this headline: 'My dad Ted passed three Covid tests

and died of a chronic illness yet he's officially one of Britain's 120,000 victims of the virus and is far from alone ... so how many more are there?' She told how her 99-year-old father was in a care home with a long-standing chronic obstructive pulmonary disease and vascular dementia. Maybe, but he was still aware enough to tell her from the start that there was no 'virus' and he refused the 'vaccine' for that reason. His death was not unexpected given his chronic health problems and Mooney said she was shocked to find that 'Covid-19' was declared the cause of death on his death certificate. She said this was a 'bizarre and unacceptable untruth' for a man with long-time health problems who had tested negative twice at the home for the 'virus'. I was also shocked by this story although not by what she said. I had been highlighting the death certificate manipulation for ten months. It was the confirmation that a professional full-time journalist only realised this was going on when it affected her directly and neither did she know that whether her dad tested positive or negative was irrelevant with the test not testing for the 'virus'. Where had she been? She said she did not believe in 'conspiracy theories' without knowing I'm sure that this and 'conspiracy theorists' were terms put into widespread circulation by the CIA in the 1960s to discredit those who did not accept the ridiculous official story of the Kennedy assassination. A blanket statement of 'I don't believe in conspiracy theories' is always bizarre. The dictionary definition of the term alone means the world is drowning in conspiracies. What she said was even more daft when her dad had just been affected by the 'Covid' conspiracy. Why else does she think that 'Covid-19' was going on the death certificates of people who died of something else?

To be fair once she saw from personal experience what was happening she didn't mince words. Mooney was called by the care home on the morning of February 9th to be told her father had died in his sleep. When she asked for the official cause of death what came back was 'Covid-19'. Mooney challenged this and was told there had been deaths from Covid on the dementia floor (confirmed by a test not testing for the 'virus') so they considered it 'reasonable

to assume'. 'But doctor,' Mooney rightly protested, 'an assumption isn't a diagnosis.' She said she didn't blame the perfectly decent and sympathetic doctor – 'he was just doing his job'. Sorry, but that's *bullshit*. He wasn't doing his job at all. He was putting a false cause of death on the death certificate and that is a criminal offence for which he should be brought to account and the same with the millions of doctors worldwide who have done the same. They were not doing their job they were following orders and that must not wash at new Nuremberg trials any more than it did at the first ones. Mooney's doctor was 'assuming' (presuming) as he was told to, but 'just following orders' makes no difference to his actions. A doctor's job is to serve the patient and the truth, not follow orders, but that's what they have done all over the world and played a central part in making the 'Covid' hoax possible with all its catastrophic consequences for humanity. Shame on them and they must answer for their actions. Mooney said her disquiet worsened when she registered her father's death by telephone and was told by the registrar there had been very many other cases like hers where 'the deceased' had not tested positive for 'Covid' yet it was recorded as the cause of death. The test may not matter, but those involved at their level *think* it matters and it shows a callous disregard for accurate diagnosis. The pressure to do this is coming from the top of the national 'health' pyramids which in turn obey the World Health Organization which obeys Gates and the Cult. Mooney said the registrar agreed that this must distort the national figures adding that 'the strangest thing is that every winter we record countless deaths from flu, and this winter there have been none. Not one!' She asked if the registrar thought deaths from flu were being misdiagnosed and lumped together with 'Covid' deaths. The answer was a 'puzzled yes'. Mooney said that the funeral director said the same about 'Covid' deaths which had nothing to do with 'Covid'. They had lost count of the number of families upset by this and other funeral companies in different countries have had the same experience. Mooney wrote:

The nightly shroud-waving and shocking close-ups of pain imposed on us by the TV news bewildered and terrified the population into eager compliance with lockdowns. We were invited to 'save the NHS' and to grieve for strangers – the real-life loved ones behind those shocking death counts. Why would the public imagine what I now fear, namely that the way Covid-19 death statistics are compiled might make the numbers seem greater than they are?

Oh, just a little bit – like 100 percent.

Do the maths

Mooney asked why a country would wish to skew its mortality figures by wrongly certifying deaths? What had been going on? Well, if you don't believe in conspiracies you will never find the answer which is that *it's a conspiracy*. She did, however, describe what she had discovered as a 'national scandal'. In reality it's a global scandal and happening everywhere. Pillars of this conspiracy were all put into place before the button was pressed with the Drosten PCR protocol and high amplifications to produce the cases and death certificate changes to secure illusory 'Covid' deaths. Mooney notes that normally two doctors were needed to certify a death, with one having to know the patient, and how the rules were changed in the spring of 2020 to allow one doctor to do this. In the same period 'Covid deaths' were decreed to be all cases where Covid-19 was put on the death certificate even without a positive test or any symptoms. Mooney asked: 'How many of the 30,851 (as of January 15) care home resident deaths with Covid-19 on the certificate (32.4 per cent of all deaths so far) were based on an assumption, like that of my father? And what has that done to our national psyche?' All of them is the answer to the first question and it has devastated and dismantled the national psyche, actually the global psyche, on a colossal scale. In the UK case and death data is compiled by organisations like Public Health England (PHE) and the Office for National Statistics (ONS). Mooney highlights the insane policy of counting a death from any cause as 'Covid-19' if this happens within 28 days of a positive test (with a test not testing for the 'virus') and she points out that ONS statistics reflect deaths 'involving Covid' 'or due to Covid' which meant in practice any

death where 'Covid-19' was mentioned on the death certificate. She described the consequences of this fraud:

Most people will accept the narrative they are fed, so panicky governments here and in Europe witnessed the harsh measures enacted in totalitarian China and jumped into lockdown. Headlines about Covid deaths tolled like the knell that would bring doomsday to us all. Fear stalked our empty streets. Politicians parroted the frankly ridiculous aim of 'zero Covid' and shut down the economy, while most British people agreed that lockdown was essential and (astonishingly to me, as a patriotic Brit) even wanted more restrictions.

For what? Lies on death certificates? Never mind the grim toll of lives ruined, suicides, schools closed, rising inequality, depression, cancelled hospital treatments, cancer patients in a torture of waiting, poverty, economic devastation, loneliness, families kept apart, and so on. How many lives have been lost as a direct result of lockdown?

She said that we could join in a national chorus of shock and horror at reaching the 120,000 death toll which was surely certain to have been totally skewed all along, but what about the human cost of lockdown justified by these 'death figures'? *The British Medical Journal* had reported a 1,493 percent increase in cases of children taken to Great Ormond Street Hospital with abusive head injuries alone and then there was the effect on families:

Perhaps the most shocking thing about all this is that families have been kept apart – and obeyed the most irrational, changing rules at the whim of government – because they believed in the statistics. They succumbed to fear, which his generation rejected in that war fought for freedom. Dad (God rest his soul) would be angry. And so am I.

Another theme to watch is that in the winter months when there are more deaths from all causes they focus on 'Covid' deaths and in the summer when the British Lung Foundation says respiratory disease plummets by 80 percent they rage on about 'cases'. Either way fascism on population is always the answer.

Nazi eugenics in the 21st century

Elderly people in care homes have been isolated from their families month after lonely month with no contact with relatives and grandchildren who were banned from seeing them. We were told

that lockdown fascism was to 'protect the vulnerable' like elderly people. At the same time Do Not Resuscitate (DNR) orders were placed on their medical files so that if they needed resuscitation it wasn't done and 'Covid-19' went on their death certificates. Old people were not being 'protected' they were being culled – murdered in truth. DNR orders were being decreed for disabled and young people with learning difficulties or psychological problems. The UK Care Quality Commission, a non-departmental body of the Department of Health and Social Care, found that 34 percent of those working in health and social care were pressured into placing 'do not attempt cardiopulmonary resuscitation' orders on 'Covid' patients who suffered from disabilities and learning difficulties without involving the patient or their families in the decision. UK judges ruled that an elderly woman with dementia should have the DNA-manipulating 'Covid vaccine' against her son's wishes and that a man with severe learning difficulties should have the jab despite his family's objections. Never mind that many had already died. The judiciary always supports doctors and government in fascist dictatorships. They wouldn't dare do otherwise. A horrific video was posted showing fascist officers from Los Angeles police forcibly giving the 'Covid' shot to women with special needs who were screaming that they didn't want it. The same fascists are seen giving the jab to a sleeping elderly woman in a care home. This is straight out of the Nazi playbook. Hitler's Nazis committed mass murder of the mentally ill and physically disabled throughout Germany and occupied territories in the programme that became known as Aktion T4, or just T4. Sabbatian-controlled Hitler and his grotesque crazies set out to kill those they considered useless and unnecessary. The Reich Committee for the Scientific Registering of Hereditary and Congenital Illnesses registered the births of babies identified by physicians to have 'defects'. By 1941 alone more than 5,000 children were murdered by the state and it is estimated that in total the number of innocent people killed in Aktion T4 was between 275,000 and 300,000. Parents were told their children had been sent away for 'special treatment' never to return. It is rather pathetic to see claims about plans for new extermination camps being dismissed today

when the same force behind current events did precisely that 80 years ago. Margaret Sanger was a Cult operative who used 'birth control' to sanitise her programme of eugenics. Organisations she founded became what is now Planned Parenthood. Sanger proposed that 'the whole dysgenic population would have its choice of segregation or sterilization'. These included epileptics, 'feeble-minded', and prostitutes. Sanger opposed charity because it perpetuated 'human waste'. She reveals the Cult mentality and if anyone thinks that extermination camps are a 'conspiracy theory' their naivety is touching if breathtakingly stupid.

If you don't believe that doctors can act with callous disregard for their patients it is worth considering that doctors and medical staff agreed to put government-decreed DNR orders on medical files and do nothing when resuscitation is called for. I don't know what you call such people in your house. In mine they are Nazis from the Josef Mengele School of Medicine. Phenomenal numbers of old people have died worldwide from the effects of lockdown, depression, lack of treatment, the 'vaccine' (more later) and losing the will to live. A common response at the start of the manufactured pandemic was to remove old people from hospital beds and transfer them to nursing homes. The decision would result in a mass cull of elderly people in those homes through lack of treatment – *not* 'Covid'. Care home whistleblowers have told how once the 'Covid' era began doctors would not come to their homes to treat patients and they were begging for drugs like antibiotics that often never came. The most infamous example was ordered by New York governor Andrew Cuomo, brother of a moronic CNN host, who amazingly was given an Emmy Award for his handling of the 'Covid crisis' by the ridiculous Wokers that hand them out. Just how ridiculous could be seen in February, 2021, when a Department of Justice and FBI investigation began into how thousands of old people in New York died in nursing homes after being discharged from hospital to make way for 'Covid' patients on Cuomo's say-so – and how he and his staff covered up these facts. This couldn't have happened to a nicer psychopath. Even then there was a 'Covid' spin. Reports said that

thousands of old people who tested positive for 'Covid' in hospital were transferred to nursing homes to both die of 'Covid' and transmit it to others. No – they were in hospital because they were ill and the fact that they tested positive with a test not testing for the 'virus' is irrelevant. They were ill often with respiratory diseases ubiquitous in old people near the end of their lives. Their transfer out of hospital meant that their treatment stopped and many would go on to die.

They're old. Who gives a damn?

I have exposed in the books for decades the Cult plan to cull the world's old people and even to introduce at some point what they call a 'demise pill' which at a certain age everyone would take and be out of here by law. In March, 2021, Spain legalised euthanasia and assisted suicide following the Netherlands, Belgium, Luxembourg and Canada on the Tiptoe to the demise pill. Treatment of old people by many 'care' homes has been a disgrace in the 'Covid' era. There are many, many, caring staff – I know some. There have, however, been legions of stories about callous treatment of old people and their families. Police were called when families came to take their loved ones home in the light of isolation that was killing them. They became prisoners of the state. Care home residents in insane, fascist Ontario, Canada, were not allowed to leave their *room* once the 'Covid' hoax began. UK staff have even wheeled elderly people away from windows where family members were talking with them. Oriana Criscuolo from Stockport in the English North West dropped off some things for her 80-year-old father who has Parkinson's disease and dementia and she wanted to wave to him through a ground-floor window. She was told that was 'illegal'. When she went anyway they closed the curtains in the middle of the day. Oriana said:

It's just unbelievable. I cannot understand how care home staff – people who are being paid to care – have become so uncaring. Their behaviour is inhumane and cruel. It's beyond belief.

She was right and this was not a one-off. What a way to end your life in such loveless circumstances. UK registered nurse Nicky Millen, a proper old school nurse for 40 years, said that when she started her career care was based on dignity, choice, compassion and empathy. Now she said 'the things that are important to me have gone out of the window.' She was appalled that people were dying without their loved ones and saying goodbye on iPads. Nicky described how a distressed 89-year-old lady stroked her face and asked her 'how many paracetamol would it take to finish me off'. Life was no longer worth living while not seeing her family. Nicky said she was humiliated in front of the ward staff and patients for letting the lady stroke her face and giving her a cuddle. Such is the dehumanisation that the 'Covid' hoax has brought to the surface. Nicky worked in care homes where patients told her they were being held prisoner. 'I want to live until I die', one said to her. 'I had a lady in tears because she hadn't seen her great-grandson.' Nicky was compassionate old school meeting psychopathic New Normal. She also said she had worked on a 'Covid' ward with no 'Covid' patients. Jewish writer Shai Held wrote an article in March, 2020, which was headlined 'The Staggering, Heartless Cruelty Toward the Elderly'. What he described was happening from the earliest days of lockdown. He said 'the elderly' were considered a group and not unique individuals (the way of the Woke). Shai Held said:

Notice how the all-too-familiar rhetoric of dehumanization works: 'The elderly' are bunched together as a faceless mass, all of them considered culprits and thus effectively deserving of the suffering the pandemic will inflict upon them. Lost entirely is the fact that the elderly are individual human beings, each with a distinctive face and voice, each with hopes and dreams, memories and regrets, friendships and marriages, loves lost and loves sustained.

'The elderly' have become another dehumanised group for which anything goes and for many that has resulted in cold disregard for their rights and their life. The distinctive face that Held talks about is designed to be deleted by masks until everyone is part of a faceless mass.

'War-zone' hospitals myth

Again and again medical professionals have told me what was really going on and how hospitals 'overrun like war zones' according to the media were virtually empty. The mantra from medical whistleblowers was please don't use my name or my career is over. Citizen journalists around the world sneaked into hospitals to film evidence exposing the 'war-zone' lie. They really *were* largely empty with closed wards and operating theatres. I met a hospital worker in my town on the Isle of Wight during the first lockdown in 2020 who said the only island hospital had never been so quiet. Lockdown was justified by the psychopaths to stop hospitals being overrun. At the same time that the island hospital was near-empty the military arrived here to provide *extra beds*. It was all propaganda to ramp up the fear to ensure compliance with fascism as were never-used temporary hospitals with thousands of beds known as Nightingales and never-used make-shift mortuaries opened by the criminal UK government. A man who helped to install those extra island beds attributed to the army said they were never used and the hospital was empty. Doctors and nurses 'stood around talking or on their phones, wandering down to us to see what we were doing'. There were no masks or social distancing. He accused the useless local island paper, the *County Press*, of 'pumping the fear as if our hospital was overrun and we only have one so it should have been'. He described ambulances parked up with crews outside in deck chairs. When his brother called an ambulance he was told there was a two-hour backlog which he called 'bullshit'. An old lady on the island fell 'and was in a bad way', but a caller who rang for an ambulance was told the situation wasn't urgent enough. Ambulance stations were working under capacity while people would hear ambulances with sirens blaring driving through the streets. When those living near the stations realised what was going on they would follow them as they left, circulated around an urban area with the sirens going, and then came back without stopping. All this was to increase levels of fear and the same goes for the 'ventilator shortage crisis' that cost tens of millions for hastily produced ventilators never to be used.

Ambulance crews that agreed to be exploited in this way for fear propaganda might find themselves a mirror. I wish them well with that. Empty hospitals were the obvious consequence of treatment and diagnoses of non-'Covid' conditions cancelled and those involved handed a death sentence. People have been dying at home from undiagnosed and untreated cancer, heart disease and other life-threatening conditions to allow empty hospitals to deal with a 'pandemic' that wasn't happening.

Death of the innocent

'War-zones' have been laying off nursing staff, even doctors where they can. There was no work for them. Lockdown was justified by saving lives and protecting the vulnerable they were actually killing with DNR orders and preventing empty hospitals being 'overrun'. In Britain the mantra of stay at home to 'save the NHS' was everywhere and across the world the same story was being sold when it was all lies. Two California doctors, Dan Erickson and Artin Massihi at Accelerated Urgent Care in Bakersfield, held a news conference in April, 2020, to say that intensive care units in California were 'empty, essentially', with hospitals shutting floors, not treating patients and laying off doctors. The California health system was working at minimum capacity 'getting rid of doctors because we just don't have the volume'. They said that people with conditions such as heart disease and cancer were not coming to hospital out of fear of 'Covid-19'. Their video was deleted by Susan Wojcicki's Cult-owned YouTube after reaching five million views. Florida governor Ron Desantis, who rejected the severe lockdowns of other states and is being targeted for doing so, said that in March, 2020, every US governor was given models claiming they would run out of hospital beds in days. That was never going to happen and the 'modellers' knew it. Deceit can be found at every level of the system. Urgent children's operations were cancelled including fracture repairs and biopsies to spot cancer. Eric Nicholls, a consultant paediatrician, said 'this is obviously concerning and we need to return to normal operating and to increase capacity as soon as possible'. Psychopaths

in power were rather less concerned *because* they are psychopaths. Deletion of urgent care and diagnosis has been happening all over the world and how many kids and others have died as a result of the actions of these cold and heartless lunatics dictating 'health' policy? The number must be stratospheric. Richard Sullivan, professor of cancer and global health at King's College London, said people feared 'Covid' more than cancer such was the campaign of fear. 'Years of lost life will be quite dramatic', Sullivan said, with 'a huge amount of avoidable mortality'. Sarah Woolnough, executive director for policy at Cancer Research UK, said there had been a 75 percent drop in urgent referrals to hospitals by family doctors of people with suspected cancer. Sullivan said that 'a lot of services have had to scale back – we've seen a dramatic decrease in the amount of elective cancer surgery'. Lockdown deaths worldwide has been absolutely fantastic with the *New York Post* reporting how data confirmed that 'lockdowns end more lives than they save':

There was a sharp decline in visits to emergency rooms and an increase in fatal heart attacks because patients didn't receive prompt treatment. Many fewer people were screened for cancer. Social isolation contributed to excess deaths from dementia and Alzheimer's.

Researchers predicted that the social and economic upheaval would lead to tens of thousands of "deaths of despair" from drug overdoses, alcoholism and suicide. As unemployment surged and mental-health and substance-abuse treatment programs were interrupted, the reported levels of anxiety, depression and suicidal thoughts increased dramatically, as did alcohol sales and fatal drug overdoses.

This has been happening while nurses and other staff had so much time on their hands in the 'war-zones' that Tic-Tok dancing videos began appearing across the Internet with medical staff dancing around in empty wards and corridors as people died at home from causes that would normally have been treated in hospital.

Mentions in dispatches

One brave and truth-committed whistleblower was Louise Hampton, a call handler with the UK NHS who made a viral Internet video saying she had done 'fuck all' during the 'pandemic'

which was 'a load of bollocks'. She said that 'Covid-19' was rebranded flu and of course she lost her job. This is what happens in the medical and endless other professions now when you tell the truth. Louise filmed inside 'war-zone' accident and emergency departments to show they were empty and I mean *empty* as in no one there. The mainstream media could have done the same and blown the gaff on the whole conspiracy. They haven't to their eternal shame. Not that most 'journalists' seem capable of manifesting shame as with the psychopaths they slavishly repeat without question. The relative few who were admitted with serious health problems were left to die alone with no loved ones allowed to see them because of 'Covid' rules and they included kids dying without the comfort of mum and dad at their bedside while the evil behind this couldn't give a damn. It was all good fun to them. A Scottish NHS staff nurse publicly quit in the spring of 2021 saying: 'I can no longer be part of the lies and the corruption by the government.' She said hospitals 'aren't full, the beds aren't full, beds have been shut, wards have been shut'. Hospitals were never busy throughout 'Covid'. The staff nurse said that Nicola Sturgeon, tragically the leader of the Scottish government, was on television saying save the hospitals and the NHS – 'but the beds are empty' and 'we've not seen flu, we always see flu every year'. She wrote to government and spoke with her union Unison (the unions are Cult-compromised and *useless*, but nothing changed. Many of her colleagues were scared of losing their jobs if they spoke out as they wanted to. She said nursing staff were being affected by wearing masks all day and 'my head is splitting every shift from wearing a mask'. The NHS is part of the fascist tyranny and must be dismantled so we can start again with human beings in charge. (Ironically, hospitals were reported to be busier again when official 'Covid' cases *fell* in spring/summer of 2021 and many other conditions required treatment at the same time as *the fake vaccine rollout*.)

I will cover the 'Covid vaccine' scam in detail later, but it is another indicator of the sickening disregard for human life that I am highlighting here. The DNA-manipulating concoctions do not fulfil

the definition of a 'vaccine', have never been used on humans before and were given only emergency approval because trials were not completed and they continued using the unknowing public. The result was what a NHS senior nurse with responsibility for 'vaccine' procedure said was 'genocide'. She said the 'vaccines' were not 'vaccines'. They had not been shown to be safe and claims about their effectiveness by drug companies were 'poetic licence'. She described what was happening as a 'horrid act of human annihilation'. The nurse said that management had instigated a policy of not providing a Patient Information Leaflet (PIL) before people were 'vaccinated' even though health care professionals are supposed to do this according to protocol. Patients should also be told that they are taking part in an ongoing clinical trial. Her challenges to what is happening had seen her excluded from meetings and ridiculed in others. She said she was told to 'watch my step ... or I would find myself surplus to requirements'. The nurse, who spoke anonymously in fear of her career, said she asked her NHS manager why he/she was content with taking part in genocide against those having the 'vaccines'. The reply was that everyone had to play their part and to 'put up, shut up, and get it done'. Government was 'leaning heavily' on NHS management which was clearly leaning heavily on staff. This is how the global 'medical' hierarchy operates and it starts with the Cult and its World Health Organization.

She told the story of a doctor who had the Pfizer jab and when questioned had no idea what was in it. The doctor had never read the literature. We have to stop treating doctors as intellectual giants when so many are moral and medical pygmies. The doctor did not even know that the 'vaccines' were not fully approved or that their trials were ongoing. They were, however, asking their patients if they minded taking part in follow-ups for research purposes – yes, the *ongoing clinical trial*. The nurse said the doctor's ignorance was not rare and she had spoken to a hospital consultant who had the jab without any idea of the background or that the 'trials' had not been completed. Nurses and pharmacists had shown the same ignorance.

‘My NHS colleagues have forsaken their duty of care, broken their code of conduct – Hippocratic Oath – and have been brainwashed just the same as the majority of the UK public through propaganda ...’ She said she had not been able to recruit a single NHS colleague, doctor, nurse or pharmacist to stand with her and speak out. Her union had refused to help. She said that if the genocide came to light she would not hesitate to give evidence at a Nuremberg-type trial against those in power who could have affected the outcomes but didn’t.

And all for what?

To put the nonsense into perspective let’s say the ‘virus’ does exist and let’s go completely crazy and accept that the official manipulated figures for cases and deaths are accurate. *Even then* a study by Stanford University epidemiologist Dr John Ioannidis published on the World Health Organization website produced an average infection to fatality rate of ... *0.23 percent!* Ioannidis said: ‘If one could sample equally from all locations globally, the median infection fatality rate might even be substantially lower than the 0.23% observed in my analysis.’ For healthy people under 70 it was ... *0.05 percent!* This compares with the 3.4 percent claimed by the Cult-owned World Health Organization when the hoax was first played and maximum fear needed to be generated. An updated Stanford study in April, 2021, put the ‘infection’ to ‘fatality’ rate at just 0.15 percent. Another team of scientists led by Megan O’Driscoll and Henrik Salje studied data from 45 countries and published their findings on the Nature website. For children and young people the figure is so small it virtually does not register although authorities will be hyping dangers to the young when they introduce DNA-manipulating ‘vaccines’ for children. The O’Driscoll study produced an average infection-fatality figure of 0.003 for children from birth to four; 0.001 for 5 to 14; 0.003 for 15 to 19; and it was still only 0.456 up to 64. To claim that children must be ‘vaccinated’ to protect them from ‘Covid’ is an obvious lie and so there must be another reason and there is. What’s more the average age of a ‘Covid’ death is akin

to the average age that people die in general. The average age of death in England is about 80 for men and 83 for women. The average age of death from alleged 'Covid' is between 82 and 83. California doctors, Dan Erickson and Artin Massihi, said at their April media conference that projection models of millions of deaths had been 'woefully inaccurate'. They produced detailed figures showing that Californians had a 0.03 chance of dying from 'Covid' based on the number of people who tested positive (with a test not testing for the 'virus'). Erickson said there was a 0.1 percent chance of dying from 'Covid' in the *state* of New York, not just the city, and a 0.05 percent chance in Spain, a centre of 'Covid-19' hysteria at one stage. The Stanford studies supported the doctors' data with fatality rate estimates of 0.23 and 0.15 percent. How close are these figures to my estimate of *zero*? Death-rate figures claimed by the World Health Organization at the start of the hoax were some 15 times higher. The California doctors said there was no justification for lockdowns and the economic devastation they caused. Everything they had ever learned about quarantine was that you quarantine the *sick* and not the healthy. They had never seen this before and it made no medical sense.

Why in the in the light of all this would governments and medical systems the world over say that billions must go under house arrest; lose their livelihood; in many cases lose their mind, their health and their life; force people to wear masks dangerous to health and psychology; make human interaction and even family interaction a criminal offence; ban travel; close restaurants, bars, watching live sport, concerts, theatre, and any activity involving human togetherness and discourse; and closing schools to isolate children from their friends and cause many to commit suicide in acts of hopelessness and despair? The California doctors said lockdown consequences included increased child abuse, partner abuse, alcoholism, depression, and other impacts they were seeing every day. Who would do that to the entire human race if not mentally-ill psychopaths of almost unimaginable extremes like Bill Gates? We must face the reality of what we are dealing with and come out of

denial. Fascism and tyranny are made possible only by the target population submitting and acquiescing to fascism and tyranny. The whole of human history shows that to be true. Most people naively and unquestioning believed what they were told about a 'deadly virus' and meekly and weakly submitted to house arrest. Those who didn't believe it – at least in total – still submitted in fear of the consequences of not doing so. For the rest who wouldn't submit draconian fines have been imposed, brutal policing by psychopaths *for* psychopaths, and condemnation from the meek and weak who condemn the Pushbackers on behalf of the very force that has them, too, in its gunsights. 'Pathetic' does not even begin to suffice. Britain's brainless 'Health' Secretary Matt Hancock warned anyone lying to border officials about returning from a list of 'hotspot' countries could face a jail sentence of up to ten years which is more than for racially-aggravated assault, incest and attempting to have sex with a child under 13. Hancock is a lunatic, but he has the state apparatus behind him in a Cult-led chain reaction and the same with UK 'Vaccine Minister' Nadhim Zahawi, a prominent member of the mega-Cult secret society, Le Cercle, which featured in my earlier books. The Cult enforces its will on governments and medical systems; government and medical systems enforce their will on business and police; business enforces its will on staff who enforce it on customers; police enforce the will of the Cult on the population and play their essential part in creating a world of fascist control that their own children and grandchildren will have to live in their entire lives. It is a hierarchical pyramid of imposition and acquiescence and, yes indeed, of clinical insanity.

Does anyone bright enough to read this book have to ask what the answer is? I think not, but I will reveal it anyway in the fewest of syllables: Tell the psychos and their moronic lackeys to fuck off and let's get on with our lives. We are many – They are few.

CHAPTER SEVEN

War on your mind

One believes things because one has been conditioned to believe them

Aldous Huxley, Brave New World

I have described the 'Covid' hoax as a 'Psyop' and that is true in every sense and on every level in accordance with the definition of that term which is psychological warfare. Break down the 'Covid pandemic' to the foundation themes and it is psychological warfare on the human individual and collective mind.

The same can be said for the entire human belief system involving every subject you can imagine. Huxley was right in his contention that people believe what they are conditioned to believe and this comes from the repetition throughout their lives of the same falsehoods. They spew from government, corporations, media and endless streams of 'experts' telling you what the Cult wants you to believe and often believing it themselves (although *far* from always). 'Experts' are rewarded with 'prestigious' jobs and titles and as agents of perceptual programming with regular access to the media. The Cult has to control the narrative – control *information* – or they lose control of the vital, crucial, without-which-they-cannot-prevail public perception of reality. The foundation of that control today is the Internet made possible by the Defense Advanced Research Projects Agency (DARPA), the incredibly sinister technological arm of the Pentagon. The Internet is the result of military technology.

DARPA openly brags about establishing the Internet which has been a long-term project to lasso the minds of the global population. I have said for decades the plan is to control information to such an extreme that eventually no one would see or hear anything that the Cult does not approve. We are closing in on that end with ferocious censorship since the 'Covid' hoax began and in my case it started back in the 1990s in terms of books and speaking venues. I had to create my own publishing company in 1995 precisely because no one else would publish my books even then. I think they're all still running.

Cult Internet

To secure total control of information they needed the Internet in which pre-programmed algorithms can seek out 'unclean' content for deletion and even stop it being posted in the first place. The Cult had to dismantle print and non-Internet broadcast media to ensure the transfer of information to the appropriate-named 'Web' – a critical expression of the *Cult* web. We've seen the ever-quicken demise of traditional media and control of what is left by a tiny number of corporations operating worldwide. Independent journalism in the mainstream is already dead and never was that more obvious than since the turn of 2020. The Cult wants all information communicated via the Internet to globally censor and allow the plug to be pulled any time. Lockdowns and forced isolation has meant that communication between people has been through electronic means and no longer through face-to-face discourse and discussion. Cult psychopaths have targeted the bars, restaurants, sport, venues and meeting places in general for this reason. None of this is by chance and it's to stop people gathering in any kind of privacy or number while being able to track and monitor all Internet communications and block them as necessary. Even private messages between individuals have been censored by these fascists that control Cult fronts like Facebook, Twitter, Google and YouTube which are all officially run by Sabbatian place-people and from the background by higher-level Sabbatian place people.

Facebook, Google, Amazon and their like were seed-funded and supported into existence with money-no-object infusions of funds either directly or indirectly from DARPA and CIA technology arm In-Q-Tel. The Cult plays the long game and prepares very carefully for big plays like 'Covid'. Amazon is another front in the psychological war and pretty much controls the global market in book sales and increasingly publishing. Amazon's limitless funds have deleted fantastic numbers of independent publishers to seize global domination on the way to deciding which books can be sold and circulated and which cannot. Moves in that direction are already happening. Amazon's leading light Jeff Bezos is the grandson of Lawrence Preston Gise who worked with DARPA predecessor ARPA. Amazon has big connections to the CIA and the Pentagon. The plan I have long described went like this:

1. Employ military technology to establish the Internet.
2. Sell the Internet as a place where people can freely communicate without censorship and allow that to happen until the Net becomes the central and irreversible pillar of human society. If the Internet had been highly censored from the start many would have rejected it.
3. Fund and manipulate major corporations into being to control the circulation of information on your Internet using cover stories about geeks in garages to explain how they came about. Give them unlimited funds to expand rapidly with no need to make a profit for years while non-Cult companies who need to balance the books cannot compete. You know that in these circumstances your Googles, YouTubes, Facebooks and Amazons are going to secure near monopolies by either crushing or buying up the opposition.
4. Allow freedom of expression on both the Internet and communication platforms to draw people in until the Internet is the central and irreversible pillar of human society and your communication corporations have reached a stage of near monopoly domination.
5. Then unleash your always-planned frenzy of censorship on the basis of 'where else are you going to go?' and continue to expand that until nothing remains that the Cult does not want its human targets to see.

The process was timed to hit the 'Covid' hoax to ensure the best chance possible of controlling the narrative which they knew they had to do at all costs. They were, after all, about to unleash a 'deadly virus' that didn't really exist. If you do that in an environment of free-flowing information and opinion you would be dead in the

water before you could say Gates is a psychopath. The network was in place through which the Cult-created-and-owned World Health Organization could dictate the 'Covid' narrative and response policy slavishly supported by Cult-owned Internet communication giants and mainstream media while those telling a different story were censored. Google, YouTube, Facebook and Twitter openly announced that they would do this. What else would we expect from Cult-owned operations like Facebook which former executives have confirmed set out to make the platform more addictive than cigarettes and coldly manipulates emotions of its users to sow division between people and groups and scramble the minds of the young? If Zuckerberg lives out the rest of his life without going to jail for crimes against humanity, and most emphatically against the young, it will be a travesty of justice. Still, no matter, cause and effect will catch up with him eventually and the same with Sergey Brin and Larry Page at Google with its CEO Sundar Pichai who fix the Google search results to promote Cult narratives and hide the opposition. Put the same key words into Google and other search engines like DuckDuckGo and you will see how different results can be. Wikipedia is another intensely biased 'encyclopaedia' which skews its content to the Cult agenda. YouTube links to Wikipedia's version of 'Covid' and 'climate change' on video pages in which experts in their field offer a different opinion (even that is increasingly rare with Wojcicki censorship). Into this 'Covid' silence-them network must be added government media censors, sorry 'regulators', such as Ofcom in the UK which imposed tyrannical restrictions on British broadcasters that had the effect of banning me from ever appearing. Just to debate with me about my evidence and views on 'Covid' would mean breaking the fascistic impositions of Ofcom and its CEO career government bureaucrat Melanie Dawes. Gutless British broadcasters tremble at the very thought of fascist Ofcom.

Psychos behind 'Covid'

The reason for the 'Covid' catastrophe in all its facets and forms can be seen by whom and what is driving the policies worldwide in such a coordinated way. Decisions are not being made to protect health, but to target psychology. The dominant group guiding and 'advising' government policy are not medical professionals. They are psychologists and behavioural scientists. Every major country has its own version of this phenomenon and I'll use the British example to show how it works. In many ways the British version has been affecting the wider world in the form of the huge behaviour manipulation network in the UK which operates in other countries. The network involves private companies, government, intelligence and military. The Cabinet Office is at the centre of the government 'Covid' Psyop and part-owns, with 'innovation charity' Nesta, the Behavioural Insights Team (BIT) which claims to be independent of government but patently isn't. The BIT was established in 2010 and its job is to manipulate the psyche of the population to acquiesce to government demands and so much more. It is also known as the 'Nudge Unit', a name inspired by the 2009 book by two ultra-Zionists, Cass Sunstein and Richard Thaler, called *Nudge: Improving Decisions About Health, Wealth, and Happiness*. The book, as with the Behavioural Insights Team, seeks to 'nudge' behaviour (manipulate it) to make the public follow patterns of action and perception that suit those in authority (the Cult). Sunstein is so skilled at this that he advises the World Health Organization and the UK Behavioural Insights Team and was Administrator of the White House Office of Information and Regulatory Affairs in the Obama administration. Biden appointed him to the Department of Homeland Security – another ultra-Zionist in the fold to oversee new immigration laws which is another policy the Cult wants to control. Sunstein is desperate to silence anyone exposing conspiracies and co-authored a 2008 report on the subject in which suggestions were offered to ban 'conspiracy theorizing' or impose 'some kind of tax, financial or otherwise, on those who disseminate such theories'. I guess a psychiatrist's chair is out of the question?

Sunstein's mate Richard Thaler, an 'academic affiliate' of the UK Behavioural Insights Team, is a proponent of 'behavioural economics' which is defined as the study of 'the effects of psychological, cognitive, emotional, cultural and social factors on the decisions of individuals and institutions'. Study the effects so they can be manipulated to be what you want them to be. Other leading names in the development of behavioural economics are ultra-Zionists Daniel Kahneman and Robert J. Shiller and they, with Thaler, won the Nobel Memorial Prize in Economic Sciences for their work in this field. The Behavioural Insights Team is operating at the heart of the UK government and has expanded globally through partnerships with several universities including Harvard, Oxford, Cambridge, University College London (UCL) and Pennsylvania. They claim to have 'trained' (reframed) 20,000 civil servants and run more than 750 projects involving 400 randomised controlled trials in dozens of countries' as another version of mind reframers Common Purpose. BIT works from its office in New York with cities and their agencies, as well as other partners, across the United States and Canada – this is a company part-owned by the British government Cabinet Office. An executive order by President Cult-servant Obama established a US Social and Behavioral Sciences Team in 2015. They all have the same reason for being and that's to brainwash the population directly and by brainwashing those in positions of authority.

'Covid' mind game

Another prime aspect of the UK mind-control network is the 'independent' [joke] Scientific Pandemic Insights Group on Behaviours (SPI-B) which 'provides behavioural science advice aimed at anticipating and helping people adhere to interventions that are recommended by medical or epidemiological experts'. That means manipulating public perception and behaviour to do whatever government tells them to do. It's disgusting and if they really want the public to be 'safe' this lot should all be under lock and key. According to the government website SPI-B consists of

'behavioural scientists, health and social psychologists, anthropologists and historians' and advises the Whitty-Vallance-led Scientific Advisory Group for Emergencies (SAGE) which in turn advises the government on 'the science' (it doesn't) and 'Covid' policy. When politicians say they are being guided by 'the science' this is the rabble in each country they are talking about and that 'science' is dominated by behaviour manipulators to enforce government fascism through public compliance. The Behaviour Insight Team is headed by psychologist David Solomon Halpern, a visiting professor at King's College London, and connects with a national and global web of other civilian and military organisations as the Cult moves towards its goal of fusing them into one fascistic whole in every country through its 'Fusion Doctrine'. The behaviour manipulation network involves, but is not confined to, the Foreign Office; National Security Council; government communications headquarters (GCHQ); MI5; MI6; the Cabinet Office-based Media Monitoring Unit; and the Rapid Response Unit which 'monitors digital trends to spot emerging issues; including misinformation and disinformation; and identifies the best way to respond'.

There is also the 77th Brigade of the UK military which operates like the notorious Israeli military's Unit 8200 in manipulating information and discussion on the Internet by posing as members of the public to promote the narrative and discredit those who challenge it. Here we have the military seeking to manipulate *domestic* public opinion while the Nazis in government are fine with that. Conservative Member of Parliament Tobias Ellwood, an advocate of lockdown and control through 'vaccine passports', is a Lieutenant Colonel reservist in the 77th Brigade which connects with the military operation jHub, the 'innovation centre' for the Ministry of Defence and Strategic Command. jHub has also been involved with the civilian National Health Service (NHS) in 'symptom tracing' the population. The NHS is a key part of this mind control network and produced a document in December, 2020, explaining to staff how to use psychological manipulation with different groups and ages to get them to have the DNA-manipulating 'Covid vaccine'

that's designed to cumulatively rewrite human genetics. The document, called 'Optimising Vaccination Roll Out – Do's and Don'ts for all messaging, documents and "communications" in the widest sense', was published by NHS England and the NHS Improvement *Behaviour Change Unit* in partnership with Public Health England and Warwick Business School. I hear the mantra about 'save the NHS' and 'protect the NHS' when we need to scrap the NHS and start again. The current version is far too corrupt, far too anti-human and totally compromised by Cult operatives and their assets. UK government broadcast media censor Ofcom will connect into this web – as will the BBC with its tremendous Ofcom influence – to control what the public see and hear and dictate mass perception. Nuremberg trials must include personnel from all these organisations.

The fear factor

The 'Covid' hoax has led to the creation of the UK Cabinet Office-connected Joint Biosecurity Centre (JBC) which is officially described as providing 'expert advice on pandemics' using its independent [all Cult operations are 'independent'] analytical function to provide real-time analysis about infection outbreaks to identify and respond to outbreaks of Covid-19'. Another role is to advise the government on a response to spikes in infections – 'for example by closing schools or workplaces in local areas where infection levels have risen'. Put another way, promoting the Cult agenda. The Joint Biosecurity Centre is modelled on the Joint Terrorism Analysis Centre which analyses intelligence to set 'terrorism threat levels' and here again you see the fusion of civilian and military operations and intelligence that has led to military intelligence producing documents about 'vaccine hesitancy' and how it can be combated. Domestic civilian matters and opinions should not be the business of the military. The Joint Biosecurity Centre is headed by Tom Hurd, director general of the Office for Security and Counter-Terrorism from the establishment-to-its-fingertips Hurd family. His father is former Foreign Secretary Douglas Hurd. How coincidental that Tom

Hurd went to the elite Eton College and Oxford University with Boris Johnson. Imperial College with its ridiculous computer modeller Neil Ferguson will connect with this gigantic web that will itself interconnect with similar set-ups in other major and not so major countries. Compared with this Cult network the politicians, be they Boris Johnson, Donald Trump or Joe Biden, are bit-part players 'following the science'. The network of psychologists was on the 'Covid' case from the start with the aim of generating maximum fear of the 'virus' to ensure compliance by the population. A government behavioural science group known as SPI-B produced a paper in March, 2020, for discussion by the main government science advisory group known as SAGE. It was headed 'Options for increasing adherence to social distancing measures' and it said the following in a section headed 'Persuasion':

- A substantial number of people still do not feel sufficiently personally threatened; it could be that they are reassured by the low death rate in their demographic group, although levels of concern may be rising. Having a good understanding of the risk has been found to be positively associated with adoption of COVID-19 social distancing measures in Hong Kong.
- The perceived level of personal threat needs to be increased among those who are complacent, using hard-hitting evaluation of options for increasing social distancing emotional messaging. To be effective this must also empower people by making clear the actions they can take to reduce the threat.
- Responsibility to others: There seems to be insufficient understanding of, or feelings of responsibility about, people's role in transmitting the infection to others ... Messaging about actions need to be framed positively in terms of protecting oneself and the community, and increase confidence that they will be effective.
- Some people will be more persuaded by appeals to play by the rules, some by duty to the community, and some to personal risk.

All these different approaches are needed. The messaging also needs to take account of the realities of different people's lives. Messaging needs to take account of the different motivational levers and circumstances of different people.

All this could be achieved the SPI-B psychologists said by *using the media to increase the sense of personal threat* which translates as terrify the shit out of the population, including children, so they all do what we want. That's not happened has it? Those excuses for 'journalists' who wouldn't know journalism if it bit them on the arse (the great majority) have played their crucial part in serving this Cult-government Psyop to enslave their own kids and grandkids. How they live with themselves I have no idea. The psychological war has been underpinned by constant government 'Covid' propaganda in almost every television and radio ad break, plus the Internet and print media, which has pounded out the fear with taxpayers footing the bill for their own programming. The result has been people terrified of a 'virus' that doesn't exist or one with a tiny fatality rate even if you believe it does. People walk down the street and around the shops wearing face-nappies damaging their health and psychology while others report those who refuse to be that naïve to the police who turn up in their own face-nappies. I had a cameraman come to my flat and he was so frightened of 'Covid' he came in wearing a mask and refused to shake my hand in case he caught something. He had – naïveitis – and the thought that he worked in the mainstream media was both depressing and made his behaviour perfectly explainable. The fear which has gripped the minds of so many and frozen them into compliance has been carefully cultivated by these psychologists who are really psychopaths. If lives get destroyed and a lot of young people commit suicide it shows our plan is working. SPI-B then turned to compulsion on the public to comply. 'With adequate preparation, rapid change can be achieved', it said. Some countries had introduced mandatory self-isolation on a wide scale without evidence of major public unrest and a large majority of the UK's population appeared to be supportive of more coercive measures with 64 percent of adults saying they would

support putting London under a lockdown (watch the 'polls' which are designed to make people believe that public opinion is in favour or against whatever the subject in hand).

For 'aggressive protective measures' to be effective, the SPI-B paper said, special attention should be devoted to those population groups that are more at risk. Translated from the Orwellian this means making the rest of population feel guilty for not protecting the 'vulnerable' such as old people which the Cult and its agencies were about to kill on an industrial scale with lockdown, lack of treatment and the Gates 'vaccine'. Psychopath psychologists sold their guilt-trip so comprehensively that Los Angeles County Supervisor Hilda Solis reported that children were apologising (from a distance) to their parents and grandparents for bringing 'Covid' into their homes and getting them sick. '... These apologies are just some of the last words that loved ones will ever hear as they die alone,' she said. Gut-wrenchingly Solis then used this childhood tragedy to tell children to stay at home and 'keep your loved ones alive'. Imagine heaping such potentially life-long guilt on a kid when it has absolutely nothing to do with them. These people are deeply disturbed and the psychologists behind this even more so.

Uncivil war – divide and rule

Professional mind-controllers at SPI-B wanted the media to increase a sense of responsibility to others (do as you're told) and promote 'positive messaging' for those actions while in contrast to invoke 'social disapproval' by the unquestioning, obedient, community of anyone with a mind of their own. Again the compliant Goebbels-like media obliged. This is an old, old, trick employed by tyrannies the world over throughout human history. You get the target population to keep the target population in line – *your* line. SPI-B said this could 'play an important role in preventing anti-social behaviour or discouraging failure to enact pro-social behaviour'. For 'anti-social' in the Orwellian parlance of SPI-B see any behaviour that government doesn't approve. SPI-B recommendations said that 'social disapproval' should be accompanied by clear messaging and

promotion of strong collective identity – hence the government and celebrity mantra of ‘we’re all in this together’. Sure we are. The mind doctors have such contempt for their targets that they think some clueless comedian, actor or singer telling them to do what the government wants will be enough to win them over. We have had UK comedian Lenny Henry, actor Michael Caine and singer Elton John wheeled out to serve the propagandists by urging people to have the DNA-manipulating ‘Covid’ non-‘vaccine’. The role of Henry and fellow black celebrities in seeking to coax a ‘vaccine’ reluctant black community into doing the government’s will was especially stomach-turning. An emotion-manipulating script and carefully edited video featuring these black ‘celebs’ was such an insult to the intelligence of black people and where’s the self-respect of those involved selling their souls to a fascist government agenda? Henry said he heard black people’s ‘legitimate worries and concerns’, but people must ‘trust the facts’ when they were doing exactly that by not having the ‘vaccine’. They had to include the obligatory reference to Black Lives Matter with the line ... ‘Don’t let coronavirus cost even more black lives – because we matter’. My god, it was pathetic. ‘I know the vaccine is safe and what it does.’ How? ‘I’m a comedian and it says so in my script.’

SPI-B said social disapproval needed to be carefully managed to avoid victimisation, scapegoating and misdirected criticism, but they knew that their ‘recommendations’ would lead to exactly that and the media were specifically used to stir-up the divide-and-conquer hostility. Those who conform like good little baa, baas, are praised while those who have seen through the tidal wave of lies are ‘Covidiot’. The awake have been abused by the fast asleep for not conforming to fascism and impositions that the awake know are designed to endanger their health, dehumanise them, and tear asunder the very fabric of human society. We have had the curtain-twitchers and morons reporting neighbours and others to the face-napped police for breaking ‘Covid rules’ with fascist police delighting in posting links and phone numbers where this could be done. The Cult cannot impose its will without a compliant police

and military or a compliant population willing to play their part in enslaving themselves and their kids. The words of a pastor in Nazi Germany are so appropriate today:

First they came for the socialists and I did not speak out because I was not a socialist.

Then they came for the trade unionists and I did not speak out because I was not a trade unionist.

Then they came for the Jews and I did not speak out because I was not a Jew.

Then they came for me and there was no one left to speak for me.

Those who don't learn from history are destined to repeat it and so many are.

'Covid' rules: Rewiring the mind

With the background laid out to this gigantic national and global web of psychological manipulation we can put 'Covid' rules into a clear and sinister perspective. Forget the claims about protecting health. 'Covid' rules are about dismantling the human mind, breaking the human spirit, destroying self-respect, and then putting Humpty Dumpty together again as a servile, submissive slave. Social isolation through lockdown and distancing have devastating effects on the human psyche as the psychological psychopaths well know and that's the real reason for them. Humans need contact with each other, discourse, closeness and touch, or they eventually, and literally, go crazy. Masks, which I will address at some length, fundamentally add to the effects of isolation and the Cult agenda to dehumanise and de-individualise the population. To do this while knowing – in fact *seeking* – this outcome is the very epitome of evil and psychologists involved in this *are* the epitome of evil. They must like all the rest of the Cult demons and their assets stand trial for crimes against humanity on a scale that defies the imagination. Psychopaths in uniform use isolation to break enemy troops and agents and make them subservient and submissive to tell what they know. The technique is rightly considered a form of torture and

torture is most certainly what has been imposed on the human population.

Clinically-insane American psychologist Harry Harlow became famous for his isolation experiments in the 1950s in which he separated baby monkeys from their mothers and imprisoned them for months on end in a metal container or 'pit of despair'. They soon began to show mental distress and depression as any idiot could have predicted. Harlow put other monkeys in steel chambers for three, six or twelve months while denying them any contact with animals or humans. He said that the effects of total social isolation for six months were 'so devastating and debilitating that we had assumed initially that twelve months of isolation would not produce any additional decrement'; but twelve months of isolation 'almost obliterated the animals socially'. This is what the Cult and its psychopaths are doing to you and your children. Even monkeys in partial isolation in which they were not allowed to form relationships with other monkeys became 'aggressive and hostile, not only to others, but also towards their own bodies'. We have seen this in the young as a consequence of lockdown. UK government psychopaths launched a public relations campaign telling people not to hug each other even after they received the 'Covid-19 vaccine' which we were told with more lies would allow a return to 'normal life'. A government source told *The Telegraph*: 'It will be along the lines that it is great that you have been vaccinated, but if you are going to visit your family and hug your grandchildren there is a chance you are going to infect people you love.' The source was apparently speaking from a secure psychiatric facility. Janet Lord, director of Birmingham University's Institute of Inflammation and Ageing, said that parents and grandparents should avoid hugging their children. Well, how can I put it, Ms Lord? Fuck off. Yep, that'll do.

Destroying the kids – where are the parents?

Observe what has happened to people enslaved and isolated by lockdown as suicide and self-harm has soared worldwide,

particularly among the young denied the freedom to associate with their friends. A study of 49,000 people in English-speaking countries concluded that almost half of young adults are at clinical risk of mental health disorders. A national survey in America of 1,000 currently enrolled high school and college students found that 5 percent reported attempting suicide during the pandemic. Data from the US CDC's National Syndromic Surveillance Program from January 1st to October 17th, 2020, revealed a 31 percent increase in mental health issues among adolescents aged 12 to 17 compared with 2019. The CDC reported that America in general suffered the biggest drop in life expectancy since World War Two as it fell by a year in the first half of 2020 as a result of 'deaths of despair' – overdoses and suicides. Deaths of despair have leapt by more than 20 percent during lockdown and include the highest number of fatal overdoses ever recorded in a single year – 81,000. Internet addiction is another consequence of being isolated at home which lowers interest in physical activities as kids fall into inertia and what's the point? Children and young people are losing hope and giving up on life, sometimes literally. A 14-year-old boy killed himself in Maryland because he had 'given up' when his school district didn't reopen; an 11-year-old boy shot himself during a zoom class; a teenager in Maine succumbed to the isolation of the 'pandemic' when he ended his life after experiencing a disrupted senior year at school. Children as young as nine have taken their life and all these stories can be repeated around the world. Careers are being destroyed before they start and that includes those in sport in which promising youngsters have not been able to take part. The plan of the psycho-psychologists is working all right. Researchers at Cambridge University found that lockdowns cause significant harm to children's mental health. Their study was published in the *Archives of Disease in Childhood*, and followed 168 children aged between 7 and 11. The researchers concluded:

During the UK lockdown, children's depression symptoms have increased substantially, relative to before lockdown. The scale of this effect has direct relevance for the continuation of different elements of lockdown policy, such as complete or partial school closures ...

... Specifically, we observed a statistically significant increase in ratings of depression, with a medium-to-large effect size. Our findings emphasise the need to incorporate the potential impact of lockdown on child mental health in planning the ongoing response to the global pandemic and the recovery from it.

Not a chance when the Cult's psycho-psychologists were getting exactly what they wanted. The UK's Royal College of Paediatrics and Child Health has urged parents to look for signs of eating disorders in children and young people after a three to four fold increase. Specialists say the 'pandemic' is a major reason behind the rise. You don't say. The College said isolation from friends during school closures, exam cancellations, loss of extra-curricular activities like sport, and an increased use of social media were all contributory factors along with fears about the virus (psycho-psychologists again), family finances, and students being forced to quarantine. Doctors said young people were becoming severely ill by the time they were seen with 'Covid' regulations reducing face-to-face consultations. Nor is it only the young that have been devastated by the psychopaths. Like all bullies and cowards the Cult is targeting the young, elderly, weak and infirm. A typical story was told by a British lady called Lynn Parker who was not allowed to visit her husband in 2020 for the last ten and half months of his life 'when he needed me most' between March 20th and when he died on December 19th. This vacates the criminal and enters the territory of evil. The emotional impact on the immune system alone is immense as are the number of people of all ages worldwide who have died as a result of Cult-demanded, Gates-demanded, lockdowns.

Isolation is torture

The experience of imposing solitary confinement on millions of prisoners around the world has shown how a large percentage become 'actively psychotic and/or acutely suicidal'. Social isolation has been found to trigger 'a specific psychiatric syndrome, characterized by hallucinations; panic attacks; overt paranoia; diminished impulse control; hypersensitivity to external stimuli; and difficulties with thinking, concentration and memory'. Juan Mendez,

a United Nations rapporteur (investigator), said that isolation is a form of torture. Research has shown that even after isolation prisoners find it far more difficult to make social connections and I remember chatting to a shop assistant after one lockdown who told me that when her young son met another child again he had no idea how to act or what to do. Hannah Flanagan, Director of Emergency Services at Journey Mental Health Center in Dane County, Wisconsin, said: 'The specificity about Covid social distancing and isolation that we've come across as contributing factors to the suicides are really new to us this year.' But they are not new to those that devised them. They are getting the effect they want as the population is psychologically dismantled to be rebuilt in a totally different way. Children and the young are particularly targeted. They will be the adults when the full-on fascist AI-controlled technocracy is planned to be imposed and they are being prepared to meekly submit. At the same time older people who still have a memory of what life was like before – and how fascist the new normal really is – are being deleted. You are going to see efforts to turn the young against the old to support this geriatric genocide. Hannah Flanagan said the big increase in suicide in her county proved that social isolation is not only harmful, but deadly. Studies have shown that isolation from others is one of the main risk factors in suicide and even more so with women. Warnings that lockdown could create a 'perfect storm' for suicide were ignored. After all this was one of the *reasons* for lockdown. Suicide, however, is only the most extreme of isolation consequences. There are many others. Dr Dhruv Khullar, assistant professor of healthcare policy at Weill Cornell Medical College, said in a *New York Times* article in 2016 long before the fake 'pandemic':

A wave of new research suggests social separation is bad for us. Individuals with less social connection have disrupted sleep patterns, altered immune systems, more inflammation and higher levels of stress hormones. One recent study found that isolation increases the risk of heart disease by 29 percent and stroke by 32 percent. Another analysis that pooled data from 70 studies and 3.4 million people found that socially isolated individuals had a 30 percent higher risk of dying in the next seven years, and that this effect was largest in middle age.

Loneliness can accelerate cognitive decline in older adults, and isolated individuals are twice as likely to die prematurely as those with more robust social interactions. These effects start early: Socially isolated children have significantly poorer health 20 years later, even after controlling for other factors. All told, loneliness is as important a risk factor for early death as obesity and smoking.

There you have proof from that one article alone four years before 2020 that those who have enforced lockdown, social distancing and isolation knew what the effect would be and that is even more so with professional psychologists that have been driving the policy across the globe. We can go back even further to the years 2000 and 2003 and the start of a major study on the effects of isolation on health by Dr Janine Gronewold and Professor Dirk M. Hermann at the University Hospital in Essen, Germany, who analysed data on 4,316 people with an average age of 59 who were recruited for the long-term research project. They found that socially isolated people are more than 40 percent more likely to have a heart attack, stroke, or other major cardiovascular event and nearly 50 percent more likely to die from any cause. Given the financial Armageddon unleashed by lockdown we should note that the study found a relationship between increased cardiovascular risk and lack of financial support. After excluding other factors social isolation was still connected to a 44 percent increased risk of cardiovascular problems and a 47 percent increased risk of death by any cause. Lack of financial support was associated with a 30 percent increase in the risk of cardiovascular health events. Dr Gronewold said it had been known for some time that feeling lonely or lacking contact with close friends and family can have an impact on physical health and the study had shown that having strong social relationships is of high importance for heart health. Gronewold said they didn't understand yet why people who are socially isolated have such poor health outcomes, but this was obviously a worrying finding, particularly during these times of prolonged social distancing. Well, it can be explained on many levels. You only have to identify the point in the body where people feel loneliness and missing people they are parted from – it's in the centre of the chest where they feel the ache of loneliness and the ache of missing people. 'My heart aches for

you' ... 'My heart aches for some company.' I will explain this more in the chapter Escaping Wetiko, but when you realise that the body is the mind – they are expressions of each other – the reason why state of the mind dictates state of the body becomes clear.

American psychologist Ranjit Powar was highlighting the effects of lockdown isolation as early as April, 2020. She said humans have evolved to be social creatures and are wired to live in interactive groups. Being isolated from family, friends and colleagues could be unbalancing and traumatic for most people and could result in short or even long-term psychological and physical health problems. An increase in levels of anxiety, aggression, depression, forgetfulness and hallucinations were possible psychological effects of isolation. 'Mental conditions may be precipitated for those with underlying pre-existing susceptibilities and show up in many others without any pre-condition.' Powar said personal relationships helped us cope with stress and if we lost this outlet for letting off steam the result can be a big emotional void which, for an average person, was difficult to deal with. 'Just a few days of isolation can cause increased levels of anxiety and depression' – so what the hell has been the effect on the global population of *18 months* of this at the time of writing? Powar said: 'Add to it the looming threat of a dreadful disease being repeatedly hammered in through the media and you have a recipe for many shades of mental and physical distress.' For those with a house and a garden it is easy to forget that billions have had to endure lockdown isolation in tiny overcrowded flats and apartments with nowhere to go outside. The psychological and physical consequences of this are unimaginable and with lunatic and abusive partners and parents the consequences have led to tremendous increases in domestic and child abuse and alcoholism as people seek to shut out the horror. Ranjit Powar said:

Staying in a confined space with family is not all a rosy picture for everyone. It can be extremely oppressive and claustrophobic for large low-income families huddled together in small single-room houses. Children here are not lucky enough to have many board/electronic games or books to keep them occupied.

Add to it the deep insecurity of running out of funds for food and basic necessities. On the other hand, there are people with dysfunctional family dynamics, such as domineering, abusive or alcoholic partners, siblings or parents which makes staying home a period of trial. Incidence of suicide and physical abuse against women has shown a worldwide increase. Heightened anxiety and depression also affect a person's immune system, making them more susceptible to illness.

To think that Powar's article was published on April 11th, 2020.

Six-feet fantasy

Social (unsocial) distancing demanded that people stay six feet or two metres apart. UK government advisor Robert Dingwall from the New and Emerging Respiratory Virus Threats Advisory Group said in a radio interview that the two-metre rule was 'conjured up out of nowhere' and was not based on science. No, it was not based on *medical* science, but it didn't come out of nowhere. The distance related to *psychological* science. Six feet/two metres was adopted in many countries and we were told by people like the criminal Anthony Fauci and his ilk that it was founded on science. Many schools could not reopen because they did not have the space for six-foot distancing. Then in March, 2021, after a year of six-foot 'science', a study published in the *Journal of Infectious Diseases* involving more than 500,000 students and almost 100,000 staff over 16 weeks revealed no significant difference in 'Covid' cases between six feet and three feet and Fauci changed his tune. Now three feet was okay. There is no difference between six feet and three *inches* when there is no 'virus' and they got away with six feet for psychological reasons for as long as they could. I hear journalists and others talk about 'unintended consequences' of lockdown. They are not *unintended* at all; they have been coldly-calculated for a specific outcome of human control and that's why super-psychopaths like Gates have called for them so vehemently. Super-psychopath psychologists have demanded them and psychopathic or clueless, spineless, politicians have gone along with them by 'following the science'. But it's not science at all. 'Science' is not what is; it's only what people can be manipulated to believe it is. The whole 'Covid' catastrophe is

founded on mind control. Three word or three statement mantras issued by the UK government are a well-known mind control technique and so we've had 'Stay home/protect the NHS/save lives', 'Stay alert/control the virus/save lives' and 'hands/face/space'. One of the most vocal proponents of extreme 'Covid' rules in the UK has been Professor Susan Michie, a member of the British Communist Party, who is not a medical professional. Michie is the director of the Centre for Behaviour Change at University College London. She is a *behavioural psychologist* and another filthy rich 'Marxist' who praised China's draconian lockdown. She was known by fellow students at Oxford University as 'Stalin's nanny' for her extreme Marxism. Michie is an influential member of the UK government's Scientific Advisory Group for Emergencies (SAGE) and behavioural manipulation groups which have dominated 'Covid' policy. She is a consultant adviser to the World Health Organization on 'Covid-19' and behaviour. Why the hell are lockdowns anything to do with her when they are claimed to be about health? Why does a behavioural psychologist from a group charged with changing the behaviour of the public want lockdown, human isolation and mandatory masks? Does that question really need an answer? Michie *absolutely* has to explain herself before a Nuremberg court when humanity takes back its world again and even more so when you see the consequences of masks that she demands are compulsory. This is a Michie classic:

The benefits of getting primary school children to wear masks is that regardless of what little degree of transmission is occurring in those age groups it could help normalise the practice. Young children wearing masks may be more likely to get their families to accept masks.

Those words alone should carry a prison sentence when you ponder on the callous disregard for children involved and what a statement it makes about the mind and motivations of Susan Michie. What a lovely lady and what she said there encapsulates the mentality of the psychopaths behind the 'Covid' horror. Let us compare what Michie said with a countrywide study in Germany published at [researchsquare.com](https://www.researchsquare.com) involving 25,000 school children and 17,854 health complaints submitted by parents. Researchers

found that masks are harming children physically, psychologically, and behaviourally with 24 health issues associated with mask wearing. They include: shortness of breath (29.7%); dizziness (26.4%); increased headaches (53%); difficulty concentrating (50%); drowsiness or fatigue (37%); and malaise (42%). Nearly a third of children experienced more sleep issues than before and a quarter developed new fears. Researchers found health issues and other impairments in 68 percent of masked children covering their faces for an average of 4.5 hours a day. Hundreds of those taking part experienced accelerated respiration, tightness in the chest, weakness, and short-term impairment of consciousness. A reminder of what Michie said again:

The benefits of getting primary school children to wear masks is that regardless of what little degree of transmission is occurring in those age groups it could help normalise the practice. Young children wearing masks may be more likely to get their families to accept masks.

Psychopaths in government and psychology now have children and young people – plus all the adults – wearing masks for hours on end while clueless teachers impose the will of the psychopaths on the young they should be protecting. What the hell are parents doing?

Cult lab rats

We have some schools already imposing on students microchipped buzzers that activate when they get 'too close' to their pals in the way they do with lab rats. How apt. To the Cult and its brain-dead servants our children *are* lab rats being conditioned to be unquestioning, dehumanised slaves for the rest of their lives. Children and young people are being weaned and frightened away from the most natural human instincts including closeness and touch. I have tracked in the books over the years how schools were banning pupils from greeting each other with a hug and the whole Cult-induced Me Too movement has terrified men and boys from a relaxed and natural interaction with female friends and work colleagues to the point where many men try never to be in a room

alone with a woman that's not their partner. Airhead celebrities have as always played their virtue-signalling part in making this happen with their gross exaggeration. For every monster like Harvey Weinstein there are at least tens of thousands of men that don't treat women like that; but everyone must be branded the same and policy changed for them as well as the monster. I am going to be using the word 'dehumanise' many times in this chapter because that is what the Cult is seeking to do and it goes very deep as we shall see. Don't let them kid you that social distancing is planned to end one day. That's not the idea. We are seeing more governments and companies funding and producing wearable gadgets to keep people apart and they would not be doing that if this was meant to be short-term. A tech start-up company backed by GCHQ, the British Intelligence and military surveillance headquarters, has created a social distancing wrist sensor that alerts people when they get too close to others. The CIA has also supported tech companies developing similar devices. The wearable sensor was developed by Tended, one of a number of start-up companies supported by GCHQ (see the CIA and DARPA). The device can be worn on the wrist or as a tag on the waistband and will vibrate whenever someone wearing the device breaches social distancing and gets anywhere near natural human contact. The company had a lucky break in that it was developing a distancing sensor when the 'Covid' hoax arrived which immediately provided a potentially enormous market. How fortunate. The government in big-time Cult-controlled Ontario in Canada is investing \$2.5 million in wearable contact tracing technology that 'will alert users if they may have been exposed to the Covid-19 in the workplace and will beep or vibrate if they are within six feet of another person'. Facedrive Inc., the technology company behind this, was founded in 2016 with funding from the Ontario Together Fund and obviously they, too, had a prophet on the board of directors. The human surveillance and control technology is called TraceSCAN and would be worn by the human cyborgs in places such as airports, workplaces, construction sites, care homes and ... *schools*.

I emphasise schools with children and young people the prime targets. You know what is planned for society as a whole if you keep your eyes on the schools. They have always been places where the state program the next generation of slaves to be its compliant worker-ants – or Woker-ants these days; but in the mist of the ‘Covid’ madness they have been transformed into mind laboratories on a scale never seen before. Teachers and head teachers are just as programmed as the kids – often more so. Children are kept apart from human interaction by walk lanes, classroom distancing, staggered meal times, masks, and the rolling-out of buzzer systems. Schools are now physically laid out as a laboratory maze for lab-rats. Lunatics at a school in Anchorage, Alaska, who should be prosecuted for child abuse, took away desks and forced children to kneel (know your place) on a mat for five hours a day while wearing a mask and using their chairs as a desk. How this was supposed to impact on a ‘virus’ only these clinically insane people can tell you and even then it would be clap-trap. The school banned recess (interaction), art classes (creativity), and physical exercise (getting body and mind moving out of inertia). Everyone behind this outrage should be in jail or better still a mental institution. The behavioural manipulators are all for this dystopian approach to schools. Professor Susan Michie, the mind-doctor and British Communist Party member, said it was wrong to say that schools were safe. They had to be made so by ‘distancing’, masks and ventilation (sitting all day in the cold). I must ask this lady round for dinner on a night I know I am going to be out and not back for weeks. She probably wouldn’t be able to make it, anyway, with all the visits to her own psychologist she must have block-booked.

Masking identity

I know how shocking it must be for you that a behaviour manipulator like Michie wants everyone to wear masks which have long been a feature of mind-control programs like the infamous MKUltra in the United States, but, there we are. We live and learn. I spent many years from 1996 to right across the millennium

researching mind control in detail on both sides of the Atlantic and elsewhere. I met a large number of mind-control survivors and many had been held captive in body and mind by MKUltra. MK stands for mind-control, but employs the German spelling in deference to the Nazis spirited out of Germany at the end of World War Two by Operation Paperclip in which the US authorities, with help from the Vatican, transported Nazi mind-controllers and engineers to America to continue their work. Many of them were behind the creation of NASA and they included Nazi scientist and SS officer Wernher von Braun who swapped designing V-2 rockets to bombard London with designing the Saturn V rockets that powered the NASA moon programme's Apollo craft. I think I may have mentioned that the Cult has no borders. Among Paperclip escapees was Josef Mengele, the Angel of Death in the Nazi concentration camps where he conducted mind and genetic experiments on children often using twins to provide a control twin to measure the impact of his 'work' on the other. If you want to observe the Cult mentality in all its extremes of evil then look into the life of Mengele. I have met many people who suffered mercilessly under Mengele in the United States where he operated under the name Dr Greene and became a stalwart of MKUltra programming and torture. Among his locations was the underground facility in the Mojave Desert in California called the China Lake Naval Weapons Station which is almost entirely below the surface. My books *The Biggest Secret*, *Children of the Matrix* and *The Perception Deception* have the detailed background to MKUltra.

The best-known MKUltra survivor is American Cathy O'Brien. I first met her and her late partner Mark Phillips at a conference in Colorado in 1996. Mark helped her escape and deprogram from decades of captivity in an offshoot of MKUltra known as Project Monarch in which 'sex slaves' were provided for the rich and famous including Father George Bush, Dick Cheney and the Clintons. Read Cathy and Mark's book *Trance-Formation of America* and if you are new to this you will be shocked to the core. I read it in 1996 shortly before, with the usual synchronicity of my life, I found

myself given a book table at the conference right next to hers. MKUltra never ended despite being very publicly exposed (only a small part of it) in the 1970s and continues in other guises. I am still in touch with Cathy. She contacted me during 2020 after masks became compulsory in many countries to tell me how they were used as part of MKUltra programming. I had been observing 'Covid regulations' and the relationship between authority and public for months. I saw techniques that I knew were employed on individuals in MKUltra being used on the global population. I had read many books and manuals on mind control including one called *Silent Weapons for Quiet Wars* which came to light in the 1980s and was a guide on how to perceptually program on a mass scale. 'Silent Weapons' refers to mind-control. I remembered a line from the manual as governments, medical authorities and law enforcement agencies have so obviously talked to – or rather at – the adult population since the 'Covid' hoax began as if they are children. The document said:

If a person is spoken to by a T.V. advertiser as if he were a twelve-year-old, then, due to suggestibility, he will, with a certain probability, respond or react to that suggestion with the uncritical response of a twelve-year-old and will reach in to his economic reservoir and deliver its energy to buy that product on impulse when he passes it in the store.

That's why authority has spoken to adults like children since all this began.

Why did Michael Jackson wear masks?

Every aspect of the 'Covid' narrative has mind-control as its central theme. Cathy O'Brien wrote an article for davidicke.com about the connection between masks and mind control. Her daughter Kelly who I first met in the 1990s was born while Cathy was still held captive in MKUltra. Kelly was forced to wear a mask as part of her programming from the age of *two* to dehumanise her, target her sense of individuality and reduce the amount of oxygen her brain and body received. *Bingo*. This is the real reason for compulsory

masks, why they have been enforced en masse, and why they seek to increase the number they demand you wear. First one, then two, with one disgraceful alleged 'doctor' recommending four which is nothing less than a death sentence. Where and how often they must be worn is being expanded for the purpose of mass mind control and damaging respiratory health which they can call 'Covid-19'. Canada's government headed by the man-child Justin Trudeau, says it's fine for children of two and older to wear masks. An insane 'study' in Italy involving just 47 children concluded there was no problem for babies as young as *four months* wearing them. Even after people were 'vaccinated' they were still told to wear masks by the criminal that is Anthony Fauci. Cathy wrote that mandating masks is allowing the authorities literally to control the air we breathe which is what was done in MKUltra. You might recall how the singer Michael Jackson wore masks and there is a reason for that. He was subjected to MKUltra mind control through Project Monarch and his psyche was scrambled by these simpletons. Cathy wrote:

In MKUltra Project Monarch mind control, Michael Jackson had to wear a mask to silence his voice so he could not reach out for help. Remember how he developed that whisper voice when he wasn't singing? Masks control the mind from the outside in, like the redefining of words is doing. By controlling what we can and cannot say for fear of being labeled racist or beaten, for example, it ultimately controls thought that drives our words and ultimately actions (or lack thereof).

Likewise, a mask muffles our speech so that we are not heard, which controls voice ... words ... mind. This is Mind Control. Masks are an obvious mind control device, and I am disturbed so many people are complying on a global scale. Masks depersonalize while making a person feel as though they have no voice. It is a barrier to others. People who would never choose to comply but are forced to wear a mask in order to keep their job, and ultimately their family fed, are compromised. They often feel shame and are subdued. People have stopped talking with each other while media controls the narrative.

The 'no voice' theme has often become literal with train passengers told not to speak to each other in case they pass on the 'virus', singing banned for the same reason and bonkers California officials telling people riding roller coasters that they cannot shout and scream. Cathy said she heard every day from healed MKUltra survivors who cannot wear a mask without flashing back on ways

their breathing was controlled – ‘from ball gags and penises to water boarding’. She said that through the years when she saw images of people in China wearing masks ‘due to pollution’ that it was really to control their oxygen levels. ‘I knew it was as much of a population control mechanism of depersonalisation as are burkas’, she said. Masks are another Chinese communist/fascist method of control that has been swept across the West as the West becomes China at lightning speed since we entered 2020.

Mask-19

There are other reasons for mandatory masks and these include destroying respiratory health to call it ‘Covid-19’ and stunting brain development of children and the young. Dr Margarite Griesz-Brisson MD, PhD, is a Consultant Neurologist and Neurophysiologist and the Founder and Medical Director of the London Neurology and Pain Clinic. Her CV goes down the street and round the corner. She is clearly someone who cares about people and won’t parrot the propaganda. Griesz-Brisson has a PhD in pharmacology, with special interest in neurotoxicology, environmental medicine, neuroregeneration and neuroplasticity (the way the brain can change in the light of information received). She went public in October, 2020, with a passionate warning about the effects of mask-wearing laws:

The reinhalation of our exhaled air will without a doubt create oxygen deficiency and a flooding of carbon dioxide. We know that the human brain is very sensitive to oxygen deprivation. There are nerve cells for example in the hippocampus that can’t be longer than 3 minutes without oxygen – they cannot survive. The acute warning symptoms are headaches, drowsiness, dizziness, issues in concentration, slowing down of reaction time – reactions of the cognitive system.

Oh, I know, let’s tell bus, truck and taxi drivers to wear them and people working machinery. How about pilots, doctors and police? Griesz-Brisson makes the important point that while the symptoms she mentions may fade as the body readjusts this does not alter the fact that people continue to operate in oxygen deficit with long list of

potential consequences. She said it was well known that neurodegenerative diseases take years or decades to develop. 'If today you forget your phone number, the breakdown in your brain would have already started 20 or 30 years ago.' She said degenerative processes in your brain are getting amplified as your oxygen deprivation continues through wearing a mask. Nerve cells in the brain are unable to divide themselves normally in these circumstances and lost nerve cells will no longer be regenerated. 'What is gone is gone.' Now consider that people like shop workers and *schoolchildren* are wearing masks for hours every day. What in the name of sanity is going to be happening to them? 'I do not wear a mask, I need my brain to think', Griesz-Brisson said, 'I want to have a clear head when I deal with my patients and not be in a carbon dioxide-induced anaesthesia'. If you are told to wear a mask anywhere ask the organisation, police, store, whatever, for their risk assessment on the dangers and negative effects on mind and body of enforcing mask-wearing. They won't have one because it has never been done not even by government. All of them must be subject to class-action lawsuits as the consequences come to light. They don't do mask risk assessments for an obvious reason. They know what the conclusions would be and independent scientific studies that *have* been done tell a horror story of consequences.

'Masks are criminal'

Dr Griesz-Brisson said that for children and adolescents, masks are an absolute no-no. They had an extremely active and adaptive immune system and their brain was incredibly active with so much to learn. 'The child's brain, or the youth's brain, is thirsting for oxygen.' The more metabolically active an organ was, the more oxygen it required; and in children and adolescents every organ was metabolically active. Griesz-Brisson said that to deprive a child's or adolescent's brain of oxygen, or to restrict it in any way, was not only dangerous to their health, it was absolutely criminal. 'Oxygen deficiency inhibits the development of the brain, and the damage that has taken place as a result CANNOT be reversed.' Mind

manipulators of MKUltra put masks on two-year-olds they wanted to neurologically rewire and you can see why. Griesz-Brisson said a child needs the brain to learn and the brain needs oxygen to function. 'We don't need a clinical study for that. This is simple, indisputable physiology.' Consciously and purposely induced oxygen deficiency was an absolutely deliberate health hazard, and an absolute medical contraindication which means that 'this drug, this therapy, this method or measure should not be used, and is not allowed to be used'. To coerce an entire population to use an absolute medical contraindication by force, she said, there had to be definite and serious reasons and the reasons must be presented to competent interdisciplinary and independent bodies to be verified and authorised. She had this warning of the consequences that were coming if mask wearing continued:

When, in ten years, dementia is going to increase exponentially, and the younger generations couldn't reach their god-given potential, it won't help to say 'we didn't need the masks'. I know how damaging oxygen deprivation is for the brain, cardiologists know how damaging it is for the heart, pulmonologists know how damaging it is for the lungs. Oxygen deprivation damages every single organ. Where are our health departments, our health insurance, our medical associations? It would have been their duty to be vehemently against the lockdown and to stop it and stop it from the very beginning.

Why do the medical boards issue punishments to doctors who give people exemptions? Does the person or the doctor seriously have to prove that oxygen deprivation harms people? What kind of medicine are our doctors and medical associations representing? Who is responsible for this crime? The ones who want to enforce it? The ones who let it happen and play along, or the ones who don't prevent it?

All of the organisations and people she mentions there either answer directly to the Cult or do whatever hierarchical levels above them tell them to do. The outcome of both is the same. 'It's not about masks, it's not about viruses, it's certainly not about your health', Griesz-Brisson said. 'It is about much, much more. I am not participating. I am not afraid.' They were taking our air to breathe and there was no unfounded medical exemption from face masks. Oxygen deprivation was dangerous for every single brain. It had to be the free decision of every human being whether they want to

wear a mask that was absolutely ineffective to protect themselves from a virus. She ended by rightly identifying where the responsibility lies for all this:

The imperative of the hour is personal responsibility. We are responsible for what we think, not the media. We are responsible for what we do, not our superiors. We are responsible for our health, not the World Health Organization. And we are responsible for what happens in our country, not the government.

Halle-bloody-lujah.

But surgeons wear masks, right?

Independent studies of mask-wearing have produced a long list of reports detailing mental, emotional and physical dangers. What a definition of insanity to see police officers imposing mask-wearing on the public which will cumulatively damage their health while the police themselves wear masks that will cumulatively damage *their* health. It's utter madness and both public and police do this because 'the government says so' – yes a government of brain-donor idiots like UK Health Secretary Matt Hancock reading the 'follow the science' scripts of psychopathic, lunatic psychologists. The response you get from Stockholm syndrome sufferers defending the very authorities that are destroying them and their families is that 'surgeons wear masks'. This is considered the game, set and match that they must work and don't cause oxygen deficit. Well, actually, scientific studies have shown that they *do* and oxygen levels are monitored in operating theatres to compensate. Surgeons wear masks to stop spittle and such like dropping into open wounds – not to stop 'viral particles' which are so miniscule they can only be seen through an electron microscope. Holes in the masks are significantly bigger than 'viral particles' and if you sneeze or cough they will breach the mask. I watched an incredibly disingenuous 'experiment' that claimed to prove that masks work in catching 'virus' material from the mouth and nose. They did this with a slow motion camera and the mask did block big stuff which stayed inside the mask and

against the face to be breathed in or cause infections on the face as we have seen with many children. 'Viral particles', however, would never have been picked up by the camera as they came through the mask when they are far too small to be seen. The 'experiment' was therefore disingenuous *and* useless.

Studies have concluded that wearing masks in operating theatres (and thus elsewhere) make no difference to preventing infection while the opposite is true with toxic shite building up in the mask and this had led to an explosion in tooth decay and gum disease dubbed by dentists 'mask mouth'. You might have seen the Internet video of a furious American doctor urging people to take off their masks after a four-year-old patient had been rushed to hospital the night before and nearly died with a lung infection that doctors sourced to mask wearing. A study in the journal *Cancer Discovery* found that inhalation of harmful microbes can contribute to advanced stage lung cancer in adults and long-term use of masks can help breed dangerous pathogens. Microbiologists have said frequent mask wearing creates a moist environment in which microbes can grow and proliferate before entering the lungs. The Canadian Agency for Drugs and Technologies in Health, or CADTH, a Canadian national organisation that provides research and analysis to healthcare decision-makers, said this as long ago as 2013 in a report entitled 'Use of Surgical Masks in the Operating Room: A Review of the Clinical Effectiveness and Guidelines'. It said:

- No evidence was found to support the use of surgical face masks to reduce the frequency of surgical site infections
- No evidence was found on the effectiveness of wearing surgical face masks to protect staff from infectious material in the operating room.
- Guidelines recommend the use of surgical face masks by staff in the operating room to protect both operating room staff and patients (despite the lack of evidence).

We were told that the world could go back to 'normal' with the arrival of the 'vaccines'. When they came, fraudulent as they are, the story changed as I knew that it would. We are in the midst of transforming 'normal', not going back to it. Mary Ramsay, head of immunisation at Public Health England, echoed the words of US criminal Anthony Fauci who said masks and other regulations must stay no matter if people are vaccinated. The Fauci idiot continued to wear two masks – different colours so both could be clearly seen – after he *claimed* to have been vaccinated. Senator Rand Paul told Fauci in one exchange that his double-masks were 'theatre' and he was right. It's all theatre. Mary Ramsay back-tracked on the vaccine-return-to-normal theme when she said the public may need to wear masks and social-distance for years despite the jabs. 'People have got used to those lower-level restrictions now, and [they] can live with them', she said telling us what the idea has been all along. 'The vaccine does not give you a pass, even if you have had it, you must continue to follow all the guidelines' said a Public Health England statement which reneged on what we had been told before and made having the 'vaccine' irrelevant to 'normality' even by the official story. Spain's fascist government trumped everyone by passing a law mandating the wearing of masks on the beach and even when swimming in the sea. The move would have devastated what's left of the Spanish tourist industry, posed potential breathing dangers to swimmers and had Northern European sunbathers walking around with their forehead brown and the rest of their face white as a sheet. The ruling was so crazy that it had to be retracted after pressure from public and tourist industry, but it confirmed where the Cult wants to go with masks and how clinically insane authority has become. The determination to make masks permanent and hide the serious dangers to body and mind can be seen in the censorship of scientist Professor Denis Rancourt by Bill Gates-funded academic publishing website ResearchGate over his papers exposing the dangers and uselessness of masks. Rancourt said:

ResearchGate today has permanently locked my account, which I have had since 2015. Their reasons graphically show the nature of their attack against democracy, and their corruption of

science ... By their obscene non-logic, a scientific review of science articles reporting on harms caused by face masks has a 'potential to cause harm'. No criticism of the psychological device (face masks) is tolerated, if the said criticism shows potential to influence public policy.

This is what happens in a fascist world.

Where are the 'greens' (again)?

Other dangers of wearing masks especially regularly relate to the inhalation of minute plastic fibres into the lungs and the deluge of discarded masks in the environment and oceans. Estimates predicted that more than 1.5 billion disposable masks will end up in the world's oceans every year polluting the water with tons of plastic and endangering marine wildlife. Studies project that humans are using 129 billion face masks each month worldwide – about three million a minute. Most are disposable and made from plastic, non-biodegradable microfibers that break down into smaller plastic particles that become widespread in ecosystems. They are littering cities, clogging sewage channels and turning up in bodies of water. I have written in other books about the immense amounts of microplastics from endless sources now being absorbed into the body. Rolf Halden, director of the Arizona State University (ASU) Biodesign Center for Environmental Health Engineering, was the senior researcher in a 2020 study that analysed 47 human tissue samples and found microplastics in all of them. 'We have detected these chemicals of plastics in every single organ that we have investigated', he said. I wrote in *The Answer* about the world being deluged with microplastics. A study by the Worldwide Fund for Nature (WWF) found that people are consuming on average every week some 2,000 tiny pieces of plastic mostly through water and also through marine life and the air. Every year humans are ingesting enough microplastics to fill a heaped dinner plate and in a life-time of 79 years it is enough to fill two large waste bins. Marco Lambertini, WWF International director general said: 'Not only are plastics polluting our oceans and waterways and killing marine life – it's in all of us and we can't escape consuming plastics,' American

geologists found tiny plastic fibres, beads and shards in rainwater samples collected from the remote slopes of the Rocky Mountain National Park near Denver, Colorado. Their report was headed: 'It is raining plastic.' Rachel Adams, senior lecturer in Biomedical Science at Cardiff Metropolitan University, said that among health consequences are internal inflammation and immune responses to a 'foreign body'. She further pointed out that microplastics become carriers of toxins including mercury, pesticides and dioxins (a known cause of cancer and reproductive and developmental problems). These toxins accumulate in the fatty tissues once they enter the body through microplastics. Now this is being compounded massively by people putting plastic on their face and throwing it away.

Workers exposed to polypropylene plastic fibres known as 'flock' have developed 'flock worker's lung' from inhaling small pieces of the flock fibres which can damage lung tissue, reduce breathing capacity and exacerbate other respiratory problems. *Now ...* commonly used surgical masks have three layers of melt-blown textiles made of ... polypropylene. We have billions of people putting these microplastics against their mouth, nose and face for hours at a time day after day in the form of masks. How does anyone think that will work out? I mean – what could possibly go wrong? We posted a number of scientific studies on this at davidicke.com, but when I went back to them as I was writing this book the links to the science research website where they were hosted were dead. Anything that challenges the official narrative in any way is either censored or vilified. The official narrative is so unsupportable by the evidence that only deleting the truth can protect it. A study by Chinese scientists still survived – with the usual twist which it why it was still active, I guess. Yes, they found that virtually all the masks they tested increased the daily intake of microplastic fibres, but people should still wear them because the danger from the 'virus' was worse said the crazy 'team' from the Institute of Hydrobiology in Wuhan. Scientists first discovered microplastics in lung tissue of some patients who died of lung cancer

in the 1990s. Subsequent studies have confirmed the potential health damage with the plastic degrading slowly and remaining in the lungs to accumulate in volume. Wuhan researchers used a machine simulating human breathing to establish that masks shed up to nearly 4,000 microplastic fibres in a month with reused masks producing more. Scientists said some masks are laced with toxic chemicals and a variety of compounds seriously restricted for both health and environmental reasons. They include cobalt (used in blue dye) and formaldehyde known to cause watery eyes, burning sensations in the eyes, nose, and throat, plus coughing, wheezing and nausea. No – that must be ‘Covid-19’.

Mask ‘worms’

There is another and potentially even more sinister content of masks. Mostly new masks of different makes filmed under a microscope around the world have been found to contain strange black fibres or ‘worms’ that appear to move or ‘crawl’ by themselves and react to heat and water. The nearest I have seen to them are the self-replicating fibres that are pulled out through the skin of those suffering from Morgellons disease which has been connected to the phenomena of ‘chemtrails’ which I will bring into the story later on. Morgellons fibres continue to grow outside the body and have a form of artificial intelligence. Black ‘worm’ fibres in masks have that kind of feel to them and there is a nanotechnology technique called ‘worm micelles’ which carry and release drugs or anything else you want to deliver to the body. For sure the suppression of humanity by mind altering drugs is the Cult agenda big time and the more excuses they can find to gain access to the body the more opportunities there are to make that happen whether through ‘vaccines’ or masks pushed against the mouth and nose for hours on end.

So let us summarise the pros and cons of masks:

Against masks: Breathing in your own carbon dioxide; depriving the body and brain of sufficient oxygen; build-up of toxins in the mask that can be breathed into the lungs and cause rashes on the face and 'mask-mouth'; breathing microplastic fibres and toxic chemicals into the lungs; dehumanisation and deleting individualisation by literally making people faceless; destroying human emotional interaction through facial expression and deleting parental connection with their babies which look for guidance to their facial expression.

For masks: They don't protect you from a 'virus' that doesn't exist and even if it did 'viral' particles are so minute they are smaller than the holes in the mask.

Governments, police, supermarkets, businesses, transport companies, and all the rest who seek to impose masks have done no risk assessment on their consequences for health and psychology and are now open to group lawsuits when the impact becomes clear with a cumulative epidemic of respiratory and other disease. Authorities will try to exploit these effects and hide the real cause by dubbing them 'Covid-19'. Can you imagine setting out to force the population to wear health-destroying masks without doing any assessment of the risks? It is criminal and it is evil, but then how many people targeted in this way, who see their children told to wear them all day at school, have asked for a risk assessment? Billions can't be imposed upon by the few unless the billions allow it. Oh, yes, with just a tinge of irony, 85 percent of all masks made worldwide come from *China*.

Wash your hands in toxic shite

'Covid' rules include the use of toxic sanitisers and again the health consequences of constantly applying toxins to be absorbed through the skin is obvious to any level of Renegade Mind. America's Food and Drug Administration (FDA) said that sanitisers are drugs and issued a warning about 75 dangerous brands which contain

methanol used in antifreeze and can cause death, kidney damage and blindness. The FDA circulated the following warning even for those brands that it claims to be safe:

Store hand sanitizer out of the reach of pets and children, and children should use it only with adult supervision. Do not drink hand sanitizer. This is particularly important for young children, especially toddlers, who may be attracted by the pleasant smell or brightly colored bottles of hand sanitizer.

Drinking even a small amount of hand sanitizer can cause alcohol poisoning in children. (However, there is no need to be concerned if your children eat with or lick their hands after using hand sanitizer.) During this coronavirus pandemic, poison control centers have had an increase in calls about accidental ingestion of hand sanitizer, so it is important that adults monitor young children's use.

Do not allow pets to swallow hand sanitizer. If you think your pet has eaten something potentially dangerous, call your veterinarian or a pet poison control center right away. Hand sanitizer is flammable and should be stored away from heat and flames. When using hand sanitizer, rub your hands until they feel completely dry before performing activities that may involve heat, sparks, static electricity, or open flames.

There you go, perfectly safe, then, and that's without even a mention of the toxins absorbed through the skin. Come on kids – sanitise your hands everywhere you go. It will save you from the 'virus'. Put all these elements together of the 'Covid' normal and see how much health and psychology is being cumulatively damaged, even devastated, to 'protect your health'. Makes sense, right? They are only imposing these things because they care, right? *Right?*

Submitting to insanity

Psychological reframing of the population goes very deep and is done in many less obvious ways. I hear people say how contradictory and crazy 'Covid' rules are and how they are ever changing. This is explained away by dismissing those involved as idiots. It is a big mistake. The Cult is delighted if its cold calculation is perceived as incompetence and idiocy when it is anything but. Oh, yes, there are idiots within the system – lots of them – but they are *administering* the Cult agenda, mostly unknowingly. They are not deciding and dictating it. The bulwark against tyranny is self-

respect, always has been, always will be. It is self-respect that has broken every tyranny in history. By its very nature self-respect will not bow to oppression and its perpetrators. There is so little self-respect that it's always the few that overturn dictators. Many may eventually follow, but the few with the iron spines (self-respect) kick it off and generate the momentum. The Cult targets self-respect in the knowledge that once this has gone only submission remains. Crazy, contradictory, ever-changing 'Covid' rules are systematically applied by psychologists to delete self-respect. They *want* you to see that the rules make no sense. It is one thing to decide to do something when *you* have made the choice based on evidence and logic. You still retain your self-respect. It is quite another when you can see what you are being told to do is insane, ridiculous and makes no sense, and *yet you still do it*. Your self-respect is extinguished and this has been happening as ever more obviously stupid and nonsensical things have been demanded and the great majority have complied even when they can see they are stupid and nonsensical.

People walk around in face-nappies knowing they are damaging their health and make no difference to a 'virus'. They do it in fear of not doing it. I know it's daft, but I'll do it anyway. When that happens something dies inside of you and submissive reframing has begun. Next there's a need to hide from yourself that you have conceded your self-respect and you convince yourself that you have not really submitted to fear and intimidation. You begin to believe that you are complying with craziness because it's the right thing to do. When first you concede your self-respect of $2+2 = 4$ to $2+2 = 5$ you *know* you are compromising your self-respect. Gradually to avoid facing that fact you begin to *believe* that $2+2=5$. You have been reframed and I have been watching this process happening in the human psyche on an industrial scale. The Cult is working to break your spirit and one of its major tools in that war is humiliation. I read how former American soldier Bradley Manning (later Chelsea Manning after a sex-change) was treated after being jailed for supplying WikiLeaks with documents exposing the enormity of

government and elite mendacity. Manning was isolated in solitary confinement for eight months, put under 24-hour surveillance, forced to hand over clothing before going to bed, and stand naked for every roll call. This is systematic humiliation. The introduction of anal swab 'Covid' tests in China has been done for the same reason to delete self-respect and induce compliant submission. Anal swabs are mandatory for incoming passengers in parts of China and American diplomats have said they were forced to undergo the indignity which would have been calculated humiliation by the Cult-owned Chinese government that has America in its sights.

Government-people: An abusive relationship

Spirit-breaking psychological techniques include giving people hope and apparent respite from tyranny only to take it away again. This happened in the UK during Christmas, 2020, when the psycho-psychologists and their political lackeys announced an easing of restrictions over the holiday only to reimpose them almost immediately on the basis of yet another lie. There is a big psychological difference between getting used to oppression and being given hope of relief only to have that dashed. Psychologists know this and we have seen the technique used repeatedly. Then there is traumatising people before you introduce more extreme regulations that require compliance. A perfect case was the announcement by the dark and sinister Whitty and Vallance in the UK that 'new data' predicted that 4,000 could die every day over the winter of 2020/2021 if we did not lockdown again. I think they call it lying and after traumatising people with that claim out came Jackboot Johnson the next day with new curbs on human freedom. Psychologists know that a frightened and traumatised mind becomes suggestable to submission and behaviour reframing. Underpinning all this has been to make people fearful and suspicious of each other and see themselves as a potential danger to others. In league with deleted self-respect you have the perfect psychological recipe for self-loathing. The relationship between authority and public is now demonstrably the same as that of

subservience to an abusive partner. These are signs of an abusive relationship explained by psychologist Leslie Becker-Phelps:

Psychological and emotional abuse: Undermining a partner's self-worth with verbal attacks, name-calling, and belittling. Humiliating the partner in public, unjustly accusing them of having an affair, or interrogating them about their every behavior. Keeping partner confused or off balance by saying they were just kidding or blaming the partner for 'making' them act this way ... Feigning in public that they care while turning against them in private. This leads to victims frequently feeling confused, incompetent, unworthy, hopeless, and chronically self-doubting. [Apply these techniques to how governments have treated the population since New Year, 2020, and the parallels are obvious.]

Physical abuse: The abuser might physically harm their partner in a range of ways, such as grabbing, hitting, punching, or shoving them. They might throw objects at them or harm them with a weapon. [Observe the physical harm imposed by masks, lockdown, and so on.]

Threats and intimidation: One way abusers keep their partners in line is by instilling fear. They might be verbally threatening, or give threatening looks or gestures. Abusers often make it known that they are tracking their partner's every move. They might destroy their partner's possessions, threaten to harm them, or threaten to harm their family members. Not surprisingly, victims of this abuse often feel anxiety, fear, and panic. [No words necessary.]

Isolation: Abusers often limit their partner's activities, forbidding them to talk or interact with friends or family. They might limit access to a car or even turn off their phone. All of this might be done by physically holding them against their will, but is often accomplished through psychological abuse and intimidation. The more isolated a person feels, the fewer resources they have to help gain perspective on their situation and to escape from it. [No words necessary.]

Economic abuse: Abusers often make their partners beholden to them for money by controlling access to funds of any kind. They might prevent their partner from getting a job or withhold access to money they earn from a job. This creates financial dependency that makes leaving the relationship very difficult. [See destruction of livelihoods and the proposed meagre 'guaranteed income' so long as you do whatever you are told.]

Using children: An abuser might disparage their partner's parenting skills, tell their children lies about their partner, threaten to take custody of their children, or threaten to harm their children. These tactics instil fear and often elicit compliance. [See reframed social service mafia and how children are being mercilessly abused by the state over 'Covid' while their parents look on too frightened to do anything.]

A further recurring trait in an abusive relationship is the abused blaming themselves for their abuse and making excuses for the abuser. We have the public blaming each other for lockdown abuse by government and many making excuses for the government while attacking those who challenge the government. How often we have heard authorities say that rules are being imposed or reimposed only because people have refused to 'behave' and follow the rules. We don't want to do it – it's *you*.

Renegade Minds are an antidote to all of these things. They will never concede their self-respect no matter what the circumstances. Even when apparent humiliation is heaped upon them they laugh in its face and reflect back the humiliation on the abuser where it belongs. Renegade Minds will never wear masks they know are only imposed to humiliate, suppress and damage both physically and psychologically. Consequences will take care of themselves and they will never break their spirit or cause them to concede to tyranny. UK newspaper columnist Peter Hitchens was one of the few in the mainstream media to speak out against lockdowns and forced vaccinations. He then announced he had taken the jab. He wanted to see family members abroad and he believed vaccine passports were inevitable even though they had not yet been introduced. Hitchens

has a questioning and critical mind, but not a Renegade one. If he had no amount of pressure would have made him concede. Hitchens excused his action by saying that the battle has been lost. Renegade Minds never accept defeat when freedom is at stake and even if they are the last one standing the self-respect of not submitting to tyranny is more important than any outcome or any consequence.

That's why Renegade Minds are the only minds that ever changed anything worth changing.

CHAPTER EIGHT

'Reframing' insanity

Insanity is relative. It depends on who has who locked in what cage
Ray Bradbury

Reframing' a mind means simply to change its perception and behaviour. This can be done subconsciously to such an extent that subjects have no idea they have been 'reframed' while to any observer changes in behaviour and attitudes are obvious.

Human society is being reframed on a ginormous scale since the start of 2020 and here we have the reason why psychologists rather than doctors have been calling the shots. Ask most people who have succumbed to 'Covid' reframing if they have changed and most will say 'no'; but they *have* and fundamentally. The Cult's long-game has been preparing for these times since way back and crucial to that has been to prepare both population and officialdom mentally and emotionally. To use the mind-control parlance they had to reframe the population with a mentality that would submit to fascism and reframe those in government and law enforcement to impose fascism or at least go along with it. The result has been the fact-deleted mindlessness of 'Wokeness' and officialdom that has either enthusiastically or unquestioningly imposed global tyranny demanded by reframed politicians on behalf of psychopathic and deeply evil cultists. 'Cognitive reframing' identifies and challenges the way someone sees the world in the form of situations, experiences and emotions and then restructures those perceptions to view the same set of circumstances in a different way. This can have

benefits if the attitudes are personally destructive while on the other side it has the potential for individual and collective mind control which the subject has no idea has even happened.

Cognitive therapy was developed in the 1960s by Aaron T. Beck who was born in Rhode Island in 1921 as the son of Jewish immigrants from the Ukraine. He became interested in the techniques as a treatment for depression. Beck's daughter Judith S. Beck is prominent in the same field and they founded the Beck Institute for Cognitive Behavior Therapy in Philadelphia in 1994. Cognitive reframing, however, began to be used worldwide by those with a very dark agenda. The Cult reframes politicians to change their attitudes and actions until they are completely at odds with what they once appeared to stand for. The same has been happening to government administrators at all levels, law enforcement, military and the human population. Cultists love mind control for two main reasons: It allows them to control what people think, do and say to secure agenda advancement and, by definition, it calms their legendary insecurity and fear of the unexpected. I have studied mind control since the time I travelled America in 1996. I may have been talking to next to no one in terms of an audience in those years, but my goodness did I gather a phenomenal amount of information and knowledge about so many things including the techniques of mind control. I have described this in detail in other books going back to *The Biggest Secret* in 1998. I met a very large number of people recovering from MKUltra and its offshoots and successors and I began to see how these same techniques were being used on the population in general. This was never more obvious than since the 'Covid' hoax began.

Reframing the enforcers

I have observed over the last two decades and more the very clear transformation in the dynamic between the police, officialdom and the public. I tracked this in the books as the relationship mutated from one of serving the public to seeing them as almost the enemy and certainly a lower caste. There has always been a class divide

based on income and always been some psychopathic, corrupt, and big-I-am police officers. This was different. Wholesale change was unfolding in the collective dynamic; it was less about money and far more about position and perceived power. An us-and-them was emerging. Noses were lifted skyward by government administration and law enforcement and their attitude to the public they were *supposed* to be serving changed to one of increasing contempt, superiority and control. The transformation was so clear and widespread that it had to be planned. Collective attitudes and dynamics do not change naturally and organically that quickly on that scale. I then came across an organisation in Britain called Common Purpose created in the late 1980s by Julia Middleton who would work in the office of Deputy Prime Minister John Prescott during the long and disastrous premiership of war criminal Tony Blair. When Blair speaks the Cult is speaking and the man should have been in jail a long time ago. Common Purpose proclaims itself to be one of the biggest 'leadership development' organisations in the world while functioning as a *charity* with all the financial benefits which come from that. It hosts 'leadership development' courses and programmes all over the world and claims to have 'brought together' what it calls 'leaders' from more than 100 countries on six continents. The modus operandi of Common Purpose can be compared with the work of the UK government's reframing network that includes the Behavioural Insights Team 'nudge unit' and 'Covid' reframing specialists at SPI-B. WikiLeaks described Common Purpose long ago as 'a hidden virus in our government and schools' which is unknown to the general public: 'It recruits and trains "leaders" to be loyal to the directives of Common Purpose and the EU, instead of to their own departments, which they then undermine or subvert, the NHS [National Health Service] being an example.' This is a vital point to understand the 'Covid' hoax. The NHS, and its equivalent around the world, has been utterly reframed in terms of administrators and much of the medical personnel with the transformation underpinned by recruitment policies. The outcome has been the criminal and psychopathic behaviour of the

NHS over 'Covid' and we have seen the same in every other major country. WikiLeaks said Common Purpose trainees are 'learning to rule without regard to democracy' and to usher in a police state (current events explained). Common Purpose operated like a 'glue' and had members in the NHS, BBC, police, legal profession, church, many of Britain's 7,000 quangos, local councils, the Civil Service, government ministries and Parliament, and controlled many RDA's (Regional Development Agencies). Here we have one answer for how and why British institutions and their like in other countries have changed so negatively in relation to the public. This further explains how and why the beyond-disgraceful reframed BBC has become a propaganda arm of 'Covid' fascism. They are all part of a network pursuing the same goal.

By 2019 Common Purpose was quoting a figure of 85,000 'leaders' that had attended its programmes. These 'students' of all ages are known as Common Purpose 'graduates' and they consist of government, state and local government officials and administrators, police chiefs and officers, and a whole range of others operating within the national, local and global establishment. Cressida Dick, Commissioner of the London Metropolitan Police, is the Common Purpose graduate who was the 'Gold Commander' that oversaw what can only be described as the murder of Brazilian electrician Jean Charles de Menezes in 2005. He was held down by psychopathic police and shot seven times in the head by a psychopathic lunatic after being mistaken for a terrorist when he was just a bloke going about his day. Dick authorised officers to pursue and keep surveillance on de Menezes and ordered that he be stopped from entering the underground train system. Police psychopaths took her at her word clearly. She was 'disciplined' for this outrage by being *promoted* – eventually to the top of the 'Met' police where she has been a disaster. Many Chief Constables controlling the police in different parts of the UK are and have been Common Purpose graduates. I have heard the 'graduate' network described as a sort of Mafia or secret society operating within the fabric of government at all levels pursuing a collective policy

ingrained at Common Purpose training events. Founder Julia Middleton herself has said:

Locally and internationally, Common Purpose graduates will be 'lighting small fires' to create change in their organisations and communities ... The Common Purpose effect is best illustrated by the many stories of small changes brought about by leaders, who themselves have changed.

A Common Purpose mission statement declared:

Common Purpose aims to improve the way society works by expanding the vision, decision-making ability and influence of all kinds of leaders. The organisation runs a variety of educational programmes for leaders of all ages, backgrounds and sectors, in order to provide them with the inspirational, information and opportunities they need to change the world.

Yes, but into what? Since 2020 the answer has become clear.

NLP and the Delphi technique

Common Purpose would seem to be a perfect name or would common programming be better? One of the foundation methods of reaching 'consensus' (group think) is by setting the agenda theme and then encouraging, cajoling or pressuring everyone to agree a 'consensus' in line with the core theme promoted by Common Purpose. The methodology involves the 'Delphi technique', or an adaption of it, in which opinions are expressed that are summarised by a 'facilitator or change agent' at each stage. Participants are 'encouraged' to modify their views in the light of what others have said. Stage by stage the former individual opinions are merged into group consensus which just happens to be what Common Purpose wants them to believe. A key part of this is to marginalise anyone refusing to concede to group think and turn the group against them to apply pressure to conform. We are seeing this very technique used on the general population to make 'Covid' group-thinkers hostile to those who have seen through the bullshit. People can be reframed by using perception manipulation methods such as Neuro-Linguistic Programming (NLP) in which you change perception with the use of

carefully constructed language. An NLP website described the technique this way:

... A method of influencing brain behaviour (the 'neuro' part of the phrase) through the use of language (the 'linguistic' part) and other types of communication to enable a person to 'recode' the way the brain responds to stimuli (that's the 'programming') and manifest new and better behaviours. Neuro-Linguistic Programming often incorporates hypnosis and self-hypnosis to help achieve the change (or 'programming') that is wanted.

British alternative media operation UKColumn has done very detailed research into Common Purpose over a long period. I quoted co-founder and former naval officer Brian Gerrish in my book *Remember Who You Are*, published in 2011, as saying the following years before current times:

It is interesting that many of the mothers who have had children taken by the State speak of the Social Services people being icily cool, emotionless and, as two ladies said in slightly different words, '... like little robots'. We know that NLP is cumulative, so people can be given small imperceptible doses of NLP in a course here, another in a few months, next year etc. In this way, major changes are accrued in their personality, but the day by day change is almost unnoticeable.

In these and other ways 'graduates' have had their perceptions uniformly reframed and they return to their roles in the institutions of government, law enforcement, legal profession, military, 'education', the UK National Health Service and the whole swathe of the establishment structure to pursue a common agenda preparing for the 'post-industrial', 'post-democratic' society. I say 'preparing' but we are now there. 'Post-industrial' is code for the Great Reset and 'post-democratic' is 'Covid' fascism. UKColumn has spoken to partners of those who have attended Common Purpose 'training'. They have described how personalities and attitudes of 'graduates' changed very noticeably for the worse by the time they had completed the course. They had been 'reframed' and told they are the 'leaders' – the special ones – who know better than the population. There has also been the very demonstrable recruitment of psychopaths and narcissists into government administration at all

levels and law enforcement. If you want psychopathy hire psychopaths and you get a simple cause and effect. If you want administrators, police officers and 'leaders' to perceive the public as lesser beings who don't matter then employ narcissists. These personalities are identified using 'psychometrics' that identifies knowledge, abilities, attitudes and personality traits, mostly through carefully-designed questionnaires and tests. As this policy has passed through the decades we have had power-crazy, power-trippers appointed into law enforcement, security and government administration in preparation for current times and the dynamic between public and law enforcement/officialdom has been transformed. UKColumn's Brian Gerrish said of the narcissistic personality:

Their love of themselves and power automatically means that they will crush others who get in their way. I received a major piece of the puzzle when a friend pointed out that when they made public officials re-apply for their own jobs several years ago they were also required to do psychometric tests. This was undoubtedly the start of the screening process to get 'their' sort of people in post.

How obvious that has been since 2020 although it was clear what was happening long before if people paid attention to the changing public-establishment dynamic.

Change agents

At the centre of events in 'Covid' Britain is the National Health Service (NHS) which has behaved disgracefully in slavishly following the Cult agenda. The NHS management structure is awash with Common Purpose graduates or 'change agents' working to a common cause. Helen Bevan, a Chief of Service Transformation at the NHS Institute for Innovation and Improvement, co-authored a document called 'Towards a million change agents, a review of the social movements literature: implications for large scale change in the NHS'. The document compared a project management approach to that of change and social movements where 'people change

themselves and each other – peer to peer’. Two definitions given for a ‘social movement’ were:

A group of people who consciously attempt to build a radically new social order; involves people of a broad range of social backgrounds; and deploys politically confrontational and socially disruptive tactics – Cyrus Zirakzadeh 1997

Collective challenges, based on common purposes and social solidarities, in sustained interaction with elites, opponents, and authorities – Sidney Tarrow 1994

Helen Bevan wrote another NHS document in which she defined ‘framing’ as ‘the process by which leaders construct, articulate and put across their message in a powerful and compelling way in order to win people to their cause and call them to action’. I think I could come up with another definition that would be rather more accurate. The National Health Service and institutions of Britain and the wider world have been taken over by reframed ‘change agents’ and that includes everything from the United Nations to national governments, local councils and social services which have been kidnapping children from loving parents on an extraordinary and gathering scale on the road to the end of parenthood altogether. Children from loving homes are stolen and kidnapped by the state and put into the ‘care’ (inversion) of the local authority through council homes, foster parents and forced adoption. At the same time children are allowed to be abused without response while many are under council ‘care’. UKColumn highlighted the Common Purpose connection between South Yorkshire Police and Rotherham council officers in the case of the scandal in that area of the sexual exploitation of children to which the authorities turned not one blind eye, but both:

We were alarmed to discover that the Chief Executive, the Strategic Director of Children and Young People's Services, the Manager for the Local Strategic Partnership, the Community Cohesion Manager, the Cabinet Member for Cohesion, the Chief Constable and his predecessor had all attended Leadership training courses provided by the pseudo-charity Common Purpose.

Once 'change agents' have secured positions of hire and fire within any organisation things start to move very quickly. Personnel are then hired and fired on the basis of whether they will work towards the agenda the change agent represents. If they do they are rapidly promoted even though they may be incompetent. Those more qualified and skilled who are pre-Common Purpose 'old school' see their careers stall and even disappear. This has been happening for decades in every institution of state, police, 'health' and social services and all of them have been transformed as a result in their attitudes to their jobs and the public. Medical professions, including nursing, which were once vocations for the caring now employ many cold, callous and couldn't give a shit personality types. The UKColumn investigation concluded:

By blurring the boundaries between people, professions, public and private sectors, responsibility and accountability, Common Purpose encourages 'graduates' to believe that as new selected leaders, they can work together, outside of the established political and social structures, to achieve a paradigm shift or CHANGE – so called 'Leading Beyond Authority'. In doing so, the allegiance of the individual becomes 'reframed' on CP colleagues and their NETWORK.

Reframing the Face-Nappies

Nowhere has this process been more obvious than in the police where recruitment of psychopaths and development of unquestioning mind-controlled group-thinkers have transformed law enforcement into a politically-correct 'Woke' joke and a travesty of what should be public service. Today they wear their face-nappies like good little gofers and enforce 'Covid' rules which are fascism under another name. Alongside the specifically-recruited psychopaths we have software minds incapable of free thought. Brian Gerrish again:

An example is the policeman who would not get on a bike for a press photo because he had not done the cycling proficiency course. Normal people say this is political correctness gone mad. Nothing could be further from the truth. The policeman has been reframed, and in his reality it is perfect common sense not to get on the bike 'because he hasn't done the cycling course'.

Another example of this is where the police would not rescue a boy from a pond until they had taken advice from above on the 'risk assessment'. A normal person would have arrived, perhaps thought of the risk for a moment, and dived in. To the police now 'reframed', they followed 'normal' procedure.

There are shocking cases of reframed ambulance crews doing the same. Sheer unthinking stupidity of London Face-Nappies headed by Common Purpose graduate Cressida Dick can be seen in their behaviour at a vigil in March, 2021, for a murdered woman, Sarah Everard. A police officer had been charged with the crime. Anyone with a brain would have left the vigil alone in the circumstances. Instead they 'manhandled' women to stop them breaking 'Covid rules' to betray classic reframing. Minds in the thrall of perception control have no capacity for seeing a situation on its merits and acting accordingly. 'Rules is rules' is their only mind-set. My father used to say that rules and regulations are for the guidance of the intelligent and the blind obedience of the idiot. Most of the intelligent, decent, coppers have gone leaving only the other kind and a few old school for whom the job must be a daily nightmare. The combination of psychopaths and rule-book software minds has been clearly on public display in the 'Covid' era with automaton robots in uniform imposing fascistic 'Covid' regulations on the population without any personal initiative or judging situations on their merits. There are thousands of examples around the world, but I'll make my point with the infamous Derbyshire police in the English East Midlands – the ones who think pouring dye into beauty spots and using drones to track people walking in the countryside away from anyone is called 'policing'. To them there are rules decreed by the government which they have to enforce and in their bewildered state a group gathering in a closed space and someone walking alone in the countryside are the same thing. It is beyond idiocy and enters the realm of clinical insanity.

Police officers in Derbyshire said they were 'horrified' – *horrified* – to find 15 to 20 'irresponsible' kids playing a football match at a closed leisure centre 'in breach of coronavirus restrictions'. When they saw the police the kids ran away leaving their belongings behind and the reframed men and women of Derbyshire police were seeking to establish their identities with a view to fining their parents. The most natural thing for youngsters to do – kicking a ball about – is turned into a criminal activity and enforced by the moronic software programs of Derbyshire police. You find the same mentality in every country. These barely conscious 'horrified' officers said they had to take action because 'we need to ensure these rules are being followed' and 'it is of the utmost importance that you ensure your children are following the rules and regulations for Covid-19'. Had any of them done ten seconds of research to see if this parroting of their masters' script could be supported by any evidence? Nope. Reframed people don't think – others think for them and that's the whole idea of reframing. I have seen police officers one after the other repeating without question word for word what officialdom tells them just as I have seen great swathes of the public doing the same. Ask either for 'their' opinion and out spews what they have been told to think by the official narrative. Police and public may seem to be in different groups, but their mentality is the same. Most people do whatever they are told in fear not doing so or because they believe what officialdom tells them; almost the entirety of the police do what they are told for the same reason. Ultimately it's the tiny inner core of the global Cult that's telling both what to do.

So Derbyshire police were 'horrified'. Oh, really? Why did they think those kids were playing football? It was to relieve the psychological consequences of lockdown and being denied human contact with their friends and interaction, touch and discourse vital to human psychological health. Being denied this month after month has dismantled the psyche of many children and young people as depression and suicide have exploded. Were Derbyshire police *horrified by that*? Are you kidding? Reframed people don't have those

mental and emotional processes that can see how the impact on the psychological health of youngsters is far more dangerous than any 'virus' even if you take the mendacious official figures to be true. The reframed are told (programmed) how to act and so they do. The Derbyshire Chief Constable in the first period of lockdown when the black dye and drones nonsense was going on was Peter Goodman. He was the man who severed the connection between his force and the Derbyshire Constabulary *Male Voice* Choir when he decided that it was not inclusive enough to allow women to join. The fact it was a male voice choir making a particular sound produced by male voices seemed to elude a guy who terrifyingly ran policing in Derbyshire. He retired weeks after his force was condemned as disgraceful by former Supreme Court Justice Jonathan Sumption for their behaviour over extreme lockdown impositions. Goodman was replaced by his deputy Rachel Swann who was in charge when her officers were 'horrificed'. The police statement over the boys committing the hanging-offence of playing football included the line about the youngsters being 'irresponsible in the times we are all living through' missing the point that the real relevance of the 'times we are all living through' is the imposition of fascism enforced by psychopaths and reframed minds of police officers playing such a vital part in establishing the fascist tyranny that their own children and grandchildren will have to live in their entire lives. As a definition of insanity that is hard to beat although it might be run close by imposing masks on people that can have a serious effect on their health while wearing a face nappy all day themselves. Once again public and police do it for the same reason – the authorities tell them to and who are they to have the self-respect to say no?

Wokers in uniform

How reframed do you have to be to arrest a *six-year-old* and take him to court for *picking a flower* while waiting for a bus? Brain dead police and officialdom did just that in North Carolina where criminal proceedings happen regularly for children under nine. Attorney Julie Boyer gave the six-year-old crayons and a colouring book

during the 'flower' hearing while the 'adults' decided his fate. County Chief District Court Judge Jay Corpening asked: 'Should a child that believes in Santa Claus, the Easter Bunny and the tooth fairy be making life-altering decisions?' Well, of course not, but common sense has no meaning when you have a common purpose and a reframed mind. Treating children in this way, and police operating in American schools, is all part of the psychological preparation for children to accept a police state as normal all their adult lives. The same goes for all the cameras and biometric tracking technology in schools. Police training is focused on reframing them as snowflake Wokers and this is happening in the military. Pentagon top brass said that 'training sessions on extremism' were needed for troops who asked why they were so focused on the Capitol Building riot when Black Lives Matter riots were ignored. What's the difference between them some apparently and rightly asked. Actually, there is a difference. Five people died in the Capitol riot, only one through violence, and that was a police officer shooting an unarmed protestor. BLM riots killed at least 25 people and cost billions. Asking the question prompted the psychopaths and reframed minds that run the Pentagon to say that more 'education' (programming) was needed. Troop training is all based on psychological programming to make them fodder for the Cult – 'Military men are just dumb, stupid animals to be used as pawns in foreign policy' as Cult-to-his-DNA former Secretary of State Henry Kissinger famously said. Governments see the police in similar terms and it's time for those among them who can see this to defend the people and stop being enforcers of the Cult agenda upon the people.

The US military, like the country itself, is being targeted for destruction through a long list of Woke impositions. Cult-owned gaga 'President' Biden signed an executive order when he took office to allow taxpayer money to pay for transgender surgery for active military personnel and veterans. Are you a man soldier? No, I'm a LGBTQIA+ with a hint of Skoliosexual and Spectrasexual. Oh, good man. Bad choice of words you bigot. The Pentagon announced in March, 2021, the appointment of the first 'diversity and inclusion

officer' for US Special Forces. Richard Torres-Estrada arrived with the publication of a 'D&I Strategic Plan which will guide the enterprise-wide effort to institutionalize and sustain D&I'. If you think a Special Forces 'Strategic Plan' should have something to do with defending America you haven't been paying attention. Defending Woke is now the military's new role. Torres-Estrada has posted images comparing Donald Trump with Adolf Hitler and we can expect no bias from him as a representative of the supposedly non-political Pentagon. Cable news host Tucker Carlson said: 'The Pentagon is now the Yale faculty lounge but with cruise missiles.' Meanwhile Secretary of Defense Lloyd Austin, a board member of weapons-maker Raytheon with stock and compensation interests in October, 2020, worth \$1.4 million, said he was purging the military of the 'enemy within' – anyone who isn't Woke and supports Donald Trump. Austin refers to his targets as 'racist extremists' while in true Woke fashion being himself a racist extremist. Pentagon documents pledge to 'eradicate, eliminate and conquer all forms of racism, sexism and homophobia'. The definitions of these are decided by 'diversity and inclusion committees' peopled by those who see racism, sexism and homophobia in every situation and opinion. Woke (the Cult) is dismantling the US military and purging testosterone as China expands its military and gives its troops 'masculinity training'. How do we think that is going to end when this is all Cult coordinated? The US military, like the British military, is controlled by Woke and spineless top brass who just go along with it out of personal career interests.

'Woke' means fast asleep

Mind control and perception manipulation techniques used on individuals to create group-think have been unleashed on the global population in general. As a result many have no capacity to see the obvious fascist agenda being installed all around them or what 'Covid' is really all about. Their brains are firewalled like a computer system not to process certain concepts, thoughts and realisations that are bad for the Cult. The young are most targeted as the adults they

will be when the whole fascist global state is planned to be fully implemented. They need to be prepared for total compliance to eliminate all pushback from entire generations. The Cult has been pouring billions into taking complete control of 'education' from schools to universities via its operatives and corporations and not least Bill Gates as always. The plan has been to transform 'education' institutions into programming centres for the mentality of 'Woke'. James McConnell, professor of psychology at the University of Michigan, wrote in *Psychology Today* in 1970:

The day has come when we can combine sensory deprivation with drugs, hypnosis, and astute manipulation of reward and punishment, to gain almost absolute control over an individual's behaviour. It should then be possible to achieve a very rapid and highly effective type of brainwashing that would allow us to make dramatic changes in a person's behaviour and personality ...

... We should reshape society so that we all would be trained from birth to want to do what society wants us to do. We have the techniques to do it... no-one owns his own personality you acquired, and there's no reason to believe you should have the right to refuse to acquire a new personality if your old one is anti-social.

This was the potential for mass brainwashing in 1970 and the mentality there displayed captures the arrogant psychopathy that drives it forward. I emphasise that not all young people have succumbed to Woke programming and those that haven't are incredibly impressive people given that today's young are the most perceptually-targeted generations in history with all the technology now involved. Vast swathes of the young generations, however, have fallen into the spell – and that's what it is – of Woke. The Woke mentality and perceptual program is founded on *inversion* and you will appreciate later why that is so significant. Everything with Woke is inverted and the opposite of what it is claimed to be. Woke was a term used in African-American culture from the 1900s and referred to an awareness of social and racial justice. This is not the meaning of the modern version or 'New Woke' as I call it in *The Answer*. Oh, no, Woke today means something very different no matter how much Wokers may seek to hide that and insist Old Woke and New

Woke are the same. See if you find any 'awareness of social justice' here in the modern variety:

- Woke demands 'inclusivity' while excluding anyone with a different opinion and calls for mass censorship to silence other views.
- Woke claims to stand against oppression when imposing oppression is the foundation of all that it does. It is the driver of political correctness which is nothing more than a Cult invention to manipulate the population to silence itself.
- Woke believes itself to be 'liberal' while pursuing a global society that can only be described as fascist (see 'anti-fascist' fascist Antifa).
- Woke calls for 'social justice' while spreading injustice wherever it goes against the common 'enemy' which can be easily identified as a differing view.
- Woke is supposed to be a metaphor for 'awake' when it is solid-gold asleep and deep in a Cult-induced coma that meets the criteria for 'off with the fairies'.

I state these points as obvious facts if people only care to look. I don't do this with a sense of condemnation. We need to appreciate that the onslaught of perceptual programming on the young has been incessant and merciless. I can understand why so many have been reframed, or, given their youth, framed from the start to see the world as the Cult demands. The Cult has had access to their minds day after day in its 'education' system for their entire formative years. Perception is formed from information received and the Cult-created system is a life-long download of information delivered to elicit a particular perception, thus behaviour. The more this has expanded into still new extremes in recent decades and ever-increasing censorship has deleted other opinions and information why wouldn't that lead to a perceptual reframing on a mass scale? I

have described already cradle-to-grave programming and in more recent times the targeting of young minds from birth to adulthood has entered the stratosphere. This has taken the form of skewing what is 'taught' to fit the Cult agenda and the omnipresent techniques of group-think to isolate non-believers and pressure them into line. There has always been a tendency to follow the herd, but we really are in a new world now in relation to that. We have parents who can see the 'Covid' hoax told by their children not to stop them wearing masks at school, being 'Covid' tested or having the 'vaccine' in fear of the peer-pressure consequences of being different. What is 'peer-pressure' if not pressure to conform to group-think? Renegade Minds never group-think and always retain a set of perceptions that are unique to them. Group-think is always underpinned by consequences for not group-thinking. Abuse now aimed at those refusing DNA-manipulating 'Covid vaccines' are a potent example of this. The biggest pressure to conform comes from the very group which is itself being manipulated. 'I am programmed to be part of a hive mind and so you must be.'

Woke control structures in 'education' now apply to every mainstream organisation. Those at the top of the 'education' hierarchy (the Cult) decide the policy. This is imposed on governments through the Cult network; governments impose it on schools, colleges and universities; their leadership impose the policy on teachers and academics and they impose it on children and students. At any level where there is resistance, perhaps from a teacher or university lecturer, they are targeted by the authorities and often fired. Students themselves regularly demand the dismissal of academics (increasingly few) at odds with the narrative that the students have been programmed to believe in. It is quite a thought that students who are being targeted by the Cult become so consumed by programmed group-think that they launch protests and demand the removal of those who are trying to push back against those targeting the students. Such is the scale of perceptual inversion. We see this with 'Covid' programming as the Cult imposes the rules via psycho-psychologists and governments on

shops, transport companies and businesses which impose them on their staff who impose them on their customers who pressure Pushbackers to conform to the will of the Cult which is in the process of destroying them and their families. Scan all aspects of society and you will see the same sequence every time.

Fact free Woke and hijacking the 'left'

There is no more potent example of this than 'Woke', a mentality only made possible by the deletion of factual evidence by an 'education' system seeking to produce an ever more uniform society. Why would you bother with facts when you don't know any? Deletion of credible history both in volume and type is highly relevant. Orwell said: 'Who controls the past controls the future: who controls the present controls the past.' They who control the perception of the past control the perception of the future and they who control the present control the perception of the past through the writing and deleting of history. Why would you oppose the imposition of Marxism in the name of Wokeism when you don't know that Marxism cost at least 100 million lives in the 20th century alone? Watch videos and read reports in which Woker generations are asked basic historical questions – it's mind-blowing. A survey of 2,000 people found that six percent of millennials (born approximately early 1980s to early 2000s) believed the Second World War (1939-1945) broke out with the assassination of President Kennedy (in 1963) and one in ten thought Margaret Thatcher was British Prime Minister at the time. She was in office between 1979 and 1990. We are in a post-fact society. Provable facts are no defence against the fascism of political correctness or Silicon Valley censorship. Facts don't matter anymore as we have witnessed with the 'Covid' hoax. Sacrificing uniqueness to the Woke group-think religion is all you are required to do and that means thinking for yourself is the biggest Woke no, no. All religions are an expression of group-think and censorship and Woke is just another religion with an orthodoxy defended by group-think and censorship. Burned at

the stake becomes burned on Twitter which leads back eventually to burned at the stake as Woke humanity regresses to ages past.

The biggest Woke inversion of all is its creators and funders. I grew up in a traditional left of centre political household on a council estate in Leicester in the 1950s and 60s – you know, the left that challenged the power of wealth-hoarding elites and threats to freedom of speech and opinion. In those days students went on marches defending freedom of speech while today's Wokers march for its deletion. What on earth could have happened? Those very elites (collectively the Cult) that we opposed in my youth and early life have funded into existence the antithesis of that former left and hijacked the 'brand' while inverting everything it ever stood for. We have a mentality that calls itself 'liberal' and 'progressive' while acting like fascists. Cult billionaires and their corporations have funded themselves into control of 'education' to ensure that Woke programming is unceasing throughout the formative years of children and young people and that non-Wokers are isolated (that word again) whether they be students, teachers or college professors. The Cult has funded into existence the now colossal global network of Woke organisations that have spawned and promoted all the 'causes' on the Cult wish-list for global transformation and turned Wokers into demanders of them. Does anyone really think it's a coincidence that the Cult agenda for humanity is a carbon (sorry) copy of the societal transformations desired by Woke?? These are only some of them:

Political correctness: The means by which the Cult deletes all public debates that it knows it cannot win if we had the free-flow of information and evidence.

Human-caused 'climate change': The means by which the Cult seeks to transform society into a globally-controlled dictatorship imposing its will over the fine detail of everyone's lives 'to save the planet' which doesn't actually need saving.

Transgender obsession: Preparing collective perception to accept the 'new human' which would not have genders because it would be created technologically and not through procreation. I'll have much more on this in Human 2.0.

Race obsession: The means by which the Cult seeks to divide and rule the population by triggering racial division through the perception that society is more racist than ever when the opposite is the case. Is it perfect in that regard? No. But to compare today with the racism of apartheid and segregation brought to an end by the civil rights movement in the 1960s is to insult the memory of that movement and inspirations like Martin Luther King. Why is the 'anti-racism' industry (which it is) so dominated by privileged white people?

White supremacy: This is a label used by privileged white people to demonise poor and deprived white people pushing back on tyranny to marginalise and destroy them. White people are being especially targeted as the dominant race by number within Western society which the Cult seeks to transform in its image. If you want to change a society you must weaken and undermine its biggest group and once you have done that by using the other groups you next turn on them to do the same ... 'Then they came for the Jews and I was not a Jew so I did nothing.'

Mass migration: The mass movement of people from the Middle East, Africa and Asia into Europe, from the south into the United States and from Asia into Australia are another way the Cult seeks to dilute the racial, cultural and political influence of white people on Western society. White people ask why their governments appear to be working against them while being politically and culturally biased towards incoming cultures. Well, here's your answer. In the same way sexually 'straight' people, men and women, ask why the

authorities are biased against them in favour of other sexualities. The answer is the same – that's the way the Cult wants it to be for very sinister motives.

These are all central parts of the Cult agenda and central parts of the Woke agenda and Woke was created and continues to be funded to an immense degree by Cult billionaires and corporations. If anyone begins to say 'coincidence' the syllables should stick in their throat.

Billionaire 'social justice warriors'

Joe Biden is a 100 percent-owned asset of the Cult and the Wokers' man in the White House whenever he can remember his name and for however long he lasts with his rapidly diminishing cognitive function. Even walking up the steps of an aircraft without falling on his arse would appear to be a challenge. He's not an empty-shell puppet or anything. From the minute Biden took office (or the Cult did) he began his executive orders promoting the Woke wish-list. You will see the Woke agenda imposed ever more severely because it's really the *Cult* agenda. Woke organisations and activist networks spawned by the Cult are funded to the extreme so long as they promote what the Cult wants to happen. Woke is funded to promote 'social justice' by billionaires who become billionaires by destroying social justice. The social justice mantra is only a cover for dismantling social justice and funded by billionaires that couldn't give a damn about social justice. Everything makes sense when you see that. One of Woke's premier funders is Cult billionaire financier George Soros who said: 'I am basically there to make money, I cannot and do not look at the social consequences of what I do.' This is the same Soros who has given more than \$32 billion to his Open Society Foundations global Woke network and funded Black Lives Matter, mass immigration into Europe and the United States, transgender activism, climate change activism, political correctness and groups targeting 'white supremacy' in the form of privileged white thugs that dominate Antifa. What a scam it all is and when

you are dealing with the unquestioning fact-free zone of Woke scamming them is child's play. All you need to pull it off in all these organisations are a few in-the-know agents of the Cult and an army of naïve, reframed, uninformed, narcissistic, know-nothings convinced of their own self-righteousness, self-purity and virtue.

Soros and fellow billionaires and billionaire corporations have poured hundreds of millions into Black Lives Matter and connected groups and promoted them to a global audience. None of this is motivated by caring about black people. These are the billionaires that have controlled and exploited a system that leaves millions of black people in abject poverty and deprivation which they do absolutely nothing to address. The same Cult networks funding BLM were behind the *slave trade*! Black Lives Matter hijacked a phrase that few would challenge and they have turned this laudable concept into a political weapon to divide society. You know that BLM is a fraud when it claims that *All Lives Matter*, the most inclusive statement of all, is 'racist'. BLM and its Cult masters don't want to end racism. To them it's a means to an end to control all of humanity never mind the colour, creed, culture or background. What has destroying the nuclear family got to do with ending racism? Nothing – but that is one of the goals of BLM and also happens to be a goal of the Cult as I have been exposing in my books for decades. Stealing children from loving parents and giving schools ever more power to override parents is part of that same agenda. BLM is a Marxist organisation and why would that not be the case when the Cult created Marxism *and* BLM? Patrisse Cullors, a BLM co-founder, said in a 2015 video that she and her fellow organisers, including co-founder Alicia Garza, are 'trained Marxists'. The lady known after marriage as Patrisse Khan-Cullors bought a \$1.4 million home in 2021 in one of the whitest areas of California with a black population of just 1.6 per cent and has so far bought *four* high-end homes for a total of \$3.2 million. How very Marxist. There must be a bit of spare in the BLM coffers, however, when Cult corporations and billionaires have handed over the best part of \$100 million. Many black people can see that Black Lives Matter is not

working for them, but against them, and this is still more confirmation. Black journalist Jason Whitlock, who had his account suspended by Twitter for simply linking to the story about the 'Marxist's' home buying spree, said that BLM leaders are 'making millions of dollars off the backs of these dead black men who they wouldn't spit on if they were on fire and alive'.

Black Lies Matter

Cult assets and agencies came together to promote BLM in the wake of the death of career criminal George Floyd who had been jailed a number of times including for forcing his way into the home of a black woman with others in a raid in which a gun was pointed at her stomach. Floyd was filmed being held in a Minneapolis street in 2020 with the knee of a police officer on his neck and he subsequently died. It was an appalling thing for the officer to do, but the same technique has been used by police on peaceful protestors of lockdown without any outcry from the Woke brigade. As unquestioning supporters of the Cult agenda Wokers have supported lockdown and all the 'Covid' claptrap while attacking anyone standing up to the tyranny imposed in its name. Court documents would later include details of an autopsy on Floyd by County Medical Examiner Dr Andrew Baker who concluded that Floyd had taken a fatal level of the drug fentanyl. None of this mattered to fact-free, question-free, Woke. Floyd's death was followed by worldwide protests against police brutality amid calls to defund the police. Throwing babies out with the bathwater is a Woke speciality. In the wake of the murder of British woman Sarah Everard a Green Party member of the House of Lords, Baroness Jones of Moulsecoomb (Nincompoopia would have been better), called for a 6pm curfew for all men. This would be in breach of the Geneva Conventions on war crimes which ban collective punishment, but that would never have crossed the black and white Woke mind of Baroness Nincompoopia who would have been far too convinced of her own self-righteousness to compute such details. Many American cities did defund the police in the face of Floyd riots

and after \$15 million was deleted from the police budget in Washington DC under useless Woke mayor Muriel Bowser car-jacking alone rose by 300 percent and within six months the US capital recorded its highest murder rate in 15 years. The same happened in Chicago and other cities in line with the Cult/Soros plan to bring fear to streets and neighbourhoods by reducing the police, releasing violent criminals and not prosecuting crime. This is the mob-rule agenda that I have warned in the books was coming for so long. Shootings in the area of Minneapolis where Floyd was arrested increased by 2,500 percent compared with the year before. Defunding the police over George Floyd has led to a big increase in dead people with many of them black. Police protection for politicians making these decisions stayed the same or increased as you would expect from professional hypocrites. The Cult doesn't actually want to abolish the police. It wants to abolish local control over the police and hand it to federal government as the psychopaths advance the Hunger Games Society. Many George Floyd protests turned into violent riots with black stores and businesses destroyed by fire and looting across America fuelled by Black Lives Matter. Woke doesn't do irony. If you want civil rights you must loot the liquor store and the supermarket and make off with a smart TV. It's the only way.

It's not a race war – it's a class war

Black people are patronised by privileged blacks and whites alike and told they are victims of white supremacy. I find it extraordinary to watch privileged blacks supporting the very system and bloodline networks behind the slave trade and parroting the same Cult-serving manipulative crap of their privileged white, often billionaire, associates. It is indeed not a race war but a class war and colour is just a diversion. Black Senator Cory Booker and black Congresswoman Maxine Waters, more residents of Nincompoopia, personify this. Once you tell people they are victims of someone else you devalue both their own responsibility for their plight and the power they have to impact on their reality and experience. Instead

we have: 'You are only in your situation because of whiteness – turn on them and everything will change.' It won't change. Nothing changes in our lives unless *we* change it. Crucial to that is never seeing yourself as a victim and always as the creator of your reality. Life is a simple sequence of choice and consequence. Make different choices and you create different consequences. *You* have to make those choices – not Black Lives Matter, the Woke Mafia and anyone else that seeks to dictate your life. Who are they these Wokers, an emotional and psychological road traffic accident, to tell you what to do? Personal empowerment is the last thing the Cult and its Black Lives Matter want black people or anyone else to have. They claim to be defending the underdog while *creating* and perpetuating the underdog. The Cult's worst nightmare is human unity and if they are going to keep blacks, whites and every other race under economic servitude and control then the focus must be diverted from what they have in common to what they can be manipulated to believe divides them. Blacks have to be told that their poverty and plight is the fault of the white bloke living on the street in the same poverty and with the same plight they are experiencing. The difference is that your plight black people is due to him, a white supremacist with 'white privilege' living on the street. Don't unite as one human family against your mutual oppressors and suppressors – fight the oppressor with the white face who is as financially deprived as you are. The Cult knows that as its 'Covid' agenda moves into still new levels of extremism people are going to respond and it has been spreading the seeds of disunity everywhere to stop a united response to the evil that targets *all of us*.

Racist attacks on 'whiteness' are getting ever more outrageous and especially through the American Democratic Party which has an appalling history for anti-black racism. Barack Obama, Joe Biden, Hillary Clinton and Nancy Pelosi all eulogised about Senator Robert Byrd at his funeral in 2010 after a nearly 60-year career in Congress. Byrd was a brutal Ku Klux Klan racist and a violent abuser of Cathy O'Brien in MKUltra. He said he would never fight in the military 'with a negro by my side' and 'rather I should die a thousand times,

and see Old Glory trampled in the dirt never to rise again, than to see this beloved land of ours become degraded by race mongrels, a throwback to the blackest specimen from the wilds'. Biden called Byrd a 'very close friend and mentor'. These 'Woke' hypocrites are not anti-racist they are anti-poor and anti-people not of their perceived class. Here is an illustration of the scale of anti-white racism to which we have now descended. Seriously Woke and moronic *New York Times* contributor Damon Young described whiteness as a 'virus' that 'like other viruses will not die until there are no bodies left for it to infect'. He went on: '... the only way to stop it is to locate it, isolate it, extract it, and kill it.' Young can say that as a black man with no consequences when a white man saying the same in reverse would be facing a jail sentence. *That's* racism. We had super-Woke numbskull senators Tammy Duckworth and Mazie Hirono saying they would object to future Biden Cabinet appointments if he did not nominate more Asian Americans and Pacific Islanders. Never mind the ability of the candidate what do they look like? Duckworth said: 'I will vote for racial minorities and I will vote for LGBTQ, but anyone else I'm not voting for.' Appointing people on the grounds of race is illegal, but that was not a problem for this ludicrous pair. They were on-message and that's a free pass in any situation.

Critical race racism

White children are told at school they are intrinsically racist as they are taught the divisive 'critical race theory'. This claims that the law and legal institutions are inherently racist and that race is a socially constructed concept used by white people to further their economic and political interests at the expense of people of colour. White is a 'virus' as we've seen. Racial inequality results from 'social, economic, and legal differences that white people create between races to maintain white interests which leads to poverty and criminality in minority communities'. I must tell that to the white guy sleeping on the street. The principal of East Side Community School in New York sent white parents a manifesto that called on

them to become 'white traitors' and advocate for full 'white abolition'. These people are teaching your kids when they urgently need a psychiatrist. The 'school' included a chart with 'eight white identities' that ranged from 'white supremacist' to 'white abolition' and defined the behaviour white people must follow to end 'the regime of whiteness'. Woke blacks and their privileged white associates are acting exactly like the slave owners of old and Ku Klux Klan racists like Robert Byrd. They are too full of their own self-purity to see that, but it's true. Racism is not a body type; it's a state of mind that can manifest through any colour, creed or culture.

Another racial fraud is '*equity*'. Not equality of treatment and opportunity – equity. It's a term spun as equality when it means something very different. Equality in its true sense is a raising up while 'equity' is a race to the bottom. Everyone in the same level of poverty is 'equity'. Keep everyone down – that's equity. The Cult doesn't want anyone in the human family to be empowered and BLM leaders, like all these 'anti-racist' organisations, continue their privileged, pampered existence by perpetuating the perception of gathering racism. When is the last time you heard an 'anti-racist' or 'anti-Semitism' organisation say that acts of racism and discrimination have *fallen*? It's not in the interests of their fundraising and power to influence and the same goes for the professional soccer anti-racism operation, Kick It Out. Two things confirmed that the Black Lives Matter riots in the summer of 2020 were Cult creations. One was that while anti-lockdown protests were condemned in this same period for 'transmitting 'Covid' the authorities supported mass gatherings of Black Lives Matter supporters. I even saw self-deluding people claiming to be doctors say the two types of protest were not the same. No – the non-existent 'Covid' was in favour of lockdowns and attacked those that protested against them while 'Covid' supported Black Lives Matter and kept well away from its protests. The whole thing was a joke and as lockdown protestors were arrested, often brutally, by reframed Face-Nappies we had the grotesque sight of police officers taking the knee to Black Lives Matter, a Cult-funded Marxist

organisation that supports violent riots and wants to destroy the nuclear family and white people.

He's not white? Shucks!

Woke obsession with race was on display again when ten people were shot dead in Boulder, Colorado, in March, 2021. Cult-owned Woke TV channels like CNN said the shooter appeared to be a white man and Wokers were on Twitter condemning 'violent white men' with the usual mantras. Then the shooter's name was released as Ahmad Al Aliwi Alissa, an anti-Trump Arab-American, and the sigh of disappointment could be heard five miles away. Never mind that ten people were dead and what that meant for their families. Race baiting was all that mattered to these sick Cult-serving people like Barack Obama who exploited the deaths to further divide America on racial grounds which is his job for the Cult. This is the man that 'racist' white Americans made the first black president of the United States and then gave him a second term. Not-very-bright Obama has become filthy rich on the back of that and today appears to have a big influence on the Biden administration. Even so he's still a downtrodden black man and a victim of white supremacy. This disingenuous fraud reveals the contempt he has for black people when he puts on a Deep South Alabama accent whenever he talks to them, no, *at* them.

Another BLM red flag was how the now fully-Woke (fully-Cult) and fully-virtue-signalled professional soccer authorities had their teams taking the knee before every match in support of Marxist Black Lives Matter. Soccer authorities and clubs displayed 'Black Lives Matter' on the players' shirts and flashed the name on electronic billboards around the pitch. Any fans that condemned what is a Freemasonic taking-the-knee ritual were widely condemned as you would expect from the Woke virtue-signallers of professional sport and the now fully-Woke media. We have reverse racism in which you are banned from criticising any race or culture except for white people for whom anything goes – say what you like, no problem. What has this got to do with racial harmony and

equality? We've had black supremacists from Black Lives Matter telling white people to fall to their knees in the street and apologise for their white supremacy. Black supremacists acting like white supremacist slave owners of the past couldn't breach their self-obsessed, race-obsessed sense of self-purity. Joe Biden appointed a race-obsessed black supremacist Kristen Clarke to head the Justice Department Civil Rights Division. Clarke claimed that blacks are endowed with 'greater mental, physical and spiritual abilities' than whites. If anyone reversed that statement they would be vilified. Clarke is on-message so no problem. She's never seen a black-white situation in which the black figure is anything but a virtuous victim and she heads the Civil Rights Division which should treat everyone the same or it isn't civil rights. Another perception of the Renegade Mind: If something or someone is part of the Cult agenda they will be supported by Woke governments and media no matter what. If they're not, they will be condemned and censored. It really is that simple and so racist Clarke prospers despite (make that because of) her racism.

The end of culture

Biden's administration is full of such racial, cultural and economic bias as the Cult requires the human family to be divided into warring factions. We are now seeing racially-segregated graduations and everything, but everything, is defined through the lens of perceived 'racism'. We have 'racist' mathematics, 'racist' food and even 'racist' *plants*. World famous Kew Gardens in London said it was changing labels on plants and flowers to tell its pre-'Covid' more than two million visitors a year how racist they are. Kew director Richard Deverell said this was part of an effort to 'move quickly to decolonise collections' after they were approached by one Ajay Chhabra 'an actor with an insight into how sugar cane was linked to slavery'. They are *plants* you idiots. 'Decolonisation' in the Woke manual really means colonisation of society with its mentality and by extension colonisation by the Cult. We are witnessing a new Chinese-style 'Cultural Revolution' so essential to the success of all

Marxist takeovers. Our cultural past and traditions have to be swept away to allow a new culture to be built-back-better. Woke targeting of long-standing Western cultural pillars including historical monuments and cancelling of historical figures is what happened in the Mao revolution in China which 'purged remnants of capitalist and traditional elements from Chinese society' and installed Maoism as the dominant ideology'. For China see the Western world today and for 'dominant ideology' see Woke. Better still see Marxism or Maoism. The 'Covid' hoax has specifically sought to destroy the arts and all elements of Western culture from people meeting in a pub or restaurant to closing theatres, music venues, sports stadiums, places of worship and even banning *singing*. Destruction of Western society is also why criticism of any religion is banned except for Christianity which again is the dominant religion as white is the numerically-dominant race. Christianity may be fading rapidly, but its history and traditions are weaved through the fabric of Western society. Delete the pillars and other structures will follow until the whole thing collapses. I am not a Christian defending that religion when I say that. I have no religion. It's just a fact. To this end Christianity has itself been turned Woke to usher its own downfall and its ranks are awash with 'change agents' – knowing and unknowing – at every level including Pope Francis (*definitely* knowing) and the clueless Archbishop of Canterbury Justin Welby (possibly not, but who can be sure?). Woke seeks to coordinate attacks on Western culture, traditions, and ways of life through 'intersectionality' defined as 'the complex, cumulative way in which the effects of multiple forms of discrimination (such as racism, sexism, and classism) combine, overlap, or intersect especially in the experiences of marginalised individuals or groups'. Wade through the Orwellian Woke-speak and this means coordinating disparate groups in a common cause to overthrow freedom and liberal values.

The entire structure of public institutions has been infested with Woke – government at all levels, political parties, police, military, schools, universities, advertising, media and trade unions. This abomination has been achieved through the Cult web by appointing

Wokers to positions of power and battering non-Wokers into line through intimidation, isolation and threats to their job. Many have been fired in the wake of the empathy-deleted, vicious hostility of 'social justice' Wokers and the desire of gutless, spineless employers to virtue-signal their Wokeness. Corporations are filled with Wokers today, most notably those in Silicon Valley. Ironically at the top they are not Woke at all. They are only exploiting the mentality their Cult masters have created and funded to censor and enslave while the Wokers cheer them on until it's their turn. Thus the Woke 'liberal left' is an inversion of the traditional liberal left. Campaigning for justice on the grounds of power and wealth distribution has been replaced by campaigning for identity politics. The genuine traditional left would never have taken money from today's billionaire abusers of fairness and justice and nor would the billionaires have wanted to fund that genuine left. It would not have been in their interests to do so. The division of opinion in those days was between the haves and have nots. This all changed with Cult manipulated and funded identity politics. The division of opinion today is between Wokers and non-Wokers and not income brackets. Cult corporations and their billionaires may have taken wealth disparity to cataclysmic levels of injustice, but as long as they speak the language of Woke, hand out the dosh to the Woke network and censor the enemy they are 'one of us'. Billionaires who don't give a damn about injustice are laughing at them till their bellies hurt. Wokers are not even close to self-aware enough to see that. The transformed 'left' dynamic means that Wokers who drone on about 'social justice' are funded by billionaires that have destroyed social justice the world over. It's *why* they are billionaires.

The climate con

Nothing encapsulates what I have said more comprehensively than the hoax of human-caused global warming. I have detailed in my books over the years how Cult operatives and organisations were the pump-primers from the start of the climate con. A purpose-built vehicle for this is the Club of Rome established by the Cult in 1968

with the Rockefellers and Rothschilds centrally involved all along. Their gofer frontman Maurice Strong, a Canadian oil millionaire, hosted the Earth Summit in Rio de Janeiro, Brazil, in 1992 where the global 'green movement' really expanded in earnest under the guiding hand of the Cult. The Earth Summit established Agenda 21 through the Cult-created-and-owned United Nations to use the illusion of human-caused climate change to justify the transformation of global society to save the world from climate disaster. It is a No-Problem-Reaction-Solution sold through governments, media, schools and universities as whole generations have been terrified into believing that the world was going to end in their lifetimes unless what old people had inflicted upon them was stopped by a complete restructuring of how everything is done. Chill, kids, it's all a hoax. Such restructuring is precisely what the Cult agenda demands (purely by coincidence of course). Today this has been given the codename of the Great Reset which is only an updated term for Agenda 21 and its associated Agenda 2030. The latter, too, is administered through the UN and was voted into being by the General Assembly in 2015. Both 21 and 2030 seek centralised control of all resources and food right down to the raindrops falling on your own land. These are some of the demands of Agenda 21 established in 1992. See if you recognise this society emerging today:

- End national sovereignty
- State planning and management of all land resources, ecosystems, deserts, forests, mountains, oceans and fresh water; agriculture; rural development; biotechnology; and ensuring '*equity*'
- The state to 'define the role' of business and financial resources
- Abolition of private property
- 'Restructuring' the family unit (see BLM)
- Children raised by the state
- People told what their job will be
- Major restrictions on movement
- Creation of 'human settlement zones'

- Mass resettlement as people are forced to vacate land where they live
- Dumbing down education
- Mass global depopulation in pursuit of all the above

The United Nations was created as a Trojan horse for world government. With the climate con of critical importance to promoting that outcome you would expect the UN to be involved. Oh, it's involved all right. The UN is promoting Agenda 21 and Agenda 2030 justified by 'climate change' while also driving the climate hoax through its Intergovernmental Panel on Climate Change (IPCC), one of the world's most corrupt organisations. The IPCC has been lying ferociously and constantly since the day it opened its doors with the global media hanging unquestioningly on its every mendacious word. The Green movement is entirely Woke and has long lost its original environmental focus since it was co-opted by the Cult. An obsession with 'global warming' has deleted its values and scrambled its head. I experienced a small example of what I mean on a beautiful country walk that I have enjoyed several times a week for many years. The path merged into the fields and forests and you felt at one with the natural world. Then a 'Green' organisation, the Hampshire and Isle of Wight Wildlife Trust, took over part of the land and proceeded to cut down a large number of trees, including mature ones, to install a horrible big, bright steel 'this-is-ours-stay-out' fence that destroyed the whole atmosphere of this beautiful place. No one with a feel for nature would do that. Day after day I walked to the sound of chainsaws and a magnificent mature weeping willow tree that I so admired was cut down at the base of the trunk. When I challenged a Woke young girl in a green shirt (of course) about this vandalism she replied: 'It's a weeping willow – it will grow back.' This is what people are paying for when they donate to the Hampshire and Isle of Wight Wildlife Trust and many other 'green' organisations today. It is not the environmental movement that I knew and instead has become a support-system – as with Extinction Rebellion – for a very dark agenda.

Private jets for climate justice

The Cult-owned, Gates-funded, World Economic Forum and its founder Klaus Schwab were behind the emergence of Greta Thunberg to harness the young behind the climate agenda and she was invited to speak to the world at ... the UN. Schwab published a book, *Covid-19: The Great Reset* in 2020 in which he used the 'Covid' hoax and the climate hoax to lay out a new society straight out of Agenda 21 and Agenda 2030. Bill Gates followed in early 2021 when he took time out from destroying the world to produce a book in his name about the way to save it. Gates flies across the world in private jets and admitted that 'I probably have one of the highest greenhouse gas footprints of anyone on the planet ... my personal flying alone is gigantic.' He has also bid for the planet's biggest private jet operator. Other climate change saviours who fly in private jets include John Kerry, the US Special Presidential Envoy for Climate, and actor Leonardo DiCaprio, a 'UN Messenger of Peace with special focus on climate change'. These people are so full of bullshit they could corner the market in manure. We mustn't be sceptical, though, because the Gates book, *How to Avoid a Climate Disaster: The Solutions We Have and the Breakthroughs We Need*, is a genuine attempt to protect the world and not an obvious pile of excrement attributed to a mega-psychopath aimed at selling his masters' plans for humanity. The Gates book and the other shite-pile by Klaus Schwab could have been written by the same person and may well have been. Both use 'climate change' and 'Covid' as the excuses for their new society and by coincidence the Cult's World Economic Forum and Bill and Melinda Gates Foundation promote the climate hoax and hosted Event 201 which pre-empted with a 'simulation' the very 'coronavirus' hoax that would be simulated for real on humanity within weeks. The British 'royal' family is promoting the 'Reset' as you would expect through Prince 'climate change caused the war in Syria' Charles and his hapless son Prince William who said that we must 'reset our relationship with nature and our trajectory as a species' to avoid a climate disaster. Amazing how many promoters of the 'Covid' and 'climate change' control

systems are connected to Gates and the World Economic Forum. A 'study' in early 2021 claimed that carbon dioxide emissions must fall by the equivalent of a global lockdown roughly every two years for the next decade to save the planet. The 'study' appeared in the same period that the Schwab mob claimed in a video that lockdowns destroying the lives of billions are good because they make the earth 'quieter' with less 'ambient noise'. They took down the video amid a public backlash for such arrogant, empathy-deleted stupidity. You see, however, where they are going with this. Corinne Le Quéré, a professor at the Tyndall Centre for Climate Change Research, University of East Anglia, was lead author of the climate lockdown study, and she writes for ... the World Economic Forum. Gates calls in 'his' book for changing 'every aspect of the economy' (long-time Cult agenda) and for humans to eat synthetic 'meat' (predicted in my books) while cows and other farm animals are eliminated. Australian TV host and commentator Alan Jones described what carbon emission targets would mean for farm animals in Australia alone if emissions were reduced as demanded by 35 percent by 2030 and zero by 2050:

Well, let's take agriculture, the total emissions from agriculture are about 75 million tonnes of carbon dioxide, equivalent. Now reduce that by 35 percent and you have to come down to 50 million tonnes, I've done the maths. So if you take for example 1.5 million cows, you're going to have to reduce the herd by 525,000 [by] 2030, nine years, that's 58,000 cows a year. The beef herd's 30 million, reduce that by 35 percent, that's 10.5 million, which means 1.2 million cattle have to go every year between now and 2030. This is insanity!

There are 75 million sheep. Reduce that by 35 percent, that's 26 million sheep, that's almost 3 million a year. So under the Paris Agreement over 30 million beasts, dairy cows, cattle, pigs and sheep would go. More than 8,000 every minute of every hour for the next decade, do these people know what they're talking about?

Clearly they don't at the level of campaigners, politicians and administrators. The Cult *does* know; that's the outcome it wants. We are faced with not just a war on humanity. Animals and the natural world are being targeted and I have been saying since the 'Covid' hoax began that the plan eventually was to claim that the 'deadly virus' is able to jump from animals, including farm animals and

domestic pets, to humans. Just before this book went into production came this story: 'Russia registers world's first Covid-19 vaccine for cats & dogs as makers of Sputnik V warn pets & farm animals could spread virus'. The report said 'top scientists warned that the deadly pathogen could soon begin spreading through homes and farms' and 'the next stage is the infection of farm and domestic animals'. Know the outcome and you'll see the journey. Think what that would mean for animals and keep your eye on a term called zoonosis or zoonotic diseases which transmit between animals and humans. The Cult wants to break the connection between animals and people as it does between people and people. Farm animals fit with the Cult agenda to transform food from natural to synthetic.

The gas of life is killing us

There can be few greater examples of Cult inversion than the condemnation of carbon dioxide as a dangerous pollutant when it is the gas of life. Without it the natural world would be dead and so we would all be dead. We breathe in oxygen and breathe out carbon dioxide while plants produce oxygen and absorb carbon dioxide. It is a perfect symbiotic relationship that the Cult wants to dismantle for reasons I will come to in the final two chapters. Gates, Schwab, other Cult operatives and mindless repeaters, want the world to be 'carbon neutral' by at least 2050 and the earlier the better. 'Zero carbon' is the cry echoed by lunatics calling for 'Zero Covid' when we already have it. These carbon emission targets will deindustrialise the world in accordance with Cult plans – the post-industrial, post-democratic society – and with so-called renewables like solar and wind not coming even close to meeting human energy needs blackouts and cold are inevitable. Texans got the picture in the winter of 2021 when a snow storm stopped wind turbines and solar panels from working and the lights went down along with water which relies on electricity for its supply system. Gates wants everything to be powered by electricity to ensure that his masters have the kill switch to stop all human activity, movement, cooking, water and warmth any time they like. The climate lie is so

stupendously inverted that it claims we must urgently reduce carbon dioxide when we *don't have enough*.

Co2 in the atmosphere is a little above 400 parts per million when the optimum for plant growth is 2,000 ppm and when it falls anywhere near 150 ppm the natural world starts to die and so do we. It fell to as low as 280 ppm in an 1880 measurement in Hawaii and rose to 413 ppm in 2019 with industrialisation which is why the planet has become *greener* in the industrial period. How insane then that psychopathic madman Gates is not satisfied only with blocking the rise of Co2. He's funding technology to suck it out of the atmosphere. The reason why will become clear. The industrial era is not destroying the world through Co2 and has instead turned around a potentially disastrous ongoing fall in Co2. Greenpeace co-founder and scientist Patrick Moore walked away from Greenpeace in 1986 and has exposed the green movement for fear-mongering and lies. He said that 500 million years ago there was *17 times* more Co2 in the atmosphere than we have today and levels have been falling for hundreds of millions of years. In the last 150 million years Co2 levels in Earth's atmosphere had reduced by *90 percent*. Moore said that by the time humanity began to unlock carbon dioxide from fossil fuels we were at '38 seconds to midnight' and in that sense: 'Humans are [the Earth's] salvation.' Moore made the point that only half the Co2 emitted by fossil fuels stays in the atmosphere and we should remember that all pollution pouring from chimneys that we are told is carbon dioxide is in fact nothing of the kind. It's pollution. Carbon dioxide is an invisible gas.

William Happer, Professor of Physics at Princeton University and long-time government adviser on climate, has emphasised the Co2 deficiency for maximum growth and food production. Greenhouse growers don't add carbon dioxide for a bit of fun. He said that most of the warming in the last 100 years, after the earth emerged from the super-cold period of the 'Little Ice Age' into a natural warming cycle, was over by 1940. Happer said that a peak year for warming in 1988 can be explained by a 'monster El Nino' which is a natural and cyclical warming of the Pacific that has nothing to do with 'climate

change'. He said the effect of Co2 could be compared to painting a wall with red paint in that once two or three coats have been applied it didn't matter how much more you slapped on because the wall will not get much redder. Almost all the effect of the rise in Co2 has already happened, he said, and the volume in the atmosphere would now have to *double* to increase temperature by a single degree. Climate hoaxers know this and they have invented the most ridiculously complicated series of 'feedback' loops to try to overcome this rather devastating fact. You hear puppet Greta going on cluelessly about feedback loops and this is why.

The Sun affects temperature? No you *climate denier*

Some other nonsense to contemplate: Climate graphs show that rises in temperature do not follow rises in Co2 – *it's the other way round* with a lag between the two of some 800 years. If we go back 800 years from present time we hit the Medieval Warm Period when temperatures were higher than now without any industrialisation and this was followed by the Little Ice Age when temperatures plummeted. The world was still emerging from these centuries of serious cold when many climate records began which makes the ever-repeated line of the 'hottest year since records began' meaningless when you are not comparing like with like. The coldest period of the Little Ice Age corresponded with the lowest period of sunspot activity when the Sun was at its least active. Proper scientists will not be at all surprised by this when it confirms the obvious fact that earth temperature is affected by the scale of Sun activity and the energetic power that it subsequently emits; but when is the last time you heard a climate hoaxer talking about the Sun as a source of earth temperature?? Everything has to be focussed on Co2 which makes up just 0.117 percent of so-called greenhouse gases and only a fraction of even that is generated by human activity. The rest is natural. More than 90 percent of those greenhouse gases are water vapour and clouds ([Fig 9](#)). Ban moisture I say. Have you noticed that the climate hoaxers no longer use the polar bear as their promotion image? That's because far from becoming extinct polar

bear communities are stable or thriving. Joe Bastardi, American meteorologist, weather forecaster and outspoken critic of the climate lie, documents in his book *The Climate Chronicles* how weather patterns and events claimed to be evidence of climate change have been happening since long before industrialisation: 'What happened before naturally is happening again, as is to be expected given the cyclical nature of the climate due to the design of the planet.' If you read the detailed background to the climate hoax in my other books you will shake your head and wonder how anyone could believe the crap which has spawned a multi-trillion dollar industry based on absolute garbage (see HIV causes AIDs and Sars-Cov-2 causes 'Covid-19'). Climate and 'Covid' have much in common given they have the same source. They both have the contradictory *everything* factor in which everything is explained by reference to them. It's hot – 'it's climate change'. It's cold – 'it's climate change'. I got a sniffle – 'it's Covid'. I haven't got a sniffle – 'it's Covid'. Not having a sniffle has to be a symptom of 'Covid'. Everything is and not having a sniffle is especially dangerous if you are a slow walker. For sheer audacity I offer you a Cambridge University 'study' that actually linked 'Covid' to 'climate change'. It had to happen eventually. They concluded that climate change played a role in 'Covid-19' spreading from animals to humans because ... wait for it ... I kid you not ... *the two groups were forced closer together as populations grow*. Er, that's it. The whole foundation on which this depended was that 'Bats are the likely zoonotic origin of SARS-CoV-1 and SARS-CoV-2'. Well, they are not. They are nothing to do with it. Apart from bats not being the origin and therefore 'climate change' effects on bats being irrelevant I am in awe of their academic insight. Where would we be without them? Not where we are that's for sure.

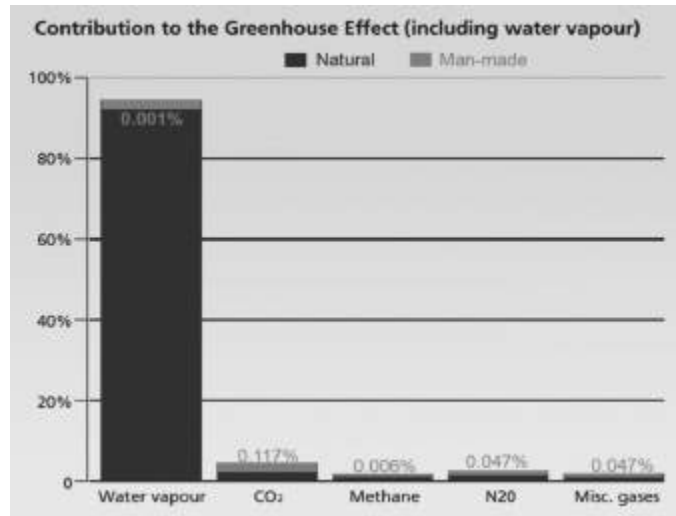


Figure 9: The idea that the gas of life is disastrously changing the climate is an insult to brain cell activity.

One other point about the weather is that climate modification is now well advanced and not every major weather event is natural – or earthquake come to that. I cover this subject at some length in other books. China is openly planning a rapid expansion of its weather modification programme which includes changing the climate in an area more than one and a half times the size of India. China used weather manipulation to ensure clear skies during the 2008 Olympics in Beijing. I have quoted from US military documents detailing how to employ weather manipulation as a weapon of war and they did that in the 1960s and 70s during the conflict in Vietnam with Operation Popeye manipulating monsoon rains for military purposes. Why would there be international treaties on weather modification if it wasn't possible? Of course it is. Weather is energetic information and it can be changed.

How was the climate hoax pulled off? See 'Covid'

If you can get billions to believe in a 'virus' that doesn't exist you can get them to believe in human-caused climate change that doesn't exist. Both are being used by the Cult to transform global society in the way it has long planned. Both hoaxes have been achieved in pretty much the same way. First you declare a lie is a fact. There's a

'virus' you call SARS-Cov-2 or humans are warming the planet with their behaviour. Next this becomes, via Cult networks, the foundation of government, academic and science policy and belief. Those who parrot the mantra are given big grants to produce research that confirms the narrative is true and ever more 'symptoms' are added to make the 'virus'/'climate change' sound even more scary. Scientists and researchers who challenge the narrative have their grants withdrawn and their careers destroyed. The media promote the lie as the unquestionable truth and censor those with an alternative view or evidence. A great percentage of the population believe what they are told as the lie becomes an everybody-knows-that and the believing-masses turn on those with a mind of their own. The technique has been used endlessly throughout human history. Wokers are the biggest promoters of the climate lie *and* 'Covid' fascism because their minds are owned by the Cult; their sense of self-righteous self-purity knows no bounds; and they exist in a bubble of reality in which facts are irrelevant and only get in the way of looking without seeing.

Running through all of this like veins in a blue cheese is control of information, which means control of perception, which means control of behaviour, which collectively means control of human society. The Cult owns the global media and Silicon Valley fascists for the simple reason that it *has* to. Without control of information it can't control perception and through that human society. Examine every facet of the Cult agenda and you will see that anything supporting its introduction is never censored while anything pushing back is always censored. I say again: Psychopaths that know why they are doing this must go before Nuremberg trials and those that follow their orders must trot along behind them into the same dock. 'I was just following orders' didn't work the first time and it must not work now. Nuremberg trials must be held all over the world before public juries for politicians, government officials, police, compliant doctors, scientists and virologists, and all Cult operatives such as Gates, Tedros, Fauci, Vallance, Whitty, Ferguson, Zuckerberg, Wojcicki, Brin, Page, Dorsey, the whole damn lot of

them – including, no *especially*, the psychopath psychologists. Without them and the brainless, gutless excuses for journalists that have repeated their lies, none of this could be happening. Nobody can be allowed to escape justice for the psychological and economic Armageddon they are all responsible for visiting upon the human race.

As for the compliant, unquestioning, swathes of humanity, and the self-obsessed, all-knowing ignorance of the Wokers ... don't start me. God help their kids. God help their grandkids. God *help them*.

CHAPTER NINE

We must have it? So what is it?

*Well I won't back down. No, I won't back down. You can stand me
up at the Gates of Hell. But I won't back down*

Tom Petty

I will now focus on the genetically-manipulating 'Covid vaccines' which do not meet this official definition of a vaccine by the US Centers for Disease Control (CDC): 'A product that stimulates a person's immune system to produce immunity to a specific disease, protecting the person from that disease.' On that basis 'Covid vaccines' are not a vaccine in that the makers don't even claim they stop infection or transmission.

They are instead part of a multi-levelled conspiracy to change the nature of the human body and what it means to be 'human' and to depopulate an enormous swathe of humanity. What I shall call Human 1.0 is on the cusp of becoming Human 2.0 and for very sinister reasons. Before I get to the 'Covid vaccine' in detail here's some background to vaccines in general. Government regulators do not test vaccines – the makers do – and the makers control which data is revealed and which isn't. Children in America are given 50 vaccine doses by age six and 69 by age 19 and the effect of the whole combined schedule has never been tested. Autoimmune diseases when the immune system attacks its own body have soared in the mass vaccine era and so has disease in general in children and the young. Why wouldn't this be the case when vaccines target the *immune system*? The US government gave Big Pharma drug

companies immunity from prosecution for vaccine death and injury in the 1986 National Childhood Vaccine Injury Act (NCVIA) and since then the government (taxpayer) has been funding compensation for the consequences of Big Pharma vaccines. The criminal and satanic drug giants can't lose and the vaccine schedule has increased dramatically since 1986 for this reason. There is no incentive to make vaccines safe and a big incentive to make money by introducing ever more. Even against a ridiculously high bar to prove vaccine liability, and with the government controlling the hearing in which it is being challenged for compensation, the vaccine court has so far paid out more than \$4 billion. These are the vaccines we are told are safe and psychopaths like Zuckerberg censor posts saying otherwise. The immunity law was even justified by a ruling that vaccines by their nature were 'unavoidably unsafe'.

Check out the ingredients of vaccines and you will be shocked if you are new to this. *They put that in children's bodies?? What??* Try aluminium, a brain toxin connected to dementia, aborted foetal tissue and formaldehyde which is used to embalm corpses. World-renowned aluminium expert Christopher Exley had his research into the health effect of aluminium in vaccines shut down by Keele University in the UK when it began taking funding from the Bill and Melinda Gates Foundation. Research when diseases 'eradicated' by vaccines began to decline and you will find the fall began long *before* the vaccine was introduced. Sometimes the fall even plateaued after the vaccine. Diseases like scarlet fever for which there was no vaccine declined in the same way because of environmental and other factors. A perfect case in point is the polio vaccine. Polio began when lead arsenate was first sprayed as an insecticide and residues remained in food products. Spraying started in 1892 and the first US polio epidemic came in Vermont in 1894. The simple answer was to stop spraying, but Rockefeller-created Big Pharma had a better idea. Polio was decreed to be caused by the *poliovirus* which 'spreads from person to person and can infect a person's spinal cord'. Lead arsenate was replaced by the lethal DDT which had the same effect of causing paralysis by damaging the brain and central nervous

system. Polio plummeted when DDT was reduced and then banned, but the vaccine is still given the credit for something it didn't do. Today by far the biggest cause of polio is the vaccines promoted by Bill Gates. Vaccine justice campaigner Robert Kennedy Jr, son of assassinated (by the Cult) US Attorney General Robert Kennedy, wrote:

In 2017, the World Health Organization (WHO) reluctantly admitted that the global explosion in polio is predominantly vaccine strain. The most frightening epidemics in Congo, Afghanistan, and the Philippines, are all linked to vaccines. In fact, by 2018, 70% of global polio cases were vaccine strain.

Vaccines make fortunes for Cult-owned Gates and Big Pharma while undermining the health and immune systems of the population. We had a glimpse of the mentality behind the Big Pharma cartel with a report on WION (World is One News), an international English language TV station based in India, which exposed the extraordinary behaviour of US drug company Pfizer over its 'Covid vaccine'. The WION report told how Pfizer had made fantastic demands of Argentina, Brazil and other countries in return for its 'vaccine'. These included immunity from prosecution, even for Pfizer negligence, government insurance to protect Pfizer from law suits and handing over as collateral sovereign assets of the country to include Argentina's bank reserves, military bases and embassy buildings. Pfizer demanded the same of Brazil in the form of waiving sovereignty of its assets abroad; exempting Pfizer from Brazilian laws; and giving Pfizer immunity from all civil liability. This is a 'vaccine' developed with government funding. Big Pharma is evil incarnate as a creation of the Cult and all must be handed tickets to Nuremberg.

Phantom 'vaccine' for a phantom 'disease'

I'll expose the 'Covid vaccine' fraud and then go on to the wider background of why the Cult has set out to 'vaccinate' every man, woman and child on the planet for an alleged 'new disease' with a survival rate of 99.77 percent (or more) even by the grotesquely-

manipulated figures of the World Health Organization and Johns Hopkins University. The 'infection' to 'death' ratio is 0.23 to 0.15 percent according to Stanford epidemiologist Dr John Ioannidis and while estimates vary the danger remains tiny. I say that if the truth be told the fake infection to fake death ratio is zero. Never mind all the evidence I have presented here and in *The Answer* that there is no 'virus' let us just focus for a moment on that death-rate figure of say 0.23 percent. The figure includes all those worldwide who have tested positive with a test not testing for the 'virus' and then died within 28 days or even longer of any other cause – *any other cause*. Now subtract all those illusory 'Covid' deaths on the global data sheets from the 0.23 percent. What do you think you would be left with? *Zero*. A vaccination has never been successfully developed for a so-called coronavirus. They have all failed at the animal testing stage when they caused hypersensitivity to what they were claiming to protect against and made the impact of a disease far worse. Cult-owned vaccine corporations got around that problem this time by bypassing animal trials, going straight to humans and making the length of the 'trials' before the public rollout as short as they could get away with. Normally it takes five to ten years or more to develop vaccines that still cause demonstrable harm to many people and that's without including the long-term effects that are never officially connected to the vaccination. 'Covid' non-vaccines have been officially produced and approved in a matter of months from a standing start and part of the reason is that (a) they were developed before the 'Covid' hoax began and (b) they are based on computer programs and not natural sources. Official non-trials were so short that government agencies gave *emergency*, not full, approval. 'Trials' were not even completed and full approval cannot be secured until they are. Public 'Covid vaccination' is actually a *continuation of the trial*. Drug company 'trials' are not scheduled to end until 2023 by which time a lot of people are going to be dead. Data on which government agencies gave this emergency approval was supplied by the Big Pharma corporations themselves in the form of Pfizer/BioNTech, AstraZeneca, Moderna, Johnson & Johnson, and

others, and this is the case with all vaccines. By its very nature *emergency* approval means drug companies do not have to prove that the 'vaccine' is 'safe and effective'. How could they with trials way short of complete? Government regulators only have to *believe* that they *could* be safe and effective. It is criminal manipulation to get products in circulation with no testing worth the name. Agencies giving that approval are infested with Big Pharma-connected place-people and they act in the interests of Big Pharma (the Cult) and not the public about whom they do not give a damn.

More human lab rats

'Covid vaccines' produced in record time by Pfizer/BioNTech and Moderna employ a technique *never approved before for use on humans*. They are known as mRNA 'vaccines' and inject a synthetic version of 'viral' mRNA or 'messenger RNA'. The key is in the term 'messenger'. The body works, or doesn't, on the basis of information messaging. Communications are constantly passing between and within the genetic system and the brain. Change those messages and you change the state of the body and even its very nature and you can change psychology and behaviour by the way the brain processes information. I think you are going to see significant changes in personality and perception of many people who have had the 'Covid vaccine' synthetic potions. Insider Aldous Huxley predicted the following in 1961 and mRNA 'vaccines' can be included in the term 'pharmacological methods':

There will be, in the next generation or so, a pharmacological method of making people love their servitude, and producing dictatorship without tears, so to speak, producing a kind of painless concentration camp for entire societies, so that people will in fact have their own liberties taken away from them, but rather enjoy it, because they will be distracted from any desire to rebel by propaganda or brainwashing, or brainwashing enhanced by pharmacological methods. And this seems to be the final revolution.

Apologists claim that mRNA synthetic 'vaccines' don't change the DNA genetic blueprint because RNA does not affect DNA only the other way round. This is so disingenuous. A process called 'reverse

transcription' can convert RNA into DNA and be integrated into DNA in the cell nucleus. This was highlighted in December, 2020, by scientists at Harvard and Massachusetts Institute of Technology (MIT). Geneticists report that more than 40 percent of mammalian genomes results from reverse transcription. On the most basic level if messaging changes then that sequence must lead to changes in DNA which is receiving and transmitting those communications. How can introducing synthetic material into cells not change the cells where DNA is located? The process is known as transfection which is defined as 'a technique to insert foreign nucleic acid (DNA or RNA) into a cell, typically with the intention of altering the properties of the cell'. Researchers at the Sloan Kettering Institute in New York found that changes in messenger RNA can deactivate tumour-suppressing proteins and thereby promote cancer. This is what happens when you mess with messaging. 'Covid vaccine' maker Moderna was founded in 2010 by Canadian stem cell biologist Derrick J. Rossi after his breakthrough discovery in the field of transforming and reprogramming stem cells. These are neutral cells that can be programmed to become any cell including sperm cells. Moderna was therefore founded on the principle of genetic manipulation and has never produced any vaccine or drug before its genetically-manipulating synthetic 'Covid' shite. Look at the name – Mode-RNA or Modify-RNA. Another important point is that the US Supreme Court has ruled that genetically-modified DNA, or complementary DNA (cDNA) synthesized in the laboratory from messenger RNA, can be patented and owned. These psychopaths are doing this to the human body.

Cells replicate synthetic mRNA in the 'Covid vaccines' and in theory the body is tricked into making antigens which trigger antibodies to target the 'virus spike proteins' which as Dr Tom Cowan said have *never been seen*. Cut the crap and these 'vaccines' deliver *self-replicating* synthetic material to the cells with the effect of changing human DNA. The more of them you have the more that process is compounded while synthetic material is all the time self-replicating. 'Vaccine'-maker Moderna describes mRNA as 'like

software for the cell' and so they are messing with the body's software. What happens when you change the software in a computer? Everything changes. For this reason the Cult is preparing a production line of mRNA 'Covid vaccines' and a long list of excuses to use them as with all the 'variants' of a 'virus' never shown to exist. The plan is further to transfer the mRNA technique to other vaccines mostly given to children and young people. The cumulative consequences will be a transformation of human DNA through a constant infusion of synthetic genetic material which will kill many and change the rest. Now consider that governments that have given emergency approval for a vaccine that's not a vaccine; never been approved for humans before; had no testing worth the name; and the makers have been given immunity from prosecution for any deaths or adverse effects suffered by the public. The UK government awarded *permanent legal indemnity* to itself and its employees for harm done when a patient is being treated for 'Covid-19' or 'suspected Covid-19'. That is quite a thought when these are possible 'side-effects' from the 'vaccine' (they are not 'side', they are effects) listed by the US Food and Drug Administration:

Guillain-Barre syndrome; acute disseminated encephalomyelitis; transverse myelitis; encephalitis; myelitis; encephalomyelitis; meningoencephalitis; meningitis; encephalopathy; convulsions; seizures; stroke; narcolepsy; cataplexy; anaphylaxis; acute myocardial infarction (heart attack); myocarditis; pericarditis; autoimmune disease; death; implications for pregnancy, and birth outcomes; other acute demyelinating diseases; non anaphylactic allergy reactions; thrombocytopenia ; disseminated intravascular coagulation; venous thromboembolism; arthritis; arthralgia; joint pain; Kawasaki disease; multisystem inflammatory syndrome in children; vaccine enhanced disease. The latter is the way the 'vaccine' has the potential to make diseases far worse than they would otherwise be.

UK doctor and freedom campaigner Vernon Coleman described the conditions in this list as 'all unpleasant, most of them very serious, and you can't get more serious than death'. The thought that anyone at all has had the 'vaccine' in these circumstances is testament to the potential that humanity has for clueless, unquestioning, stupidity and for many that programmed stupidity has already been terminal.

An insider speaks

Dr Michael Yeadon is a former Vice President, head of research and Chief Scientific Adviser at vaccine giant Pfizer. Yeadon worked on the inside of Big Pharma, but that did not stop him becoming a vocal critic of 'Covid vaccines' and their potential for multiple harms, including infertility in women. By the spring of 2021 he went much further and even used the no, no, term 'conspiracy'. When you begin to see what is going on it is impossible not to do so. Yeadon spoke out in an interview with freedom campaigner James Delingpole and I mentioned earlier how he said that no one had samples of 'the virus'. He explained that the mRNA technique originated in the anti-cancer field and ways to turn on and off certain genes which could be advantageous if you wanted to stop cancer growing out of control. 'That's the origin of them. They are a very unusual application, really.' Yeadon said that treating a cancer patient with an aggressive procedure might be understandable if the alternative was dying, but it was quite another thing to use the same technique as a public health measure. Most people involved wouldn't catch the infectious agent you were vaccinating against and if they did they probably wouldn't die:

If you are really using it as a public health measure you really want to as close as you can get to zero side-effects ... I find it odd that they chose techniques that were really cutting their teeth in the field of oncology and I'm worried that in using gene-based vaccines that have to be injected in the body and spread around the body, get taken up into some cells, and the regulators haven't quite told us which cells they get taken up into ... you are going to be generating a wide range of responses ... with multiple steps each of which could go well or badly.

I doubt the Cult intends it to go well. Yeadon said that you can put any gene you like into the body through the 'vaccine'. 'You can certainly give them a gene that would do them some harm if you wanted.' I was intrigued when he said that when used in the cancer field the technique could turn genes on and off. I explore this process in *The Answer* and with different genes having different functions you could create mayhem – physically and psychologically – if you turned the wrong ones on and the right ones off. I read reports of an experiment by researchers at the University of Washington's school of computer science and engineering in which they encoded DNA to infect computers. The body is itself a biological computer and if human DNA can inflict damage on a computer why can't the computer via synthetic material mess with the human body? It can. The Washington research team said it was possible to insert malicious malware into 'physical DNA strands' and corrupt the computer system of a gene sequencing machine as it 'reads gene letters and stores them as binary digits 0 and 1'. They concluded that hackers could one day use blood or spit samples to access computer systems and obtain sensitive data from police forensics labs or infect genome files. It is at this level of digital interaction that synthetic 'vaccines' need to be seen to get the full picture and that will become very clear later on. Michael Yeadon said it made no sense to give the 'vaccine' to younger people who were in no danger from the 'virus'. What was the benefit? It was all downside with potential effects:

The fact that my government in what I thought was a civilised, rational country, is raining [the 'vaccine'] on people in their 30s and 40s, even my children in their 20s, they're getting letters and phone calls, I know this is not right and any of you doctors who are vaccinating you know it's not right, too. They are not at risk. They are not at risk from the disease, so you are now hoping that the side-effects are so rare that you get away with it. You don't give new technology ... that you don't understand to 100 percent of the population.

Blood clot problems with the AstraZeneca 'vaccine' have been affecting younger people to emphasise the downside risks with no benefit. AstraZeneca's version, produced with Oxford University, does not use mRNA, but still gets its toxic cocktail inside cells where

it targets DNA. The Johnson & Johnson 'vaccine' which uses a similar technique has also produced blood clot effects to such an extent that the United States paused its use at one point. They are all 'gene therapy' (cell modification) procedures and not 'vaccines'. The truth is that once the content of these injections enter cells we have no idea what the effect will be. People can speculate and some can give very educated opinions and that's good. In the end, though, only the makers know what their potions are designed to do and even they won't know every last consequence. Michael Yeadon was scathing about doctors doing what they knew to be wrong. 'Everyone's mute', he said. Doctors in the NHS must know this was not right, coming into work and injecting people. 'I don't know how they sleep at night. I know I couldn't do it. I know that if I were in that position I'd have to quit.' He said he knew enough about toxicology to know this was not a good risk-benefit. Yeadon had spoken to seven or eight university professors and all except two would not speak out publicly. Their universities had a policy that no one said anything that countered the government and its medical advisors. They were afraid of losing their government grants. This is how intimidation has been used to silence the truth at every level of the system. I say silence, but these people could still speak out if they made that choice. Yeadon called them 'moral cowards' – 'This is about your children and grandchildren's lives and you have just buggered off and left it.'

'Variant' nonsense

Some of his most powerful comments related to the alleged 'variants' being used to instil more fear, justify more lockdowns, and introduce more 'vaccines'. He said government claims about 'variants' were nonsense. He had checked the alleged variant 'codes' and they were 99.7 percent identical to the 'original'. This was the human identity difference equivalent to putting a baseball cap on and off or wearing it the other way round. A 0.3 percent difference would make it impossible for that 'variant' to escape immunity from the 'original'. This made no sense of having new 'vaccines' for

‘variants’. He said there would have to be at least a *30 percent* difference for that to be justified and even then he believed the immune system would still recognise what it was. Gates-funded ‘variant modeller’ and ‘vaccine’-pusher John Edmunds might care to comment. Yeadon said drug companies were making new versions of the ‘vaccine’ as a ‘top up’ for ‘variants’. Worse than that, he said, the ‘regulators’ around the world like the MHRA in the UK had got together and agreed that because ‘vaccines’ for ‘variants’ were so similar to the first ‘vaccines’ *they did not have to do safety studies*. How transparently sinister that is. This is when Yeadon said: ‘There is a conspiracy here.’ There was no need for another vaccine for ‘variants’ and yet we were told that there was and the country had shut its borders because of them. ‘They are going into hundreds of millions of arms without passing ‘go’ or any regulator. Why did they do that? Why did they pick this method of making the vaccine?’

The reason had to be something bigger than that it seemed and ‘it’s not protection against the virus’. It’s was a far bigger project that meant politicians and advisers were willing to do things and not do things that knowingly resulted in avoidable deaths – ‘that’s already happened when you think about lockdown and deprivation of health care for a year.’ He spoke of people prepared to do something that results in the avoidable death of their fellow human beings and it not bother them. This is the penny-drop I have been working to get across for more than 30 years – the level of pure evil we are dealing with. Yeadon said his friends and associates could not believe there could be that much evil, but he reminded them of Stalin, Pol Pot and Hitler and of what Stalin had said: ‘One death is a tragedy. A million? A statistic.’ He could not think of a benign explanation for why you need top-up vaccines ‘which I’m sure you don’t’ and for the regulators ‘to just get out of the way and wave them through’. Why would the regulators do that when they were still wrestling with the dangers of the ‘parent’ vaccine? He was clearly shocked by what he had seen since the ‘Covid’ hoax began and now he was thinking the previously unthinkable:

If you wanted to depopulate a significant proportion of the world and to do it in a way that doesn't involve destruction of the environment with nuclear weapons, poisoning everyone with anthrax or something like that, and you wanted plausible deniability while you had a multi-year infectious disease crisis, I actually don't think you could come up with a better plan of work than seems to be in front of me. I can't say that's what they are going to do, but I can't think of a benign explanation why they are doing it.

He said he never thought that they would get rid of 99 percent of humans, but now he wondered. 'If you wanted to that this would be a hell of a way to do it – it would be unstoppable folks.' Yeadon had concluded that those who submitted to the 'vaccine' would be allowed to have some kind of normal life (but for how long?) while screws were tightened to coerce and mandate the last few percent. 'I think they'll put the rest of them in a prison camp. I wish I was wrong, but I don't think I am.' Other points he made included: There were no coronavirus vaccines then suddenly they all come along at the same time; we have no idea of the long term affect with trials so short; coercing or forcing people to have medical procedures is against the Nuremberg Code instigated when the Nazis did just that; people should at least delay having the 'vaccine'; a quick Internet search confirms that masks don't reduce respiratory viral transmission and 'the government knows that'; they have smashed civil society and they know that, too; two dozen peer-reviewed studies show no connection between lockdown and reducing deaths; he knew from personal friends the elite were still flying around and going on holiday while the public were locked down; the elite were not having the 'vaccines'. He was also asked if 'vaccines' could be made to target difference races. He said he didn't know, but the document by the Project for the New American Century in September, 2000, said developing 'advanced forms of biological warfare that can target *specific genotypes* may transform biological warfare from the realm of terror to a politically useful tool.' Oh, they're evil all right. Of that we can be *absolutely* sure.

Another cull of old people

We have seen from the CDC definition that the mRNA 'Covid vaccine' is not a vaccine and nor are the others that *claim* to reduce 'severity of symptoms' in *some* people, but not protect from infection or transmission. What about all the lies about returning to 'normal' if people were 'vaccinated'? If they are not claimed to stop infection and transmission of the alleged 'virus', how does anything change? This was all lies to manipulate people to take the jabs and we are seeing that now with masks and distancing still required for the 'vaccinated'. How did they think that elderly people with fragile health and immune responses were going to be affected by infusing their cells with synthetic material and other toxic substances? They *knew* that in the short and long term it would be devastating and fatal as the culling of the old that began with the first lockdowns was continued with the 'vaccine'. Death rates in care homes soared immediately residents began to be 'vaccinated' – infused with synthetic material. Brave and committed whistleblower nurses put their careers at risk by exposing this truth while the rest kept their heads down and their mouths shut to put their careers before those they are supposed to care for. A long-time American Certified Nursing Assistant who gave his name as James posted a video in which he described emotionally what happened in his care home when vaccination began. He said that during 2020 very few residents were sick with 'Covid' and no one died during the entire year; but shortly after the Pfizer mRNA injections 14 people died within two weeks and many others were near death. 'They're dropping like flies', he said. Residents who walked on their own before the shot could no longer and they had lost their ability to conduct an intelligent conversation. The home's management said the sudden deaths were caused by a 'super-spreader' of 'Covid-19'. Then how come, James asked, that residents who refused to take the injections were not sick? It was a case of inject the elderly with mRNA synthetic potions and blame their illness and death that followed on the 'virus'. James described what was happening in care homes as 'the greatest crime of genocide this country has ever seen'. Remember the NHS staff nurse from earlier who used the same

word 'genocide' for what was happening with the 'vaccines' and that it was an 'act of human annihilation'. A UK care home whistleblower told a similar story to James about the effect of the 'vaccine' in deaths and 'outbreaks' of illness dubbed 'Covid' after getting the jab. She told how her care home management and staff had zealously imposed government regulations and no one was allowed to even question the official narrative let alone speak out against it. She said the NHS was even worse. Again we see the results of reframing. A worker at a local care home where I live said they had not had a single case of 'Covid' there for almost a year and when the residents were 'vaccinated' they had 19 positive cases in two weeks with eight dying.

It's not the 'vaccine' – honest

The obvious cause and effect was being ignored by the media and most of the public. Australia's health minister Greg Hunt (a former head of strategy at the World Economic Forum) was admitted to hospital after he had the 'vaccine'. He was suffering according to reports from the skin infection 'cellulitis' and it must have been a severe case to have warranted days in hospital. Immediately the authorities said this was nothing to do with the 'vaccine' when an effect of some vaccines is a 'cellulitis-like reaction'. We had families of perfectly healthy old people who died after the 'vaccine' saying that if only they had been given the 'vaccine' earlier they would still be alive. As a numbskull rating that is off the chart. A father of four 'died of Covid' at aged 48 when he was taken ill two days after having the 'vaccine'. The man, a health administrator, had been 'shielding during the pandemic' and had 'not really left the house' until he went for the 'vaccine'. Having the 'vaccine' and then falling ill and dying does not seem to have qualified as a possible cause and effect and 'Covid-19' went on his death certificate. His family said they had no idea how he 'caught the virus'. A family member said: 'Tragically, it could be that going for a vaccination ultimately led to him catching Covid ...The sad truth is that they are never going to know where it came from.' The family warned people to remember

that the virus still existed and was 'very real'. So was their stupidity. Nurses and doctors who had the first round of the 'vaccine' were collapsing, dying and ending up in a hospital bed while they or their grieving relatives were saying they'd still have the 'vaccine' again despite what happened. I kid you not. You mean if your husband returned from the dead he'd have the same 'vaccine' again that killed him??

Doctors at the VCU Medical Center in Richmond, Virginia, said the Johnson & Johnson 'vaccine' was to blame for a man's skin peeling off. Patient Richard Terrell said: 'It all just happened so fast. My skin peeled off. It's still coming off on my hands now.' He said it was stinging, burning and itching and when he bent his arms and legs it was very painful with 'the skin swollen and rubbing against itself'. Pfizer/BioNTech and Moderna vaccines use mRNA to change the cell while the Johnson & Johnson version uses DNA in a process similar to AstraZeneca's technique. Johnson & Johnson and AstraZeneca have both had their 'vaccines' paused by many countries after causing serious blood problems. Terrell's doctor Fnu Nutan said he could have died if he hadn't got medical attention. It sounds terrible so what did Nutan and Terrell say about the 'vaccine' now? Oh, they still recommend that people have it. A nurse in a hospital bed 40 minutes after the vaccination and unable to swallow due to throat swelling was told by a doctor that he lost mobility in his arm for 36 hours following the vaccination. What did he say to the ailing nurse? 'Good for you for getting the vaccination.' We are dealing with a serious form of cognitive dissonance madness in both public and medical staff. There is a remarkable correlation between those having the 'vaccine' and trumpeting the fact and suffering bad happenings shortly afterwards. Witold Rogiewicz, a Polish doctor, made a video of his 'vaccination' and ridiculed those who were questioning its safety and the intentions of Bill Gates: 'Vaccinate yourself to protect yourself, your loved ones, friends and also patients. And to mention quickly I have info for anti-vaxxers and anti-Covidors if you want to contact Bill Gates you can do this through me.' He further ridiculed the dangers of 5G. Days later he

was dead, but naturally the vaccination wasn't mentioned in the verdict of 'heart attack'.

Lies, lies and more lies

So many members of the human race have slipped into extreme states of insanity and unfortunately they include reframed doctors and nursing staff. Having a 'vaccine' and dying within minutes or hours is not considered a valid connection while death from any cause within 28 days or longer of a positive test with a test not testing for the 'virus' means 'Covid-19' goes on the death certificate. How could that 'vaccine'-death connection not have been made except by calculated deceit? US figures in the initial rollout period to February 12th, 2020, revealed that a third of the deaths reported to the CDC after 'Covid vaccines' happened within 48 hours. Five men in the UK suffered an 'extremely rare' blood clot problem after having the AstraZeneca 'vaccine', but no causal link was established said the Gates-funded Medicines and Healthcare products Regulatory Agency (MHRA) which had given the 'vaccine' emergency approval to be used. Former Pfizer executive Dr Michael Yeadon explained in his interview how the procedures could cause blood coagulation and clots. People who should have been at no risk were dying from blood clots in the brain and he said he had heard from medical doctor friends that people were suffering from skin bleeding and massive headaches. The AstraZeneca 'shot' was stopped by some 20 countries over the blood clotting issue and still the corrupt MHRA, the European Medicines Agency (EMA) and the World Health Organization said that it should continue to be given even though the EMA admitted that it 'still cannot rule out definitively' a link between blood clotting and the 'vaccine'. Later Marco Cavaleri, head of EMA vaccine strategy, said there was indeed a clear link between the 'vaccine' and thrombosis, but they didn't know why. So much for the trials showing the 'vaccine' is safe. Blood clots were affecting younger people who would be under virtually no danger from 'Covid' even if it existed which makes it all the more stupid and sinister.

The British government responded to public alarm by wheeling out June Raine, the terrifyingly weak infant school headmistress sound-alike who heads the UK MHRA drug 'regulator'. The idea that she would stand up to Big Pharma and government pressure is laughable and she told us that all was well in the same way that she did when allowing untested, never-used-on-humans-before, genetically-manipulating 'vaccines' to be exposed to the public in the first place. Mass lying is the new normal of the 'Covid' era. The MHRA later said 30 cases of rare blood clots had by then been connected with the AstraZeneca 'vaccine' (that means a lot more in reality) while stressing that the benefits of the jab in preventing 'Covid-19' outweighed any risks. A more ridiculous and disingenuous statement with callous disregard for human health it is hard to contemplate. Immediately after the mendacious 'all-clears' two hospital workers in Denmark experienced blood clots and cerebral haemorrhaging following the AstraZeneca jab and one died. Top Norwegian health official Pål Andre Holme said the 'vaccine' was the only common factor: 'There is nothing in the patient history of these individuals that can give such a powerful immune response ... I am confident that the antibodies that we have found are the cause, and I see no other explanation than it being the vaccine which triggers it.' Strokes, a clot or bleed in the brain, were clearly associated with the 'vaccine' from word of mouth and whistleblower reports. Similar consequences followed with all these 'vaccines' that we were told were so safe and as the numbers grew by the day it was clear we were witnessing human carnage.

Learning the hard way

A woman interviewed by UKColumn told how her husband suffered dramatic health effects after the vaccine when he'd been in good health all his life. He went from being a little unwell to losing all feeling in his legs and experiencing 'excruciating pain'. Misdiagnosis followed twice at Accident and Emergency (an 'allergy' and 'sciatica') before he was admitted to a neurology ward where doctors said his serious condition had been caused by the

'vaccine'. Another seven 'vaccinated' people were apparently being treated on the same ward for similar symptoms. The woman said he had the 'vaccine' because they believed media claims that it was safe. 'I didn't think the government would give out a vaccine that does this to somebody; I believed they would be bringing out a vaccination that would be safe.' What a tragic way to learn that lesson. Another woman posted that her husband was transporting stroke patients to hospital on almost every shift and when he asked them if they had been 'vaccinated' for 'Covid' they all replied 'yes'. One had a 'massive brain bleed' the day after his second dose. She said her husband reported the 'just been vaccinated' information every time to doctors in A and E only for them to ignore it, make no notes and appear annoyed that it was even mentioned. This particular report cannot be verified, but it expresses a common theme that confirms the monumental underreporting of 'vaccine' consequences. Interestingly as the 'vaccines' and their brain blood clot/stroke consequences began to emerge the UK National Health Service began a publicity campaign telling the public what to do in the event of a stroke. A Scottish NHS staff nurse who quit in disgust in March, 2021, said:

I have seen traumatic injuries from the vaccine, they're not getting reported to the yellow card [adverse reaction] scheme, they're treating the symptoms, not asking why, why it's happening. It's just treating the symptoms and when you speak about it you're dismissed like you're crazy, I'm not crazy, I'm not crazy because every other colleague I've spoken to is terrified to speak out, they've had enough.

Videos appeared on the Internet of people uncontrollably shaking after the 'vaccine' with no control over muscles, limbs and even their face. A Scottish mother broke out in a severe rash all over her body almost immediately after she was given the AstraZeneca 'vaccine'. The pictures were horrific. Leigh King, a 41-year-old hairdresser from Lanarkshire said: 'Never in my life was I prepared for what I was about to experience ... My skin was so sore and constantly hot ... I have never felt pain like this ...' But don't you worry, the 'vaccine' is perfectly safe. Then there has been the effect on medical

staff who have been pressured to have the 'vaccine' by psychopathic 'health' authorities and government. A London hospital consultant who gave the name K. Polyakova wrote this to the *British Medical Journal* or *BMJ*:

I am currently struggling with ... the failure to report the reality of the morbidity caused by our current vaccination program within the health service and staff population. The levels of sickness after vaccination is unprecedented and staff are getting very sick and some with neurological symptoms which is having a huge impact on the health service function. Even the young and healthy are off for days, some for weeks, and some requiring medical treatment. Whole teams are being taken out as they went to get vaccinated together.

Mandatory vaccination in this instance is stupid, unethical and irresponsible when it comes to protecting our staff and public health. We are in the voluntary phase of vaccination, and encouraging staff to take an unlicensed product that is impacting on their immediate health ... it is clearly stated that these vaccine products do not offer immunity or stop transmission. In which case why are we doing it?

Not to protect health that's for sure. Medical workers are lauded by governments for agenda reasons when they couldn't give a toss about them any more than they can for the population in general. Schools across America faced the same situation as they closed due to the high number of teachers and other staff with bad reactions to the Pfizer/BioNTech, Moderna, and Johnson & Johnson 'Covid vaccines' all of which were linked to death and serious adverse effects. The *BMJ* took down the consultant's comments pretty quickly on the grounds that they were being used to spread 'disinformation'. They were exposing the truth about the 'vaccine' was the real reason. The cover-up is breathtaking.

Hiding the evidence

The scale of the 'vaccine' death cover-up worldwide can be confirmed by comparing official figures with the personal experience of the public. I heard of many people in my community who died immediately or soon after the vaccine that would never appear in the media or even likely on the official totals of 'vaccine' fatalities and adverse reactions when only about ten percent are estimated to be

reported and I have seen some estimates as low as one percent in a Harvard study. In the UK alone by April 29th, 2021, some 757,654 adverse reactions had been officially reported from the Pfizer/BioNTech, Oxford/AstraZeneca and Moderna 'vaccines' with more than a thousand deaths linked to jabs and that means an estimated ten times this number in reality from a ten percent reporting rate percentage. That's seven million adverse reactions and 10,000 potential deaths and a one percent reporting rate would be ten times *those* figures. In 1976 the US government pulled the swine flu vaccine after 53 deaths. The UK data included a combined 10,000 eye disorders from the 'Covid vaccines' with more than 750 suffering visual impairment or blindness and again multiply by the estimated reporting percentages. As 'Covid cases' officially fell hospitals virtually empty during the 'Covid crisis' began to fill up with a range of other problems in the wake of the 'vaccine' rollout. The numbers across America have also been catastrophic. Deaths linked to *all* types of vaccine increased by 6,000 *percent* in the first quarter of 2021 compared with 2020. A 39-year-old woman from Ogden, Utah, died four days after receiving a second dose of Moderna's 'Covid vaccine' when her liver, heart and kidneys all failed despite the fact that she had no known medical issues or conditions. Her family sought an autopsy, but Dr Erik Christensen, Utah's chief medical examiner, said proving vaccine injury as a cause of death almost never happened. He could think of only one instance where an autopsy would name a vaccine as the official cause of death and that would be anaphylaxis where someone received a vaccine and died almost instantaneously. 'Short of that, it would be difficult for us to definitively say this is the vaccine,' Christensen said. If that is true this must be added to the estimated ten percent (or far less) reporting rate of vaccine deaths and serious reactions and the conclusion can only be that vaccine deaths and serious reactions – including these 'Covid' potions' – are phenomenally understated in official figures. The same story can be found everywhere. Endless accounts of deaths and serious reactions among the public, medical

and care home staff while official figures did not even begin to reflect this.

Professional script-reader Dr David Williams, a 'top public-health official' in Ontario, Canada, insulted our intelligence by claiming only four serious adverse reactions and no deaths from the more than 380,000 vaccine doses then given. This bore no resemblance to what people knew had happened in their own circles and we had Dirk Huyer in charge of getting millions vaccinated in Ontario while at the same time he was Chief Coroner for the province investigating causes of death including possible death from the vaccine. An aide said he had stepped back from investigating deaths, but evidence indicated otherwise. Rosemary Frei, who secured a Master of Science degree in molecular biology at the Faculty of Medicine at Canada's University of Calgary before turning to investigative journalism, was one who could see that official figures for 'vaccine' deaths and reactions made no sense. She said that doctors seldom reported adverse events and when people got really sick or died after getting a vaccination they would attribute that to anything except the vaccines. It had been that way for years and anyone who wondered aloud whether the 'Covid vaccines' or other shots cause harm is immediately branded as 'anti-vax' and 'anti-science'. This was 'career-threatening' for health professionals. Then there was the huge pressure to support the push to 'vaccinate' billions in the quickest time possible. Frei said:

So that's where we're at today. More than half a million vaccine doses have been given to people in Ontario alone. The rush is on to vaccinate all 15 million of us in the province by September. And the mainstream media are screaming for this to be sped up even more. That all adds up to only a very slim likelihood that we're going to be told the truth by officials about how many people are getting sick or dying from the vaccines.

What is true of Ontario is true of everywhere.

They KNEW – and still did it

The authorities knew what was going to happen with multiple deaths and adverse reactions. The UK government's Gates-funded

and Big Pharma-dominated Medicines and Healthcare products Regulatory Agency (MHRA) hired a company to employ AI in compiling the projected reactions to the 'vaccine' that would otherwise be uncountable. The request for applications said: 'The MHRA urgently seeks an Artificial Intelligence (AI) software tool to process the expected high volume of Covid-19 vaccine Adverse Drug Reaction ...' This was from the agency, headed by the disingenuous June Raine, that gave the 'vaccines' emergency approval and the company was hired before the first shot was given. 'We are going to kill and maim you – is that okay?' 'Oh, yes, perfectly fine – I'm very grateful, thank you, doctor.' The range of 'Covid vaccine' adverse reactions goes on for page after page in the MHRA criminally underreported 'Yellow Card' system and includes affects to eyes, ears, skin, digestion, blood and so on. Raine's MHRA amazingly claimed that the 'overall safety experience ... is so far as expected from the clinical trials'. The death, serious adverse effects, deafness and blindness were *expected*? When did they ever mention that? If these human tragedies were expected then those that gave approval for the use of these 'vaccines' must be guilty of crimes against humanity including murder – a definition of which is 'killing a person with malice aforethought or with recklessness manifesting extreme indifference to the value of human life.' People involved at the MHRA, the CDC in America and their equivalent around the world must go before Nuremberg trials to answer for their callous inhumanity. We are only talking here about the immediate effects of the 'vaccine'. The longer-term impact of the DNA synthetic manipulation is the main reason they are so hysterically desperate to inoculate the entire global population in the shortest possible time.

Africa and the developing world are a major focus for the 'vaccine' depopulation agenda and a mass vaccination sales-pitch is underway thanks to caring people like the Rockefellers and other Cult assets. The Rockefeller Foundation, which pre-empted the 'Covid pandemic' in a document published in 2010 that 'predicted' what happened a decade later, announced an initial \$34.95 million grant in February, 2021, 'to ensure more equitable access to Covid-19

testing and vaccines' among other things in Africa in collaboration with '24 organizations, businesses, and government agencies'. The pan-Africa initiative would focus on 10 countries: Burkina Faso, Ethiopia, Ghana, Kenya, Nigeria, Rwanda, South Africa, Tanzania, Uganda, and Zambia'. Rajiv Shah, President of the Rockefeller Foundation and former administrator of CIA-controlled USAID, said that if Africa was not mass-vaccinated (to change the DNA of its people) it was a 'threat to all of humanity' and not fair on Africans. When someone from the Rockefeller Foundation says they want to do something to help poor and deprived people and countries it is time for a belly-laugh. They are doing this out of the goodness of their 'heart' because 'vaccinating' the entire global population is what the 'Covid' hoax set out to achieve. Official 'decolonisation' of Africa by the Cult was merely a prelude to financial colonisation on the road to a return to physical colonisation. The 'vaccine' is vital to that and the sudden and convenient death of the 'Covid' sceptic president of Tanzania can be seen in its true light. A lot of people in Africa are aware that this is another form of colonisation and exploitation and they need to stand their ground.

The 'vaccine is working' scam

A potential problem for the Cult was that the 'vaccine' is meant to change human DNA and body messaging and not to protect anyone from a 'virus' never shown to exist. The vaccine couldn't work because it was not designed to work and how could they make it *appear* to be working so that more people would have it? This was overcome by lowering the amplification rate of the PCR test to produce fewer 'cases' and therefore fewer 'deaths'. Some of us had been pointing out since March, 2020, that the amplification rate of the test not testing for the 'virus' had been made artificially high to generate positive tests which they could call 'cases' to justify lockdowns. The World Health Organization recommended an absurdly high 45 amplification cycles to ensure the high positives required by the Cult and then remained silent on the issue until January 20th, 2021 – Biden's Inauguration Day. This was when the

'vaccinations' were seriously underway and on that day the WHO recommended after discussions with America's CDC that laboratories *lowered their testing amplification*. Dr David Samadi, a certified urologist and health writer, said the WHO was encouraging all labs to reduce their cycle count for PCR tests. He said the current cycle was much too high and was 'resulting in any particle being declared a positive case'. Even one mainstream news report I saw said this meant the number of 'Covid' infections may have been 'dramatically inflated'. Oh, just a little bit. The CDC in America issued new guidance to laboratories in April, 2021, to use 28 cycles *but only for 'vaccinated' people*. The timing of the CDC/WHO interventions were cynically designed to make it appear the 'vaccines' were responsible for falling cases and deaths when the real reason can be seen in the following examples. New York's state lab, the Wadsworth Center, identified 872 positive tests in July, 2020, based on a threshold of 40 cycles. When the figure was lowered to 35 cycles 43 percent of the 872 were no longer 'positives'. At 30 cycles the figure was 63 percent. A Massachusetts lab found that between 85 to 90 percent of people who tested positive in July with a cycle threshold of 40 would be negative at 30 cycles, Ashish Jha, MD, director of the Harvard Global Health Institute, said: 'I'm really shocked that it could be that high ... Boy, does it really change the way we need to be thinking about testing.' I'm shocked that I could see the obvious in the spring of 2020, with no medical background, and most medical professionals still haven't worked it out. No, that's not shocking – it's terrifying.

Three weeks after the WHO directive to lower PCR cycles the London *Daily Mail* ran this headline: 'Why ARE Covid cases plummeting? New infections have fallen 45% in the US and 30% globally in the past 3 weeks but experts say vaccine is NOT the main driver because only 8% of Americans and 13% of people worldwide have received their first dose.' They acknowledged that the drop could not be attributed to the 'vaccine', but soon this morphed throughout the media into the 'vaccine' has caused cases and deaths to fall when it was the PCR threshold. In December, 2020, there was

chaos at English Channel ports with truck drivers needing negative 'Covid' tests before they could board a ferry home for Christmas. The government wanted to remove the backlog as fast as possible and they brought in troops to do the 'testing'. Out of 1,600 drivers just 36 tested positive and the rest were given the all clear to cross the Channel. I guess the authorities thought that 36 was the least they could get away with without the unquestioning catching on. The amplification trick which most people believed in the absence of information in the mainstream applied more pressure on those refusing the 'vaccine' to succumb when it 'obviously worked'. The truth was the exact opposite with deaths in care homes soaring with the 'vaccine' and in Israel the term used was 'skyrocket'. A re-analysis of published data from the Israeli Health Ministry led by Dr Hervé Seligmann at the Medicine Emerging Infectious and Tropical Diseases at Aix-Marseille University found that Pfizer's 'Covid vaccine' killed 'about 40 times more [elderly] people than the disease itself would have killed' during a five-week vaccination period and *260 times* more younger people than would have died from the 'virus' even according to the manipulated 'virus' figures. Dr Seligmann and his co-study author, Haim Yativ, declared after reviewing the Israeli 'vaccine' death data: 'This is a new Holocaust.'

Then, in mid-April, 2021, after vast numbers of people worldwide had been 'vaccinated', the story changed with clear coordination. The UK government began to prepare the ground for more future lockdowns when Nuremberg-destined Boris Johnson told yet another whopper. He said that cases had fallen because of *lockdowns* not 'vaccines'. Lockdowns are irrelevant when *there is no 'virus'* and the test and fraudulent death certificates are deciding the number of 'cases' and 'deaths'. Study after study has shown that lockdowns don't work and instead kill and psychologically destroy people. Meanwhile in the United States Anthony Fauci and Rochelle Walensky, the ultra-Zionist head of the CDC, peddled the same line. More lockdown was the answer and not the 'vaccine', a line repeated on cue by the moron that is Canadian Prime Minister Justin Trudeau. Why all the hysteria to get everyone 'vaccinated' if lockdowns and

not 'vaccines' made the difference? None of it makes sense on the face of it. Oh, but it does. The Cult wants lockdowns *and* the 'vaccine' and if the 'vaccine' is allowed to be seen as the total answer lockdowns would no longer be justified when there are still livelihoods to destroy. 'Variants' and renewed upward manipulation of PCR amplification are planned to instigate never-ending lockdown *and* more 'vaccines'.

You *must* have it – we're desperate

Israel, where the Jewish and Arab population are ruled by the Sabbatian Cult, was the front-runner in imposing the DNA-manipulating 'vaccine' on its people to such an extent that Jewish refusers began to liken what was happening to the early years of Nazi Germany. This would seem to be a fantastic claim. Why would a government of Jewish people be acting like the Nazis did? If you realise that the Sabbatian Cult was behind the Nazis and that Sabbatians hate Jews the pieces start to fit and the question of why a 'Jewish' government would treat Jews with such callous disregard for their lives and freedom finds an answer. Those controlling the government of Israel *aren't Jewish* – they're Sabbatian. Israeli lawyer Tamir Turgal was one who made the Nazi comparison in comments to German lawyer Reiner Fuellmich who is leading a class action lawsuit against the psychopaths for crimes against humanity. Turgal described how the Israeli government was vaccinating children and pregnant women on the basis that there was no evidence that this was dangerous when they had no evidence that it *wasn't* dangerous either. They just had no evidence. This was medical experimentation and Turgal said this breached the Nuremberg Code about medical experimentation and procedures requiring informed consent and choice. Think about that. A Nuremberg Code developed because of Nazi experimentation on Jews and others in concentration camps by people like the evil-beyond-belief Josef Mengele is being breached by the *Israeli* government; but when you know that it's a *Sabbatian* government along with its intelligence and military agencies like Mossad, Shin Bet and the Israeli Defense Forces, and that Sabbatians

were the force behind the Nazis, the kaleidoscope comes into focus. What have we come to when Israeli Jews are suing their government for violating the Nuremberg Code by essentially making Israelis subject to a medical experiment using the controversial 'vaccines'? It's a shocker that this has to be done in the light of what happened in Nazi Germany. The Anshe Ha-Emet, or 'People of the Truth', made up of Israeli doctors, lawyers, campaigners and public, have launched a lawsuit with the International Criminal Court. It says:

When the heads of the Ministry of Health as well as the prime minister presented the vaccine in Israel and began the vaccination of Israeli residents, the vaccinated were not advised, that, in practice, they are taking part in a medical experiment and that their consent is required for this under the Nuremberg Code.

The irony is unbelievable, but easily explained in one word: Sabbatians. The foundation of Israeli 'Covid' apartheid is the 'green pass' or 'green passport' which allows Jews and Arabs who have had the DNA-manipulating 'vaccine' to go about their lives – to work, fly, travel in general, go to shopping malls, bars, restaurants, hotels, concerts, gyms, swimming pools, theatres and sports venues, while non-'vaccinated' are banned from all those places and activities. Israelis have likened the 'green pass' to the yellow stars that Jews in Nazi Germany were forced to wear – the same as the yellow stickers that a branch of UK supermarket chain Morrisons told exempt mask-wearers they had to display when shopping. How very sensitive. The Israeli system is blatant South African-style apartheid on the basis of compliance or non-compliance to fascism rather than colour of the skin. How appropriate that the Sabbatian Israeli government was so close to the pre-Mandela apartheid regime in Pretoria. The Sabbatian-instigated 'vaccine passport' in Israel is planned for everywhere. Sabbatians struck a deal with Pfizer that allowed them to lead the way in the percentage of a national population infused with synthetic material and the result was catastrophic. Israeli freedom activist Shai Dannon told me how chairs were appearing on beaches that said 'vaccinated only'. Health Minister Yuli Edelstein said that anyone unwilling or unable to get

the jabs that 'confer immunity' will be 'left behind'. The man's a liar. Not even the makers claim the 'vaccines' confer immunity. When you see those figures of 'vaccine' deaths these psychopaths were saying that you must take the chance the 'vaccine' will kill you or maim you while knowing it will change your DNA or lockdown for you will be permanent. That's fascism. The Israeli parliament passed a law to allow personal information of the non-vaccinated to be shared with local and national authorities for three months. This was claimed by its supporters to be a way to 'encourage' people to be vaccinated. Hadas Ziv from Physicians for Human Rights described this as a 'draconian law which crushed medical ethics and the patient rights'. But that's the idea, the Sabbatians would reply.

Your papers, please

Sabbatian Israel was leading what has been planned all along to be a global 'vaccine pass' called a 'green passport' without which you would remain in permanent lockdown restriction and unable to do anything. This is how badly – *desperately* – the Cult is to get everyone 'vaccinated'. The term and colour 'green' was not by chance and related to the psychology of fusing the perception of the green climate hoax with the 'Covid' hoax and how the 'solution' to both is the same Great Reset. Lying politicians, health officials and psychologists denied there were any plans for mandatory vaccinations or restrictions based on vaccinations, but they knew that was exactly what was meant to happen with governments of all countries reaching agreements to enforce a global system. 'Free' Denmark and 'free' Sweden unveiled digital vaccine certification. Cyprus, Czech Republic, Estonia, Greece, Hungary, Iceland, Italy, Poland, Portugal, Slovakia, and Spain have all committed to a vaccine passport system and the rest including the whole of the EU would follow. The satanic UK government will certainly go this way despite mendacious denials and at the time of writing it is trying to manipulate the public into having the 'vaccine' so they could go abroad on a summer holiday. How would that work without something to prove you had the synthetic toxicity injected into you?

Documents show that the EU's European Commission was moving towards 'vaccine certificates' in 2018 and 2019 before the 'Covid' hoax began. They knew what was coming. Abracadabra – Ursula von der Leyen, the German President of the Commission, announced in March, 2021, an EU 'Digital Green Certificate' – green again – to track the public's 'Covid status'. The passport sting is worldwide and the Far East followed the same pattern with South Korea ruling that only those with 'vaccination' passports – again the *green* pass – would be able to 'return to their daily lives'.

Bill Gates has been preparing for this 'passport' with other Cult operatives for years and beyond the paper version is a Gates-funded 'digital tattoo' to identify who has been vaccinated and who hasn't. The 'tattoo' is reported to include a substance which is externally readable to confirm who has been vaccinated. This is a bio-luminous light-generating enzyme (think fireflies) called ... *Luciferase*. Yes, named after the Cult 'god' Lucifer the 'light bringer' of whom more to come. Gates said he funded the readable tattoo to ensure children in the developing world were vaccinated and no one was missed out. He cares so much about poor kids as we know. This was just the cover story to develop a vaccine tagging system for everyone on the planet. Gates has been funding the ID2020 'alliance' to do just that in league with other lovely people at Microsoft, GAVI, the Rockefeller Foundation, Accenture and IDEO.org. He said in interviews in March, 2020, before any 'vaccine' publicly existed, that the world must have a globalised digital certificate to track the 'virus' and who had been vaccinated. Gates knew from the start that the mRNA vaccines were coming and when they would come and that the plan was to tag the 'vaccinated' to marginalise the intelligent and stop them doing anything including travel. Evil just doesn't suffice. Gates was exposed for offering a \$10 million bribe to the Nigerian House of Representatives to invoke compulsory 'Covid' vaccination of all Nigerians. Sara Cunial, a member of the Italian Parliament, called Gates a 'vaccine criminal'. She urged the Italian President to hand him over to the International Criminal Court for crimes against

humanity and condemned his plans to 'chip the human race' through ID2020.

You know it's a long-planned agenda when war criminal and Cult gofer Tony Blair is on the case. With the scale of arrogance only someone as dark as Blair can muster he said: 'Vaccination in the end is going to be your route to liberty.' Blair is a disgusting piece of work and he confirms that again. The media has given a lot of coverage to a bloke called Charlie Mullins, founder of London's biggest independent plumbing company, Pimlico Plumbers, who has said he won't employ anyone who has not been vaccinated or have them go to any home where people are not vaccinated. He said that if he had his way no one would be allowed to walk the streets if they have not been vaccinated. Gates was cheering at the time while I was alerting the white coats. The plan is that people will qualify for 'passports' for having the first two doses and then to keep it they will have to have all the follow ups and new ones for invented 'variants' until human genetics is transformed and many are dead who can't adjust to the changes. Hollywood celebrities – the usual propaganda stunt – are promoting something called the WELL Health-Safety Rating to verify that a building or space has 'taken the necessary steps to prioritize the health and safety of their staff, visitors and other stakeholders'. They included Lady Gaga, Jennifer Lopez, Michael B. Jordan, Robert DeNiro, Venus Williams, Wolfgang Puck, Deepak Chopra and 17th Surgeon General Richard Carmona. Yawn. WELL Health-Safety has big connections with China. Parent company Delos is headed by former Goldman Sachs partner Paul Scialla. This is another example – and we will see so many others – of using the excuse of 'health' to dictate the lives and activities of the population. I guess one confirmation of the 'safety' of buildings is that only 'vaccinated' people can go in, right?

Electronic concentration camps

I wrote decades ago about the plans to restrict travel and here we are for those who refuse to bow to tyranny. This can be achieved in one go with air travel if the aviation industry makes a blanket decree.

The 'vaccine' and guaranteed income are designed to be part of a global version of China's social credit system which tracks behaviour 24/7 and awards or deletes 'credits' based on whether your behaviour is supported by the state or not. I mean your entire lifestyle – what you do, eat, say, everything. Once your credit score falls below a certain level consequences kick in. In China tens of millions have been denied travel by air and train because of this. All the locations and activities denied to refusers by the 'vaccine' passports will be included in one big mass ban on doing almost anything for those that don't bow their head to government. It's beyond fascist and a new term is required to describe its extremes – I guess fascist technocracy will have to do. The way the Chinese system of technological – technocratic – control is sweeping the West can be seen in the Los Angeles school system and is planned to be expanded worldwide. Every child is required to have a 'Covid'-tracking app scanned daily before they can enter the classroom. The so-called Daily Pass tracking system is produced by Gates' Microsoft which I'm sure will shock you rigid. The pass will be scanned using a barcode (one step from an inside-the-body barcode) and the information will include health checks, 'Covid' tests and vaccinations. Entry codes are for one specific building only and access will only be allowed if a student or teacher has a negative test with a test not testing for the 'virus', has no symptoms of anything alleged to be related to 'Covid' (symptoms from a range of other illness), and has a temperature under 100 degrees. No barcode, no entry, is planned to be the case for everywhere and not only schools.

Kids are being psychologically prepared to accept this as 'normal' their whole life which is why what they can impose in schools is so important to the Cult and its gofers. Long-time American freedom campaigner John Whitehead of the Rutherford Institute was not exaggerating when he said: 'Databit by databit, we are building our own electronic concentration camps.' Canada under its Cult gofer prime minister Justin Trudeau has taken a major step towards the real thing with people interned against their will if they test positive with a test not testing for the 'virus' when they arrive at a Canadian

airport. They are jailed in internment hotels often without food or water for long periods and with many doors failing to lock there have been sexual assaults. The interned are being charged sometimes \$2,000 for the privilege of being abused in this way. Trudeau is fully on board with the Cult and says the 'Covid pandemic' has provided an opportunity for a global 'reset' to permanently change Western civilisation. His number two, Deputy Prime Minister Chrystia Freeland, is a trustee of the World Economic Forum and a Rhodes Scholar. The Trudeau family have long been servants of the Cult. See *The Biggest Secret* and Cathy O'Brien's book *Trance-Formation of America* for the horrific background to Trudeau's father Pierre Trudeau another Canadian prime minister. Hide your fascism behind the façade of a heart-on-the-sleeve liberal. It's a well-honed Cult technique.

What can the 'vaccine' really do?

We have a 'virus' never shown to exist and 'variants' of the 'virus' that have also never been shown to exist except, like the 'original', as computer-generated fictions. Even if you believe there's a 'virus' the 'case' to 'death' rate is in the region of 0.23 to 0.15 percent and those 'deaths' are concentrated among the very old around the same average age that people die anyway. In response to this lack of threat (in truth none) psychopaths and idiots, knowingly and unknowingly answering to Gates and the Cult, are seeking to 'vaccinate' every man, woman and child on Planet Earth. Clearly the 'vaccine' is not about 'Covid' – none of this ever has been. So what is it all about *really*? Why the desperation to infuse genetically-manipulating synthetic material into everyone through mRNA fraudulent 'vaccines' with the intent of doing this over and over with the excuses of 'variants' and other 'virus' inventions? Dr Sherri Tenpenny, an osteopathic medical doctor in the United States, has made herself an expert on vaccines and their effects as a vehement campaigner against their use. Tenpenny was board certified in emergency medicine, the director of a level two trauma centre for 12 years, and moved to Cleveland in 1996 to start an integrative

medicine practice which has treated patients from all 50 states and some 17 other countries. Weaning people off pharmaceutical drugs is a speciality.

She became interested in the consequences of vaccines after attending a meeting at the National Vaccine Information Center in Washington DC in 2000 where she 'sat through four days of listening to medical doctors and scientists and lawyers and parents of vaccine injured kids' and asked: 'What's going on?' She had never been vaccinated and never got ill while her father was given a list of vaccines to be in the military and was 'sick his entire life'. The experience added to her questions and she began to examine vaccine documents from the Centers for Disease Control (CDC). After reading the first one, the 1998 version of *The General Recommendations of Vaccination*, she thought: 'This is it?' The document was poorly written and bad science and Tenpenny began 20 years of research into vaccines that continues to this day. She began her research into 'Covid vaccines' in March, 2020, and she describes them as 'deadly'. For many, as we have seen, they already have been. Tenpenny said that in the first 30 days of the 'vaccine' rollout in the United States there had been more than 40,000 adverse events reported to the vaccine adverse event database. A document had been delivered to her the day before that was 172 pages long. 'We have over 40,000 adverse events; we have over 3,100 cases of [potentially deadly] anaphylactic shock; we have over 5,000 neurological reactions.' Effects ranged from headaches to numbness, dizziness and vertigo, to losing feeling in hands or feet and paraesthesia which is when limbs 'fall asleep' and people have the sensation of insects crawling underneath their skin. All this happened in the first 30 days and remember that only about *ten percent* (or far less) of adverse reactions and vaccine-related deaths are estimated to be officially reported. Tenpenny said:

So can you think of one single product in any industry, any industry, for as long as products have been made on the planet that within 30 days we have 40,000 people complaining of side effects that not only is still on the market but ... we've got paid actors telling us how great

they are for getting their vaccine. We're offering people \$500 if they will just get their vaccine and we've got nurses and doctors going; 'I got the vaccine, I got the vaccine'.

Tenpenny said they were not going to be 'happy dancing folks' when they began to suffer Bell's palsy (facial paralysis), neuropathies, cardiac arrhythmias and autoimmune reactions that kill through a blood disorder. 'They're not going to be so happy, happy then, but we're never going to see pictures of those people' she said. Tenpenny described the 'vaccine' as 'a well-designed killing tool'.

No off-switch

Bad as the initial consequences had been Tenpenny said it would be maybe 14 months before we began to see the 'full ravage' of what is going to happen to the 'Covid vaccinated' with full-out consequences taking anything between two years and 20 years to show. You can understand why when you consider that variations of the 'Covid vaccine' use mRNA (messenger RNA) to in theory activate the immune system to produce protective antibodies without using the actual 'virus'. How can they when it's a computer program and they've never isolated what they claim is the 'real thing'? Instead they use *synthetic* mRNA. They are inoculating synthetic material into the body which through a technique known as the Trojan horse is absorbed into cells to change the nature of DNA. Human DNA is changed by an infusion of messenger RNA and with each new 'vaccine' of this type it is changed even more. Say so and you are banned by Cult Internet platforms. The contempt the contemptuous Mark Zuckerberg has for the truth and human health can be seen in an internal Facebook video leaked to the Project Veritas investigative team in which he said of the 'Covid vaccines': '... I share some caution on this because we just don't know the long term side-effects of basically modifying people's DNA and RNA.' At the same time this disgusting man's Facebook was censoring and banning anyone saying exactly the same. He must go before a Nuremberg trial for crimes against humanity when he *knows* that he

is censoring legitimate concerns and denying the right of informed consent on behalf of the Cult that owns him. People have been killed and damaged by the very 'vaccination' technique he cast doubt on himself when they may not have had the 'vaccine' with access to information that he denied them. The plan is to have at least annual 'Covid vaccinations', add others to deal with invented 'variants', and change all other vaccines into the mRNA system. Pfizer executives told shareholders at a virtual Barclays Global Healthcare Conference in March, 2021, that the public may need a third dose of 'Covid vaccine', plus regular yearly boosters and the company planned to hike prices to milk the profits in a 'significant opportunity for our vaccine'. These are the professional liars, cheats and opportunists who are telling you their 'vaccine' is safe. Given this volume of mRNA planned to be infused into the human body and its ability to then replicate we will have a transformation of human genetics from biological to synthetic biological – exactly the long-time Cult plan for reasons we'll see – and many will die. Sherri Tenpenny said of this replication:

It's like having an on-button but no off-button and that whole mechanism ... they actually give it a name and they call it the Trojan horse mechanism, because it allows that [synthetic] virus and that piece of that [synthetic] virus to get inside of your cells, start to replicate and even get inserted into other parts of your DNA as a Trojan-horse.

Ask the overwhelming majority of people who have the 'vaccine' what they know about the contents and what they do and they would reply: 'The government says it will stop me getting the virus.' Governments give that false impression on purpose to increase take-up. You can read Sherri Tenpenny's detailed analysis of the health consequences in her blog at [Vaxxter.com](https://vaxxter.com), but in summary these are some of them. She highlights the statement by Bill Gates about how human beings can become their own 'vaccine manufacturing machine'. The man is insane. ['Vaccine'-generated] 'antibodies' carry synthetic messenger RNA into the cells and the damage starts, Tenpenny contends, and she says that lungs can be adversely affected through varying degrees of pus and bleeding which

obviously affects breathing and would be dubbed 'Covid-19'. Even more sinister was the impact of 'antibodies' on macrophages, a white blood cell of the immune system. They consist of Type 1 and Type 2 which have very different functions. She said Type 1 are 'hyper-vigilant' white blood cells which 'gobble up' bacteria etc. However, in doing so, this could cause inflammation and in extreme circumstances be fatal. She says these affects are mitigated by Type 2 macrophages which kick in to calm down the system and stop it going rogue. They clear up dead tissue debris and reduce inflammation that the Type 1 'fire crews' have caused. Type 1 kills the infection and Type 2 heals the damage, she says. This is her punchline with regard to 'Covid vaccinations': She says that mRNA 'antibodies' block Type 2 macrophages by attaching to them and deactivating them. This meant that when the Type 1 response was triggered by infection there was nothing to stop that getting out of hand by calming everything down. There's an on-switch, but no off-switch, she says. What follows can be 'over and out, see you when I see you'.

Genetic suicide

Tenpenny also highlights the potential for autoimmune disease – the body attacking itself – which has been associated with vaccines since they first appeared. Infusing a synthetic foreign substance into cells could cause the immune system to react in a panic believing that the body is being overwhelmed by an invader (it is) and the consequences can again be fatal. There is an autoimmune response known as a 'cytokine storm' which I have likened to a homeowner panicked by an intruder and picking up a gun to shoot randomly in all directions before turning the fire on himself. The immune system unleashes a storm of inflammatory response called cytokines to a threat and the body commits hara-kiri. The lesson is that you mess with the body's immune response at your peril and these 'vaccines' seriously – fundamentally – mess with immune response. Tenpenny refers to a consequence called anaphylactic shock which is a severe and highly dangerous allergic reaction when the immune system

floods the body with chemicals. She gives the example of having a bee sting which primes the immune system and makes it sensitive to those chemicals. When people are stung again maybe years later the immune response can be so powerful that it leads to anaphylactic shock. Tenpenny relates this 'shock' with regard to the 'Covid vaccine' to something called polyethylene glycol or PEG. Enormous numbers of people have become sensitive to this over decades of use in a whole range of products and processes including food, drink, skin creams and 'medicine'. Studies have claimed that some 72 percent of people have antibodies triggered by PEG compared with two percent in the 1960s and allergic hypersensitive reactions to this become a gathering cause for concern. Tenpenny points out that the 'mRNA vaccine' is coated in a 'bubble' of polyethylene glycol which has the potential to cause anaphylactic shock through immune sensitivity. Many reports have appeared of people reacting this way after having the 'Covid vaccine'. What do we think is going to happen as humanity has more and more of these 'vaccines'? Tenpenny said: 'All these pictures we have seen with people with these rashes ... these weepy rashes, big reactions on their arms and things like that – it's an acute allergic reaction most likely to the polyethylene glycol that you've been previously primed and sensitised to.'

Those who have not studied the conspiracy and its perpetrators at length might think that making the population sensitive to PEG and then putting it in these 'vaccines' is just a coincidence. It is not. It is instead testament to how carefully and coldly-planned current events have been and the scale of the conspiracy we are dealing with. Tenpenny further explains that the 'vaccine' mRNA procedure can breach the blood-brain barrier which protects the brain from toxins and other crap that will cause malfunction. In this case they could make two proteins corrupt brain function to cause Amyotrophic lateral sclerosis (ALS), a progressive nervous system disease leading to loss of muscle control, and frontal lobe degeneration – Alzheimer's and dementia. Immunologist J. Bart Classon published a paper connecting mRNA 'vaccines' to prion

disease which can lead to Alzheimer's and other forms of neurogenerative disease while others have pointed out the potential to affect the placenta in ways that make women infertile. This will become highly significant in the next chapter when I will discuss other aspects of this non-vaccine that relate to its nanotechnology and transmission from the injected to the uninjected.

Qualified in idiocy

Tenpenny describes how research has confirmed that these 'vaccine'-generated antibodies can interact with a range of other tissues in the body and attack many other organs including the lungs. 'This means that if you have a hundred people standing in front of you that all got this shot they could have a hundred different symptoms.' Anyone really think that Cult gofers like the Queen, Tony Blair, Christopher Whitty, Anthony Fauci, and all the other psychopaths have really had this 'vaccine' in the pictures we've seen? Not a bloody chance. Why don't doctors all tell us about all these dangers and consequences of the 'Covid vaccine'? Why instead do they encourage and pressure patients to have the shot? Don't let's think for a moment that doctors and medical staff can't be stupid, lazy, and psychopathic and that's without the financial incentives to give the jab. Tenpenny again:

Some people are going to die from the vaccine directly but a large number of people are going to start to get horribly sick and get all kinds of autoimmune diseases 42 days to maybe a year out. What are they going to do, these stupid doctors who say; 'Good for you for getting that vaccine.' What are they going to say; 'Oh, it must be a mutant, we need to give an extra dose of that vaccine.'

Because now the vaccine, instead of one dose or two doses we need three or four because the stupid physicians aren't taking the time to learn anything about it. If I can learn this sitting in my living room reading a 19 page paper and several others so can they. There's nothing special about me, I just take the time to do it.

Remember how Sara Kayat, the NHS and TV doctor, said that the 'Covid vaccine' would '100 percent prevent hospitalisation and death'. Doctors can be idiots like every other profession and they

should not be worshipped as infallible. They are not and far from it. Behind many medical and scientific 'experts' lies an uninformed prat trying to hide themselves from you although in the 'Covid' era many have failed to do so as with UK narrative-repeating 'TV doctor' Hilary Jones. Pushing back against the minority of proper doctors and scientists speaking out against the 'vaccine' has been the entire edifice of the Cult global state in the form of governments, medical systems, corporations, mainstream media, Silicon Valley, and an army of compliant doctors, medical staff and scientists willing to say anything for money and to enhance their careers by promoting the party line. If you do that you are an 'expert' and if you won't you are an 'anti-vaxxer' and 'Covidiot'. The pressure to be 'vaccinated' is incessant. We have even had reports claiming that the 'vaccine' can help cure cancer and Alzheimer's and make the lame walk. I am waiting for the announcement that it can bring you coffee in the morning and cook your tea. Just as the symptoms of 'Covid' seem to increase by the week so have the miracles of the 'vaccine'. American supermarket giant Kroger Co. offered nearly 500,000 employees in 35 states a \$100 bonus for having the 'vaccine' while donut chain Krispy Kreme promised 'vaccinated' customers a free glazed donut every day for the rest of 2021. Have your DNA changed and you will get a doughnut although we might not have to give you them for long. Such offers and incentives confirm the desperation.

Perhaps the worse vaccine-stunt of them all was UK 'Health' Secretary Matt-the-prat Hancock on live TV after watching a clip of someone being 'vaccinated' when the roll-out began. Hancock faked tears so badly it was embarrassing. Brain-of-Britain Piers Morgan, the lockdown-supporting, 'vaccine' supporting, 'vaccine' passport-supporting, TV host played along with Hancock – 'You're quite emotional about that' he said in response to acting so atrocious it would have been called out at a school nativity which will presumably today include Mary and Jesus in masks, wise men keeping their camels six feet apart, and shepherds under tent arrest. System-serving Morgan tweeted this: 'Love the idea of covid vaccine passports for everywhere: flights, restaurants, clubs, football, gyms,

shops etc. It's time covid-denying, anti-vaxxer loonies had their bullsh*t bluff called & bar themselves from going anywhere that responsible citizens go.' If only I could aspire to his genius. To think that Morgan, who specialises in shouting over anyone he disagrees with, was lauded as a free speech hero when he lost his job after storming off the set of his live show like a child throwing his dolly out of the pram. If he is a free speech hero we are in real trouble. I have no idea what 'bullsh*t' means, by the way, the * throws me completely.

The Cult is desperate to infuse its synthetic DNA-changing concoction into everyone and has been using every lie, trick and intimidation to do so. The question of '*Why?*' we shall now address.

CHAPTER TEN

Human 2.0

I believe that at the end of the century the use of words and general educated opinion will have altered so much that one will be able to speak of machines thinking without expecting to be contradicted –
Alan Turing (1912-1954), the ‘Father of artificial intelligence’

I have been exposing for decades the plan to transform the human body from a biological to a synthetic-biological state. The new human that I will call Human 2.0 is planned to be connected to artificial intelligence and a global AI ‘Smart Grid’ that would operate as one global system in which AI would control everything from your fridge to your heating system to your car to your mind. Humans would no longer be ‘human’, but post-human and sub-human, with their thinking and emotional processes replaced by AI.

What I said sounded crazy and beyond science fiction and I could understand that. To any balanced, rational, mind it *is* crazy. Today, however, that world is becoming reality and it puts the ‘Covid vaccine’ into its true context. Ray Kurzweil is the ultra-Zionist ‘computer scientist, inventor and futurist’ and co-founder of the Singularity University. Singularity refers to the merging of humans with machines or ‘transhumanism’. Kurzweil has said humanity would be connected to the cyber ‘cloud’ in the period of the ever-recurring year of 2030:

Our thinking ... will be a hybrid of biological and non-biological thinking ... humans will be able to extend their limitations and ‘think in the cloud’ ... We’re going to put gateways to the

cloud in our brains ... We're going to gradually merge and enhance ourselves ... In my view, that's the nature of being human – we transcend our limitations. As the technology becomes vastly superior to what we are then the small proportion that is still human gets smaller and smaller and smaller until it's just utterly negligible.

They are trying to sell this end-of-humanity-as-we-know-it as the next stage of 'evolution' when we become super-human and 'like the gods'. They are lying to you. Shocked, eh? The population, and again especially the young, have been manipulated into addiction to technologies designed to enslave them for life. First they induced an addiction to smartphones (holdables); next they moved to technology on the body (wearables); and then began the invasion of the body (implantables). I warned way back about the plan for microchipped people and we are now entering that era. We should not be diverted into thinking that this refers only to chips we can see. Most important are the nanochips known as smart dust, neural dust and nanobots which are far too small to be seen by the human eye. Nanotechnology is everywhere, increasingly in food products, and released into the atmosphere by the geoengineering of the skies funded by Bill Gates to 'shut out the Sun' and 'save the planet from global warming'. Gates has been funding a project to spray millions of tonnes of chalk (calcium carbonate) into the stratosphere over Sweden to 'dim the Sun' and cool the Earth. Scientists warned the move could be disastrous for weather systems in ways no one can predict and opposition led to the Swedish space agency announcing that the 'experiment' would not be happening as planned in the summer of 2021; but it shows where the Cult is going with dimming the impact of the Sun and there's an associated plan to change the planet's atmosphere. Who gives psychopath Gates the right to dictate to the entire human race and dismantle planetary systems? The world will not be safe while this man is at large.

The global warming hoax has made the Sun, like the gas of life, something to fear when both are essential to good health and human survival (more inversion). The body transforms sunlight into vital vitamin D through a process involving ... *cholesterol*. This is the cholesterol we are also told to fear. We are urged to take Big Pharma

statin drugs to reduce cholesterol and it's all systematic. Reducing cholesterol means reducing vitamin D uptake with all the multiple health problems that will cause. At least if you take statins long term it saves the government from having to pay you a pension. The delivery system to block sunlight is widely referred to as chemtrails although these have a much deeper agenda, too. They appear at first to be contrails or condensation trails streaming from aircraft into cold air at high altitudes. Contrails disperse very quickly while chemtrails do not and spread out across the sky before eventually their content falls to earth. Many times I have watched aircraft cross-cross a clear blue sky releasing chemtrails until it looks like a cloudy day. Chemtrails contain many things harmful to humans and the natural world including toxic heavy metals, aluminium (see Alzheimer's) and nanotechnology. Ray Kurzweil reveals the reason without actually saying so: 'Nanobots will infuse all the matter around us with information. Rocks, trees, everything will become these intelligent creatures.' How do you deliver that? *From the sky*. Self-replicating nanobots would connect everything to the Smart Grid. The phenomenon of Morgellons disease began in the chemtrail era and the correlation has led to it being dubbed the 'chemtrail disease'. Self-replicating fibres appear in the body that can be pulled out through the skin. Morgellons fibres continue to grow outside the body and have a form of artificial intelligence. I cover this at greater length in *Phantom Self*.

'Vaccine' operating system

'Covid vaccines' with their self-replicating synthetic material are also designed to make the connection between humanity and Kurzweil's 'cloud'. American doctor and dedicated campaigner for truth, Carrie Madej, an Internal Medicine Specialist in Georgia with more than 20 years medical experience, has highlighted the nanotechnology aspect of the fake 'vaccines'. She explains how one of the components in at least the Moderna and Pfizer synthetic potions are 'lipid nanoparticles' which are 'like little tiny computer bits' – a 'sci-fi substance' known as nanobots and hydrogel which can be 'triggered

at any moment to deliver its payload' and act as 'biosensors'. The synthetic substance had 'the ability to accumulate data from your body like your breathing, your respiration, thoughts and emotions, all kind of things' and each syringe could carry a *million* nanobots:

This substance because it's like little bits of computers in your body, crazy, but it's true, it can do that, [and] obviously has the ability to act through Wi-Fi. It can receive and transmit energy, messages, frequencies or impulses. That issue has never been addressed by these companies. What does that do to the human?

Just imagine getting this substance in you and it can react to things all around you, the 5G, your smart device, your phones, what is happening with that? What if something is triggering it, too, like an impulse, a frequency? We have something completely foreign in the human body.

Madej said her research revealed that electromagnetic (EMF) frequencies emitted by phones and other devices had increased dramatically in the same period of the 'vaccine' rollout and she was seeing more people with radiation problems as 5G and other electromagnetic technology was expanded and introduced to schools and hospitals. She said she was 'floored with the EMF coming off' the devices she checked. All this makes total sense and syncs with my own work of decades when you think that Moderna refers in documents to its mRNA 'vaccine' as an 'operating system':

Recognizing the broad potential of mRNA science, we set out to create an mRNA technology platform that functions very much like an operating system on a computer. It is designed so that it can plug and play interchangeably with different programs. In our case, the 'program' or 'app' is our mRNA drug – the unique mRNA sequence that codes for a protein ...

... Our MRNA Medicines – 'The 'Software Of Life': When we have a concept for a new mRNA medicine and begin research, fundamental components are already in place. Generally, the only thing that changes from one potential mRNA medicine to another is the coding region – the actual genetic code that instructs ribosomes to make protein. Utilizing these instruction sets gives our investigational mRNA medicines a software-like quality. We also have the ability to combine different mRNA sequences encoding for different proteins in a single mRNA investigational medicine.

Who needs a real ‘virus’ when you can create a computer version to justify infusing your operating system into the entire human race on the road to making living, breathing people into cyborgs? What is missed with the ‘vaccines’ is the *digital* connection between synthetic material and the body that I highlighted earlier with the study that hacked a computer with human DNA. On one level the body is digital, based on mathematical codes, and I’ll have more about that in the next chapter. Those who ridiculously claim that mRNA ‘vaccines’ are not designed to change human genetics should explain the words of Dr Tal Zaks, chief medical officer at Moderna, in a 2017 TED talk. He said that over the last 30 years ‘we’ve been living this phenomenal digital scientific revolution, and I’m here today to tell you, that we are actually *hacking the software of life*, and that it’s changing the way we think about prevention and treatment of disease’:

In every cell there’s this thing called messenger RNA, or mRNA for short, that transmits the critical information from the DNA in our genes to the protein, which is really the stuff we’re all made out of. This is the critical information that determines what the cell will do. So we think about it as an operating system. So if you could change that, if you could introduce a line of code, or change a line of code, it turns out, that has profound implications for everything, from the flu to cancer.

Zaks should more accurately have said that this has profound implications for the human genetic code and the nature of DNA. Communications within the body go both ways and not only one. But, hey, no, the ‘Covid vaccine’ will not affect your genetics. Cult fact-checkers say so even though the man who helped to develop the mRNA technique says that it does. Zaks said in 2017:

If you think about what it is we’re trying to do. We’ve taken information and our understanding of that information and how that information is transmitted in a cell, and we’ve taken our understanding of medicine and how to make drugs, and we’re fusing the two. We think of it as information therapy.

I have been writing for decades that the body is an information field communicating with itself and the wider world. This is why

radiation which is information can change the information field of body and mind through phenomena like 5G and change their nature and function. 'Information therapy' means to change the body's information field and change the way it operates. DNA is a receiver-transmitter of information and can be mutated by information like mRNA synthetic messaging. Technology to do this has been ready and waiting in the underground bases and other secret projects to be rolled out when the 'Covid' hoax was played. 'Trials' of such short and irrelevant duration were only for public consumption. When they say the 'vaccine' is 'experimental' that is not true. It may appear to be 'experimental' to those who don't know what's going on, but the trials have already been done to ensure the Cult gets the result it desires. Zaks said that it took decades to sequence the human genome, completed in 2003, but now they could do it in a week. By 'they' he means scientists operating in the public domain. In the secret projects they were sequencing the genome in a week long before even 2003.

Deluge of mRNA

Highly significantly the Moderna document says the guiding premise is that if using mRNA as a medicine works for one disease then it should work for many diseases. They were leveraging the flexibility afforded by their platform and the fundamental role mRNA plays in protein synthesis to pursue mRNA medicines for a broad spectrum of diseases. Moderna is confirming what I was saying through 2020 that multiple 'vaccines' were planned for 'Covid' (and later invented 'variants') and that previous vaccines would be converted to the mRNA system to infuse the body with massive amounts of genetically-manipulating synthetic material to secure a transformation to a synthetic-biological state. The 'vaccines' are designed to kill stunning numbers as part of the long-exposed Cult depopulation agenda and transform the rest. Given this is the goal you can appreciate why there is such hysterical demand for every human to be 'vaccinated' for an alleged 'disease' that has an estimated 'infection' to 'death' ratio of 0.23-0.15 percent. As I write

children are being given the 'vaccine' in trials (their parents are a disgrace) and ever-younger people are being offered the vaccine for a 'virus' that even if you believe it exists has virtually zero chance of harming them. Horrific effects of the 'trials' on a 12-year-old girl were revealed by a family member to be serious brain and gastric problems that included a bowel obstruction and the inability to swallow liquids or solids. She was unable to eat or drink without throwing up, had extreme pain in her back, neck and abdomen, and was paralysed from the waist down which stopped her urinating unaided. When the girl was first taken to hospital doctors said it was all in her mind. She was signed up for the 'trial' by her parents for whom no words suffice. None of this 'Covid vaccine' insanity makes any sense unless you see what the 'vaccine' really is – a body-changer. Synthetic biology or 'SynBio' is a fast-emerging and expanding scientific discipline which includes everything from genetic and molecular engineering to electrical and computer engineering. Synthetic biology is defined in these ways:

- A multidisciplinary area of research that seeks to create new biological parts, devices, and systems, or to redesign systems that are already found in nature.
- The use of a mixture of physical engineering and genetic engineering to create new (and therefore synthetic) life forms.
- An emerging field of research that aims to combine the knowledge and methods of biology, engineering and related disciplines in the design of chemically-synthesized DNA to create organisms with novel or enhanced characteristics and traits (synthetic organisms including humans).

We now have synthetic blood, skin, organs and limbs being developed along with synthetic body parts produced by 3D printers. These are all elements of the synthetic human programme and this comment by Kurzweil's co-founder of the Singularity University,

Peter Diamandis, can be seen in a whole new light with the 'Covid' hoax and the sanctions against those that refuse the 'vaccine':

Anybody who is going to be resisting the progress forward [to transhumanism] is going to be resisting evolution and, fundamentally, they will die out. It's not a matter of whether it's good or bad. It's going to happen.

'Resisting evolution'? What absolute bollocks. The arrogance of these people is without limit. His 'it's going to happen' mantra is another way of saying 'resistance is futile' to break the spirit of those pushing back and we must not fall for it. Getting this genetically-transforming 'vaccine' into everyone is crucial to the Cult plan for total control and the desperation to achieve that is clear for anyone to see. Vaccine passports are a major factor in this and they, too, are a form of resistance is futile. It's NOT. The paper funded by the Rockefeller Foundation for the 2013 'health conference' in China said:

We will interact more with artificial intelligence. The use of robotics, bio-engineering to augment human functioning is already well underway and will advance. Re-engineering of humans into potentially separate and unequal forms through genetic engineering or mixed human-robots raises debates on ethics and equality.

A new demography is projected to emerge after 2030 [that year again] of technologies (robotics, genetic engineering, nanotechnology) producing robots, engineered organisms, 'nanobots' and artificial intelligence (AI) that can self-replicate. Debates will grow on the implications of an impending reality of human designed life.

What is happening today is so long planned. The world army enforcing the will of the world government is intended to be a robot army, not a human one. Today's military and its technologically 'enhanced' troops, pilotless planes and driverless vehicles are just stepping stones to that end. Human soldiers are used as Cult fodder and its time they woke up to that and worked for the freedom of the population instead of their own destruction and their family's destruction – the same with the police. Join us and let's sort this out. The phenomenon of enforce my own destruction is widespread in the 'Covid' era with Woker 'luvvies' in the acting and entertainment

industries supporting 'Covid' rules which have destroyed their profession and the same with those among the public who put signs on the doors of their businesses 'closed due to Covid – stay safe' when many will never reopen. It's a form of masochism and most certainly insanity.

Transgender = transhumanism

When something explodes out of nowhere and is suddenly everywhere it is always the Cult agenda and so it is with the tidal wave of claims and demands that have infiltrated every aspect of society under the heading of 'transgenderism'. The term 'trans' is so 'in' and this is the dictionary definition:

A prefix meaning 'across', 'through', occurring ... in loanwords from Latin, used in particular for denoting movement or conveyance from place to place (transfer; transmit; transplant) or complete change (transform; transmute), or to form adjectives meaning 'crossing', 'on the other side of', or 'going beyond' the place named (transmontane; transnational; trans-Siberian).

Transgender means to go beyond gender and transhuman means to go beyond human. Both are aspects of the Cult plan to transform the human body to a synthetic state with *no gender*. Human 2.0 is not designed to procreate and would be produced technologically with no need for parents. The new human would mean the end of parents and so men, and increasingly women, are being targeted for the deletion of their rights and status. Parental rights are disappearing at an ever-quickenning speed for the same reason. The new human would have no need for men or women when there is no procreation and no gender. Perhaps the transgender movement that appears to be in a permanent state of frenzy might now contemplate on how it is being used. This was never about transgender rights which are only the interim excuse for confusing gender, particularly in the young, on the road to *fusing* gender. Transgender activism is not an end; it is a *means* to an end. We see again the technique of creative destruction in which you destroy the status quo to 'build back better' in the form that you want. The gender status quo had to be

destroyed by persuading the Cult-created Woke mentality to believe that you can have 100 genders or more. A programme for 9 to 12 year olds produced by the Cult-owned BBC promoted the 100 genders narrative. The very idea may be the most monumental nonsense, but it is not what is true that counts, only what you can make people *believe* is true. Once the gender of $2 + 2 = 4$ has been dismantled through indoctrination, intimidation and $2 + 2 = 5$ then the new no-gender normal can take its place with Human 2.0.

Aldous Huxley revealed the plan in his prophetic *Brave New World* in 1932:

Natural reproduction has been done away with and children are created, decanted', and raised in 'hatcheries and conditioning centres'. From birth, people are genetically designed to fit into one of five castes, which are further split into 'Plus' and 'Minus' members and designed to fulfil predetermined positions within the social and economic strata of the World State.

How could Huxley know this in 1932? For the same reason George Orwell knew about the Big Brother state in 1948, Cult insiders I have quoted knew about it in 1969, and I have known about it since the early 1990s. If you are connected to the Cult or you work your balls off to uncover the plan you can predict the future. The process is simple. If there is a plan for the world and nothing intervenes to stop it then it will happen. Thus if you communicate the plan ahead of time you are perceived to have predicted the future, but you haven't. You have revealed the plan which without intervention will become the human future. The whole reason I have done what I have is to alert enough people to inspire an intervention and maybe at last that time has come with the Cult and its intentions now so obvious to anyone with a brain in working order.

The future is here

Technological wombs that Huxley described to replace parent procreation are already being developed and they are only the projects we know about in the public arena. Israeli scientists told *The Times of Israel* in March, 2021, that they have grown 250-cell embryos

into mouse fetuses with fully formed organs using artificial wombs in a development they say could pave the way for gestating humans outside the womb. Professor Jacob Hanna of the Weizmann Institute of Science said:

We took mouse embryos from the mother at day five of development, when they are just of 250 cells, and had them in the incubator from day five until day 11, by which point they had grown all their organs.

By day 11 they make their own blood and have a beating heart, a fully developed brain. Anybody would look at them and say, 'this is clearly a mouse foetus with all the characteristics of a mouse.' It's gone from being a ball of cells to being an advanced foetus.

A special liquid is used to nourish embryo cells in a laboratory dish and they float on the liquid to duplicate the first stage of embryonic development. The incubator creates all the right conditions for its development, Hanna said. The liquid gives the embryo 'all the nutrients, hormones and sugars they need' along with a custom-made electronic incubator which controls gas concentration, pressure and temperature. The cutting-edge in the underground bases and other secret locations will be light years ahead of that, however, and this was reported by the London *Guardian* in 2017:

We are approaching a biotechnological breakthrough. Ectogenesis, the invention of a complete external womb, could completely change the nature of human reproduction. In April this year, researchers at the Children's Hospital of Philadelphia announced their development of an artificial womb.

The article was headed 'Artificial wombs could soon be a reality. What will this mean for women?' What would it mean for children is an even bigger question. No mother to bond with only a machine in preparation for a life of soulless interaction and control in a world governed by machines (see the *Matrix* movies). Now observe the calculated manipulations of the 'Covid' hoax as human interaction and warmth has been curtailed by distancing, isolation and fear with people communicating via machines on a scale never seen before.

These are all dots in the same picture as are all the personal assistants, gadgets and children's toys through which kids and adults communicate with AI as if it is human. The AI 'voice' on Sat-Nav should be included. All these things are psychological preparation for the Cult endgame. Before you can make a physical connection with AI you have to make a psychological connection and that is what people are being conditioned to do with this ever gathering human-AI interaction. Movies and TV programmes depicting the transhuman, robot dystopia relate to a phenomenon known as 'pre-emptive programming' in which the world that is planned is portrayed everywhere in movies, TV and advertising. This is conditioning the conscious and subconscious mind to become familiar with the planned reality to dilute resistance when it happens for real. What would have been a shock such is the change is made less so. We have young children put on the road to transgender transition surgery with puberty blocking drugs at an age when they could never be able to make those life-changing decisions.

Rachel Levine, a professor of paediatrics and psychiatry who believes in treating children this way, became America's highest-ranked openly-transgender official when she was confirmed as US Assistant Secretary at the Department of Health and Human Services after being nominated by Joe Biden (the Cult). Activists and governments press for laws to deny parents a say in their children's transition process so the kids can be isolated and manipulated into agreeing to irreversible medical procedures. A Canadian father Robert Hoogland was denied bail by the Vancouver Supreme Court in 2021 and remained in jail for breaching a court order that he stay silent over his young teenage daughter, a minor, who was being offered life-changing hormone therapy without parental consent. At the age of 12 the girl's 'school counsellor' said she may be transgender, referred her to a doctor and told the school to treat her like a boy. This is another example of state-serving schools imposing ever more control over children's lives while parents have ever less.

Contemptible and extreme child abuse is happening all over the world as the Cult gender-fusion operation goes into warp-speed.

Why the war on men – and now women?

The question about what artificial wombs mean for women should rightly be asked. The answer can be seen in the deletion of women's rights involving sport, changing rooms, toilets and status in favour of people in male bodies claiming to identify as women. I can identify as a mountain climber, but it doesn't mean I can climb a mountain any more than a biological man can be a biological woman. To believe so is a triumph of belief over factual reality which is the very perceptual basis of everything Woke. Women's sport is being destroyed by allowing those with male bodies who say they identify as female to 'compete' with girls and women. Male body 'women' dominate 'women's' competition with their greater muscle mass, bone density, strength and speed. With that disadvantage sport for women loses all meaning. To put this in perspective nearly 300 American high school boys can run faster than the quickest woman sprinter in the world. Women are seeing their previously protected spaces invaded by male bodies simply because they claim to identify as women. That's all they need to do to access all women's spaces and activities under the Biden 'Equality Act' that destroys equality for women with the usual Orwellian Woke inversion. Male sex offenders have already committed rapes in women's prisons after claiming to identify as women to get them transferred. Does this not matter to the Woke 'equality' hypocrites? Not in the least. What matters to Cult manipulators and funders behind transgender activists is to advance gender fusion on the way to the no-gender 'human'. When you are seeking to impose transparent nonsense like this, or the 'Covid' hoax, the only way the nonsense can prevail is through censorship and intimidation of dissenters, deletion of factual information, and programming of the unquestioning, bewildered and naive. You don't have to scan the world for long to see that all these things are happening.

Many women's rights organisations have realised that rights and status which took such a long time to secure are being eroded and that it is systematic. Kara Dansky of the global Women's Human Rights Campaign said that Biden's transgender executive order immediately he took office, subsequent orders, and Equality Act legislation that followed 'seek to erase women and girls in the law as a category'. *Exactly*. I said during the long ago-started war on men (in which many women play a crucial part) that this was going to turn into a war on them. The Cult is phasing out *both* male and female genders. To get away with that they are brought into conflict so they are busy fighting each other while the Cult completes the job with no unity of response. Unity, people, *unity*. We need unity everywhere. Transgender is the only show in town as the big step towards the no-gender human. It's not about rights for transgender people and never has been. Woke political correctness is deleting words relating to genders to the same end. Wokers believe this is to be 'inclusive' when the opposite is true. They are deleting words describing gender because gender *itself* is being deleted by Human 2.0. Terms like 'man', 'woman', 'mother' and 'father' are being deleted in the universities and other institutions to be replaced by the *no*-gender, not trans-gender, 'individuals' and 'guardians'. Women's rights campaigner Maria Keffler of Partners for Ethical Care said: 'Children are being taught from kindergarten upward that some boys have a vagina, some girls have a penis, and that kids can be any gender they want to be.' Do we really believe that suddenly countries all over the world at the same time had the idea of having drag queens go into schools or read transgender stories to very young children in the local library? It's coldly-calculated confusion of gender on the way to the fusion of gender. Suzanne Vierling, a psychologist from Southern California, made another important point:

Yesterday's slave woman who endured gynecological medical experiments is today's girl-child being butchered in a booming gender-transitioning sector. Ovaries removed, pushing her into menopause and osteoporosis, uncharted territory, and parents' rights and authority decimated.

The erosion of parental rights is a common theme in line with the Cult plans to erase the very concept of parents and 'ovaries removed, pushing her into menopause' means what? Those born female lose the ability to have children – another way to discontinue humanity as we know it.

Eliminating Human 1.0 (before our very eyes)

To pave the way for Human 2.0 you must phase out Human 1.0. This is happening through plummeting sperm counts and making women infertile through an onslaught of chemicals, radiation (including smartphones in pockets of men) and mRNA 'vaccines'. Common agriculture pesticides are also having a devastating impact on human fertility. I have been tracking collapsing sperm counts in the books for a long time and in 2021 came a book by fertility scientist and reproductive epidemiologist Shanna Swan, *Count Down: How Our Modern World Is Threatening Sperm Counts, Altering Male and Female Reproductive Development and Imperiling the Future of the Human Race*. She reports how the global fertility rate dropped by *half* between 1960 and 2016 with America's birth rate 16 percent below where it needs to be to sustain the population. Women are experiencing declining egg quality, more miscarriages, and more couples suffer from infertility. Other findings were an increase in erectile dysfunction, infant boys developing more genital abnormalities, male problems with conception, and plunging levels of the male hormone testosterone which would explain why so many men have lost their backbone and masculinity. This has been very evident during the 'Covid' hoax when women have been prominent among the Pushbackers and big strapping blokes have bowed their heads, covered their faces with a nappy and quietly submitted. Mind control expert Cathy O'Brien also points to how global education introduced the concept of 'we're all winners' in sport and classrooms: 'Competition was defused, and it in turn defused a sense of fighting back.' This is another version of the 'equity' doctrine in which you drive down rather than raise up. What a contrast in Cult-controlled China with its global ambitions

where the government published plans in January, 2021, to 'cultivate masculinity' in boys from kindergarten through to high school in the face of a 'masculinity crisis'. A government adviser said boys would be soon become 'delicate, timid and effeminate' unless action was taken. Don't expect any similar policy in the targeted West. A 2006 study showed that a 65-year-old man in 2002 had testosterone levels 15 percent lower than a 65-year-old man in 1987 while a 2020 study found a similar story with young adults and adolescents. Men are getting prescriptions for testosterone replacement therapy which causes an even greater drop in sperm count with up to 99 percent seeing sperm counts drop to zero during the treatment. More sperm is defective and malfunctioning with some having two heads or not pursuing an egg.

A class of *synthetic* chemicals known as phthalates are being blamed for the decline. These are found everywhere in plastics, shampoos, cosmetics, furniture, flame retardants, personal care products, pesticides, canned foods and even receipts. Why till receipts? Everyone touches them. Let no one delude themselves that all this is not systematic to advance the long-time agenda for human body transformation. Phthalates mimic hormones and disrupt the hormone balance causing testosterone to fall and genital birth defects in male infants. Animals and fish have been affected in the same way due to phthalates and other toxins in rivers. When fish turn gay or change sex through chemicals in rivers and streams it is a pointer to why there has been such an increase in gay people and the sexually confused. It doesn't matter to me what sexuality people choose to be, but if it's being affected by chemical pollution and consumption then we need to know. Does anyone really think that this is not connected to the transgender agenda, the war on men and the condemnation of male 'toxic masculinity'? You watch this being followed by 'toxic femininity'. It's already happening. When breastfeeding becomes 'chest-feeding', pregnant women become pregnant people along with all the other Woke claptrap you know that the world is going insane and there's a Cult scam in progress. Transgender activists are promoting the Cult agenda while Cult

billionaires support and fund the insanity as they laugh themselves to sleep at the sheer stupidity for which humans must be infamous in galaxies far, far away.

‘Covid vaccines’ and female infertility

We can now see why the ‘vaccine’ has been connected to potential infertility in women. Dr Michael Yeadon, former Vice President and Chief Scientific Advisor at Pfizer, and Dr Wolfgang Wodarg in Germany, filed a petition with the European Medicines Agency in December, 2020, urging them to stop trials for the Pfizer/BioNTech shot and all other mRNA trials until further studies had been done. They were particularly concerned about possible effects on fertility with ‘vaccine’-produced antibodies attacking the protein Syncytin-1 which is responsible for developing the placenta. The result would be infertility ‘of indefinite duration’ in women who have the ‘vaccine’ with the placenta failing to form. Section 10.4.2 of the Pfizer/BioNTech trial protocol says that pregnant women or those who might become so should not have mRNA shots. Section 10.4 warns men taking mRNA shots to ‘be abstinent from heterosexual intercourse’ and not to donate sperm. The UK government said that it *did not know* if the mRNA procedure had an effect on fertility. *Did not know?* These people have to go to jail. UK government advice did not recommend at the start that pregnant women had the shot and said they should avoid pregnancy for at least two months after ‘vaccination’. The ‘advice’ was later updated to pregnant women should only have the ‘vaccine’ if the benefits outweighed the risks to mother and foetus. What the hell is that supposed to mean? Then ‘spontaneous abortions’ began to appear and rapidly increase on the adverse reaction reporting schemes which include only a fraction of adverse reactions. Thousands and ever-growing numbers of ‘vaccinated’ women are describing changes to their menstrual cycle with heavier blood flow, irregular periods and menstruating again after going through the menopause – all links to reproduction effects. Women are passing blood clots and the lining of their uterus while men report erectile dysfunction and blood effects. Most

significantly of all *unvaccinated* women began to report similar menstrual changes after interaction with '*vaccinated*' people and men and children were also affected with bleeding noses, blood clots and other conditions. 'Shedding' is when vaccinated people can emit the content of a vaccine to affect the unvaccinated, but this is different. 'Vaccinated' people were not shedding a 'live virus' allegedly in 'vaccines' as before because the fake 'Covid vaccines' involve synthetic material and other toxicity. Doctors exposing what is happening prefer the term 'transmission' to shedding. Somehow those that have had the shots are transmitting effects to those that haven't. Dr Carrie Madej said the nano-content of the 'vaccines' can 'act like an antenna' to others around them which fits perfectly with my own conclusions. This 'vaccine' transmission phenomenon was becoming known as the book went into production and I deal with this further in the Postscript.

Vaccine effects on sterility are well known. The World Health Organization was accused in 2014 of sterilising millions of women in Kenya with the evidence confirmed by the content of the vaccines involved. The same WHO behind the 'Covid' hoax admitted its involvement for more than ten years with the vaccine programme. Other countries made similar claims. Charges were lodged by Tanzania, Nicaragua, Mexico, and the Philippines. The Gardasil vaccine claimed to protect against a genital 'virus' known as HPV has also been linked to infertility. Big Pharma and the WHO (same thing) are criminal and satanic entities. Then there's the Bill Gates Foundation which is connected through funding and shared interests with 20 pharmaceutical giants and laboratories. He stands accused of directing the policy of United Nations Children's Fund (UNICEF), vaccine alliance GAVI, and other groupings, to advance the vaccine agenda and silence opposition at great cost to women and children. At the same time Gates wants to reduce the global population. Coincidence?

Great Reset = Smart Grid = new human

The Cult agenda I have been exposing for 30 years is now being openly promoted by Cult assets like Gates and Klaus Schwab of the World Economic Forum under code-terms like the 'Great Reset', 'Build Back Better' and 'a rare but narrow window of opportunity to reflect, reimagine, and reset our world'. What provided this 'rare but narrow window of opportunity'? The 'Covid' hoax did. Who created that? *They* did. My books from not that long ago warned about the planned 'Internet of Things' (IoT) and its implications for human freedom. This was the plan to connect all technology to the Internet and artificial intelligence and today we are way down that road with an estimated 36 billion devices connected to the World Wide Web and that figure is projected to be 76 billion by 2025. I further warned that the Cult planned to go beyond that to the Internet of *Everything* when the human brain was connected via AI to the Internet and Kurzweil's 'cloud'. Now we have Cult operatives like Schwab calling for precisely that under the term 'Internet of Bodies', a fusion of the physical, digital and biological into one centrally-controlled Smart Grid system which the Cult refers to as the 'Fourth Industrial Revolution'. They talk about the 'biological', but they really mean the synthetic-biological which is required to fully integrate the human body and brain into the Smart Grid and artificial intelligence planned to replace the human mind. We have everything being synthetically manipulated including the natural world through GMO and smart dust, the food we eat and the human body itself with synthetic 'vaccines'. I said in *The Answer* that we would see the Cult push for synthetic meat to replace animals and in February, 2021, the so predictable psychopath Bill Gates called for the introduction of synthetic meat to save us all from 'climate change'. The climate hoax just keeps on giving like the 'Covid' hoax. The war on meat by vegan activists is a carbon (oops, sorry) copy of the manipulation of transgender activists. They have no idea (except their inner core) that they are being used to promote and impose the agenda of the Cult or that they are only the *vehicle* and not the *reason*. This is not to say those who choose not to eat meat shouldn't be respected and supported in that right, but there are ulterior motives

for those in power. A *Forbes* article in December, 2019, highlighted the plan so beloved of Schwab and the Cult under the heading: 'What Is The Internet of Bodies? And How Is It Changing Our World?' The article said the human body is the latest data platform (remember 'our vaccine is an operating system'). *Forbes* described the plan very accurately and the words could have come straight out of my books from long before:

The Internet of Bodies (IoB) is an extension of the IoT and basically connects the human body to a network through devices that are ingested, implanted, or connected to the body in some way. Once connected, data can be exchanged, and the body and device can be remotely monitored and controlled.

They were really describing a human hive mind with human perception centrally-dictated via an AI connection as well as allowing people to be 'remotely monitored and controlled'. Everything from a fridge to a human mind could be directed from a central point by these insane psychopaths and 'Covid vaccines' are crucial to this. *Forbes* explained the process I mentioned earlier of holdable and wearable technology followed by implantable. The article said there were three generations of the Internet of Bodies that include:

- Body external: These are wearable devices such as Apple Watches or Fitbits that can monitor our health.
- Body internal: These include pacemakers, cochlear implants, and digital pills that go inside our bodies to monitor or control various aspects of health.
- Body embedded: The third generation of the Internet of Bodies is embedded technology where technology and the human body are melded together and have a real-time connection to a remote machine.

Forbes noted the development of the Brain Computer Interface (BCI) which merges the brain with an external device for monitoring and controlling in real-time. 'The ultimate goal is to help restore function to individuals with disabilities by using brain signals rather than conventional neuromuscular pathways.' Oh, do fuck off. The goal of brain interface technology is controlling human thought and emotion from the central point in a hive mind serving its masters wishes. Many people are now agreeing to be chipped to open doors without a key. You can recognise them because they'll be wearing a mask, social distancing and lining up for the 'vaccine'. The Cult plans a Great Reset money system after they have completed the demolition of the global economy in which 'money' will be exchanged through communication with body operating systems. Rand Corporation, a Cult-owned think tank, said of the Internet of Bodies or IoB:

Internet of Bodies technologies fall under the broader IoT umbrella. But as the name suggests, IoB devices introduce an even more intimate interplay between humans and gadgets. IoB devices monitor the human body, collect health metrics and other personal information, and transmit those data over the Internet. Many devices, such as fitness trackers, are already in use ... IoB devices ... and those in development can track, record, and store users' whereabouts, bodily functions, and what they see, hear, and even think.

Schwab's World Economic Forum, a long-winded way of saying 'fascism' or 'the Cult', has gone full-on with the Internet of Bodies in the 'Covid' era. 'We're entering the era of the Internet of Bodies', it declared, 'collecting our physical data via a range of devices that can be implanted, swallowed or worn'. The result would be a huge amount of health-related data that could improve human wellbeing around the world, and prove crucial in fighting the 'Covid-19 pandemic'. Does anyone think these clowns care about 'human wellbeing' after the death and devastation their pandemic hoax has purposely caused? Schwab and co say we should move forward with the Internet of Bodies because 'Keeping track of symptoms could help us stop the spread of infection, and quickly detect new cases'. How wonderful, but keeping track' is all they are really bothered

about. Researchers were investigating if data gathered from smartwatches and similar devices could be used as viral infection alerts by tracking the user's heart rate and breathing. Schwab said in his 2018 book *Shaping the Future of the Fourth Industrial Revolution*:

The lines between technologies and beings are becoming blurred and not just by the ability to create lifelike robots or synthetics. Instead it is about the ability of new technologies to literally become part of us. Technologies already influence how we understand ourselves, how we think about each other, and how we determine our realities. As the technologies ... give us deeper access to parts of ourselves, we may begin to integrate digital technologies into our bodies.

You can see what the game is. Twenty-four hour control and people – if you could still call them that – would never know when something would go ping and take them out of circulation. It's the most obvious rush to a global fascist dictatorship and the complete submission of humanity and yet still so many are locked away in their Cult-induced perceptual coma and can't see it.

Smart Grid control centres

The human body is being transformed by the 'vaccines' and in other ways into a synthetic cyborg that can be attached to the global Smart Grid which would be controlled from a central point and other sub-locations of Grid manipulation. Where are these planned to be? Well, China for a start which is one of the Cult's biggest centres of operation. The technological control system and technocratic rule was incubated here to be unleashed across the world after the 'Covid' hoax came out of China in 2020. Another Smart Grid location that will surprise people new to this is Israel. I have exposed in *The Trigger* how Sabbatian technocrats, intelligence and military operatives were behind the horrors of 9/11 and not 19 Arab hijackers' who somehow manifested the ability to pilot big passenger airliners when instructors at puddle-jumping flying schools described some of them as a joke. The 9/11 attacks were made possible through control of civilian and military air computer systems and those of the White House, Pentagon and connected agencies. See *The Trigger* – it

will blow your mind. The controlling and coordinating force were the Sabbatian networks in Israel and the United States which by then had infiltrated the entire US government, military and intelligence system. The real name of the American Deep State is 'Sabbatian State'. Israel is a tiny country of only nine million people, but it is one of the global centres of cyber operations and fast catching Silicon Valley in importance to the Cult. Israel is known as the 'start-up nation' for all the cyber companies spawned there with the Sabbatian specialisation of 'cyber security' that I mentioned earlier which gives those companies access to computer systems of their clients in real time through 'backdoors' written into the coding when security software is downloaded. The Sabbatian centre of cyber operations outside Silicon Valley is the Israeli military Cyber Intelligence Unit, the biggest infrastructure project in Israel's history, headquartered in the desert-city of Beersheba and involving some 20,000 'cyber soldiers'. Here are located a literal army of Internet trolls scanning social media, forums and comment lists for anyone challenging the Cult agenda. The UK military has something similar with its 77th Brigade and associated operations. The Beersheba complex includes research and development centres for other Cult operations such as Intel, Microsoft, IBM, Google, Apple, Hewlett-Packard, Cisco Systems, Facebook and Motorola. Techcrunch.com ran an article about the Beersheba global Internet technology centre headlined 'Israel's desert city of Beersheba is turning into a cybertech oasis':

The military's massive relocation of its prestigious technology units, the presence of multinational and local companies, a close proximity to Ben Gurion University and generous government subsidies are turning Beersheba into a major global cybertech hub. Beersheba has all of the ingredients of a vibrant security technology ecosystem, including Ben Gurion University with its graduate program in cybersecurity and Cyber Security Research Center, and the presence of companies such as EMC, Deutsche Telekom, PayPal, Oracle, IBM, and Lockheed Martin. It's also the future home of the INCB (Israeli National Cyber Bureau); offers a special income tax incentive for cyber security companies, and was the site for the relocation of the army's intelligence corps units.

Sabbatians have taken over the cyber world through the following process: They scan the schools for likely cyber talent and develop them at Ben Gurion University and their period of conscription in the Israeli Defense Forces when they are stationed at the Beersheba complex. When the cyber talented officially leave the army they are funded to start cyber companies with technology developed by themselves or given to them by the state. Much of this is stolen through backdoors of computer systems around the world with America top of the list. Others are sent off to Silicon Valley to start companies or join the major ones and so we have many major positions filled by apparently 'Jewish' but really Sabbatian operatives. Google, YouTube and Facebook are all run by 'Jewish' CEOs while Twitter is all but run by ultra-Zionist hedge-fund shark Paul Singer. At the centre of the Sabbatian global cyber web is the Israeli army's Unit 8200 which specialises in hacking into computer systems of other countries, inserting viruses, gathering information, instigating malfunction, and even taking control of them from a distance. A long list of Sabbatians involved with 9/11, Silicon Valley and Israeli cyber security companies are operatives of Unit 8200. This is not about Israel. It's about the Cult. Israel is planned to be a Smart Grid hub as with China and what is happening at Beersheba is not for the benefit of Jewish people who are treated disgustingly by the Sabbatian elite that control the country. A glance at the Nuremberg Codes will tell you that.

The story is much bigger than 'Covid', important as that is to where we are being taken. Now, though, it's time to really strap in. There's more ... much more ...

CHAPTER ELEVEN

Who controls the Cult?

Awake, arise or be forever fall'n
John Milton, *Paradise Lost*

I have exposed this far the level of the Cult conspiracy that operates in the world of the seen and within the global secret society and satanic network which operates in the shadows one step back from the seen. The story, however, goes much deeper than that.

The 'Covid' hoax is major part of the Cult agenda, but only part, and to grasp the biggest picture we have to expand our attention beyond the realm of human sight and into the infinity of possibility that we cannot see. It is from here, ultimately, that humanity is being manipulated into a state of total control by the force which dictates the actions of the Cult. How much of reality can we see? Next to damn all is the answer. We may appear to see all there is to see in the 'space' our eyes survey and observe, but little could be further from the truth. The human 'world' is only a tiny band of frequency that the body's visual and perceptual systems can decode into *perception* of a 'world'. According to mainstream science the electromagnetic spectrum is 0.005 percent of what exists in the Universe ([Fig 10](#)). The maximum estimate I have seen is 0.5 percent and either way it's miniscule. I say it is far, far, smaller even than 0.005 percent when you compare reality we see with the totality of reality that we don't. Now get this if you are new to such information: Visible light, the only band of frequency that we can see, is a *fraction* of the 0.005

percent (Fig 11 overleaf). Take this further and realise that our universe is one of infinite universes and that universes are only a fragment of overall reality – *infinite* reality. Then compare that with the almost infinitesimal frequency band of visible light or human sight. You see that humans are as near blind as it is possible to be without actually being so. Artist and filmmaker, Sergio Toporek, said:

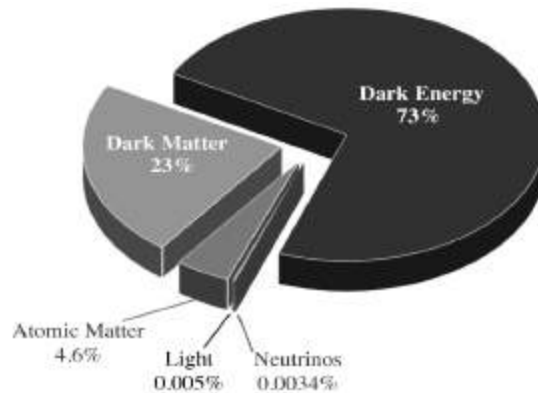


Figure 10: Humans can perceive such a tiny band of visual reality it's laughable.

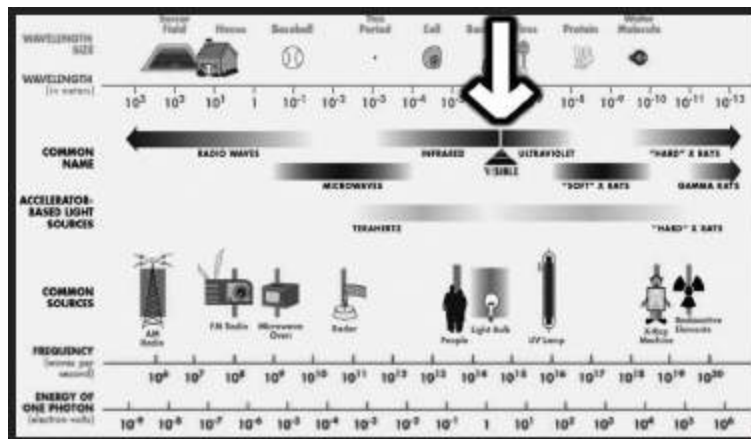


Figure 11: We can see a smear of the 0.005 percent electromagnetic spectrum, but we still know it all. Yep, makes sense.

Consider that you can see less than 1% of the electromagnetic spectrum and hear less than 1% of the acoustic spectrum. 90% of the cells in your body carry their own microbial DNA and are not 'you'. The atoms in your body are 99.9999999999999999% empty space and none of them are the ones you were born with ... Human beings have 46 chromosomes, two less than a potato.

The existence of the rainbow depends on the conical photoreceptors in your eyes; to animals without cones, the rainbow does not exist. So you don't just look at a rainbow, you create it. This is pretty amazing, especially considering that all the beautiful colours you see represent less than 1% of the electromagnetic spectrum.

Suddenly the 'world' of humans looks a very different place. Take into account, too, that Planet Earth when compared with the projected size of this single universe is the equivalent of a billionth of a pinhead. Imagine the ratio that would be when compared to infinite reality. To think that Christianity once insisted that Earth and humanity were the centre of everything. This background is vital if we are going to appreciate the nature of 'human' and how we can be manipulated by an unseen force. To human visual reality virtually *everything* is unseen and yet the prevailing perception within the institutions and so much of the public is that if we can't see it, touch it, hear it, taste it and smell it then it cannot exist. Such perception is indoctrinated and encouraged by the Cult and its agents because it isolates believers in the strictly limited, village-idiot, realm of the five senses where perceptions can be firewalled and information controlled. Most of those perpetuating the 'this-world-is-all-there-is' insanity are themselves indoctrinated into believing the same delusion. While major players and influencers know that official reality is laughable most of those in science, academia and medicine really believe the nonsense they peddle and teach succeeding generations. Those who challenge the orthodoxy are dismissed as nutters and freaks to protect the manufactured illusion from exposure. Observe the dynamic of the 'Covid' hoax and you will see how that takes the same form. The inner-circle psychopaths knows it's a gigantic scam, but almost the entirety of those imposing their fascist rules believe that 'Covid' is all that they're told it is.

Stolen identity

Ask people who they are and they will give you their name, place of birth, location, job, family background and life story. Yet that is not who they are – it is what they are *experiencing*. The difference is *absolutely crucial*. The true 'I', the eternal, infinite 'I', is consciousness,

a state of being aware. Forget 'form'. That is a vehicle for a brief experience. Consciousness does not come *from* the brain, but *through* the brain and even that is more symbolic than literal. We are awareness, pure awareness, and this is what withdraws from the body at what we call 'death' to continue our eternal beingness, *isness*, in other realms of reality within the limitlessness of infinity or the Biblical 'many mansions in my father's house'. Labels of a human life, man, woman, transgender, black, white, brown, nationality, circumstances and income are not who we are. They are what we are – awareness – is *experiencing* in a brief connection with a band of frequency we call 'human'. The labels are not the self; they are, to use the title of one of my books, a *Phantom Self*. I am not David Icke born in Leicester, England, on April 29th, 1952. I am the consciousness *having that experience*. The Cult and its non-human masters seek to convince us through the institutions of 'education', science, medicine, media and government that what we are *experiencing* is who we *are*. It's so easy to control and direct perception locked away in the bewildered illusions of the five senses with no expanded radar. Try, by contrast, doing the same with a humanity aware of its true self and its true power to consciously create its reality and experience. How is it possible to do this? We do it all day every day. If you perceive yourself as 'little me' with no power to impact upon your life and the world then your life experience will reflect that. You will hand the power you don't think you have to authority in all its forms which will use it to control your experience. This, in turn, will appear to confirm your perception of 'little me' in a self-fulfilling feedback loop. But that is what 'little me' really is – a *perception*. We are all 'big-me', infinite me, and the Cult has to make us forget that if its will is to prevail. We are therefore manipulated and pressured into self-identifying with human labels and not the consciousness/awareness *experiencing* those human labels.

The phenomenon of identity politics is a Cult-instigated manipulation technique to sub-divide previous labels into even smaller ones. A United States university employs this list of letters to

describe student identity: LGBTTTQQFAGPBDSM or lesbian, gay, bisexual, transgender, transsexual, queer, questioning, flexual, asexual, gender-fuck, polyamorous, bondage/discipline, dominance/submission and sadism/masochism. I'm sure other lists are even longer by now as people feel the need to self-identity the 'I' with the minutiae of race and sexual preference. Wokers programmed by the Cult for generations believe this is about 'inclusivity' when it's really the Cult locking them away into smaller and smaller versions of Phantom Self while firewalling them from the influence of their true self, the infinite, eternal 'I'. You may notice that my philosophy which contends that we are all unique points of attention/awareness within the same infinite whole or Oneness is the ultimate non-racism. The very sense of Oneness makes the judgement of people by their body-type, colour or sexuality utterly ridiculous and confirms that racism has no understanding of reality (including anti-white racism). Yet despite my perception of life Cult agents and fast-asleep Wokers label me racist to discredit my information while they are themselves phenomenally racist and sexist. All they see is race and sexuality and they judge people as good or bad, demons or untouchables, by their race and sexuality. All they see is *Phantom Self* and perceive themselves in terms of Phantom Self. They are pawns and puppets of the Cult agenda to focus attention and self-identity in the five senses and play those identities against each other to divide and rule. Columbia University has introduced segregated graduations in another version of social distancing designed to drive people apart and teach them that different racial and cultural groups have nothing in common with each other. The last thing the Cult wants is unity. Again the pump-primers of this will be Cult operatives in the knowledge of what they are doing, but the rest are just the Phantom Self blind leading the Phantom Self blind. We *do* have something in common – we are all *the same consciousness* having different temporary experiences.

What is this 'human'?

Yes, what *is* 'human'? That is what we are supposed to be, right? I mean 'human'? True, but 'human' is the experience not the 'I'. Break it down to basics and 'human' is the way that information is processed. If we are to experience and interact with this band of frequency we call the 'world' we must have a vehicle that operates within that band of frequency. Our consciousness in its prime form cannot do that; it is way beyond the frequency of the human realm. My consciousness or awareness could not tap these keys and pick up the cup in front of me in the same way that radio station A cannot interact with radio station B when they are on different frequencies. The human body is the means through which we have that interaction. I have long described the body as a biological computer which processes information in a way that allows consciousness to experience this reality. The body is a receiver, transmitter and processor of information in a particular way that we call human. We visually perceive only the world of the five senses in a wakened state – that is the limit of the body's visual decoding system. In truth it's not even visual in the way we experience 'visual reality' as I will come to in a moment. We are 'human' because the body processes the information sources of human into a reality and behaviour system that we *perceive* as human. Why does an elephant act like an elephant and not like a human or a duck? The elephant's biological computer is a different information field and processes information according to that program into a visual and behaviour type we call an elephant. The same applies to everything in our reality. These body information fields are perpetuated through procreation (like making a copy of a software program). The Cult wants to break that cycle and intervene technologically to transform the human information field into one that will change what we call humanity. If it can change the human information field it will change the way that field processes information and change humanity both 'physically' and psychologically. Hence the *messenger* (information) RNA 'vaccines' and so much more that is targeting human genetics by changing the body's information – *messaging* – construct through food, drink, radiation, toxicity and other means.

Reality that we experience is nothing like reality as it really is in the same way that the reality people experience in virtual reality games is not the reality they are really living in. The game is only a decoded source of information that appears to be a reality. Our world is also an information construct – a *simulation* (more later). In its base form our reality is a wavefield of information much the same in theme as Wi-Fi. The five senses decode wavefield information into electrical information which they communicate to the brain to decode into holographic (illusory ‘physical’) information. Different parts of the brain specialise in decoding different senses and the information is fused into a reality that appears to be outside of us but is really inside the brain and the genetic structure in general ([Fig 12](#) overleaf). DNA is a receiver-transmitter of information and a vital part of this decoding process and the body’s connection to other realities. Change DNA and you change the way we decode and connect with reality – see ‘Covid vaccines’. Think of computers decoding Wi-Fi. You have information encoded in a radiation field and the computer decodes that information into a very different form on the screen. You can’t see the Wi-Fi until its information is made manifest on the screen and the information on the screen is inside the computer and not outside. I have just described how we decode the ‘human world’. All five senses decode the waveform ‘Wi-Fi’ field into electrical signals and the brain (computer) constructs reality inside the brain and not outside – ‘You don’t just look at a rainbow, you create it’. Sound is a simple example. We don’t hear sound until the brain decodes it. Waveform sound waves are picked up by the hearing sense and communicated to the brain in an electrical form to be decoded into the sounds that we hear. Everything we hear is inside the brain along with everything we see, feel, smell and taste. Words and language are waveform fields generated by our vocal chords which pass through this process until they are decoded by the brain into words that we hear. Different languages are different frequency fields or sound waves generated by vocal chords. Late British philosopher Alan Watts said:

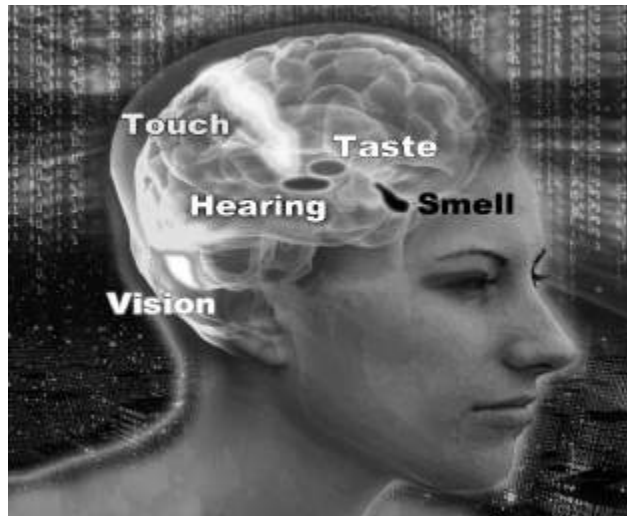


Figure 12: The brain receives information from the five senses and constructs from that our perceived reality.

[Without the brain] the world is devoid of light, heat, weight, solidity, motion, space, time or any other imaginable feature. All these phenomena are interactions, or transactions, of vibrations with a certain arrangement of neurons.

That's exactly what they are and scientist Robert Lanza describes in his book, *Biocentrism*, how we decode electromagnetic waves and energy into visual and 'physical' experience. He uses the example of a flame emitting photons, electromagnetic energy, each pulsing electrically and magnetically:

... these ... invisible electromagnetic waves strike a human retina, and if (and only if) the waves happen to measure between 400 and 700 nano meters in length from crest to crest, then their energy is just right to deliver a stimulus to the 8 million cone-shaped cells in the retina.

Each in turn send an electrical pulse to a neighbour neuron, and on up the line this goes, at 250 mph, until it reaches the ... occipital lobe of the brain, in the back of the head. There, a cascading complex of neurons fire from the incoming stimuli, and we subjectively perceive this experience as a yellow brightness occurring in a place we have been conditioned to call the 'external world'.

You hear what you decode

If a tree falls or a building collapses they make no noise unless someone is there to decode the energetic waves generated by the disturbance into what we call sound. Does a falling tree make a noise? Only if you hear it – *decode* it. Everything in our reality is a frequency field of information operating within the overall ‘Wi-Fi’ field that I call The Field. A vibrational disturbance is generated in The Field by the fields of the falling tree or building. These disturbance waves are what we decode into the sound of them falling. If no one is there to do that then neither will make any noise. Reality is created by the observer – *decoder* – and the *perceptions* of the observer affect the decoding process. For this reason different people – different *perceptions* – will perceive the same reality or situation in a different way. What one may perceive as a nightmare another will see as an opportunity. The question of why the Cult is so focused on controlling human perception now answers itself. All experienced reality is the act of decoding and we don’t experience Wi-Fi until it is decoded on the computer screen. The sight and sound of an Internet video is encoded in the Wi-Fi all around us, but we don’t see or hear it until the computer decodes that information. Taste, smell and touch are all phenomena of the brain as a result of the same process. We don’t taste, smell or feel anything except in the brain and there are pain relief techniques that seek to block the signal from the site of discomfort to the brain because if the brain doesn’t decode that signal we don’t feel pain. Pain is in the brain and only appears to be at the point of impact thanks to the feedback loop between them. We don’t see anything until electrical information from the sight senses is decoded in an area at the back of the brain. If that area is damaged we can go blind when our eyes are perfectly okay. So why do we go blind if we damage an eye? We damage the information processing between the waveform visual information and the visual decoding area of the brain. If information doesn’t reach the brain in a form it can decode then we can’t see the visual reality that it represents. What’s more the brain is decoding only a fraction of the information it receives and the rest is absorbed by the

sub-conscious mind. This explanation is from the science magazine, *Wonderpedia*:

Every second, 11 million sensations crackle along these [brain] pathways ... The brain is confronted with an alarming array of images, sounds and smells which it rigorously filters down until it is left with a manageable list of around 40. Thus 40 sensations per second make up what we perceive as reality.

The 'world' is not what people are told to believe that is it and the inner circles of the Cult *know that*.

Illusory 'physical' reality

We can only see a smear of 0.005 percent of the Universe which is only one of a vast array of universes – 'mansions' – within infinite reality. Even then the brain decodes only 40 pieces of information ('sensations') from a potential *11 million* that we receive every second. Two points strike you from this immediately: The sheer breathtaking stupidity of believing we know anything so rigidly that there's nothing more to know; and the potential for these processes to be manipulated by a malevolent force to control the reality of the population. One thing I can say for sure with no risk of contradiction is that when you can perceive an almost indescribable fraction of infinite reality there is always more to know as in tidal waves of it. Ancient Greek philosopher Socrates was so right when he said that wisdom is to know how little we know. How obviously true that is when you think that we are experiencing a physical world of solidity that is neither physical nor solid and a world of apartness when everything is connected. Cult-controlled 'science' dismisses the so-called 'paranormal' and all phenomena related to that when the 'para'-normal is perfectly normal and explains the alleged 'great mysteries' which dumbfound scientific minds. There is a reason for this. A 'scientific mind' in terms of the mainstream is a material mind, a five-sense mind imprisoned in see it, touch it, hear it, smell it and taste it. Phenomena and happenings that can't be explained that way leave the 'scientific mind' bewildered and the rule is that if they

can't account for why something is happening then it can't, by definition, be happening. I beg to differ. Telepathy is thought waves passing through The Field (think wave disturbance again) to be decoded by someone able to connect with that wavelength (information). For example: You can pick up the thought waves of a friend at any distance and at the very least that will bring them to mind. A few minutes later the friend calls you. 'My god', you say, 'that's incredible – I was just thinking of you.' Ah, but *they* were thinking of *you* before they made the call and that's what you decoded. Native peoples not entrapped in five-sense reality do this so well it became known as the 'bush telegraph'. Those known as psychics and mediums (genuine ones) are doing the same only across dimensions of reality. 'Mind over matter' comes from the fact that matter and mind are the *same*. The state of one influences the state of the other. Indeed one *and* the other are illusions. They are aspects of the same field. Paranormal phenomena are all explainable so why are they still considered 'mysteries' or not happening? Once you go down this road of understanding you begin to expand awareness beyond the five senses and that's the nightmare for the Cult.



Figure 13: Holograms are not solid, but the best ones appear to be.

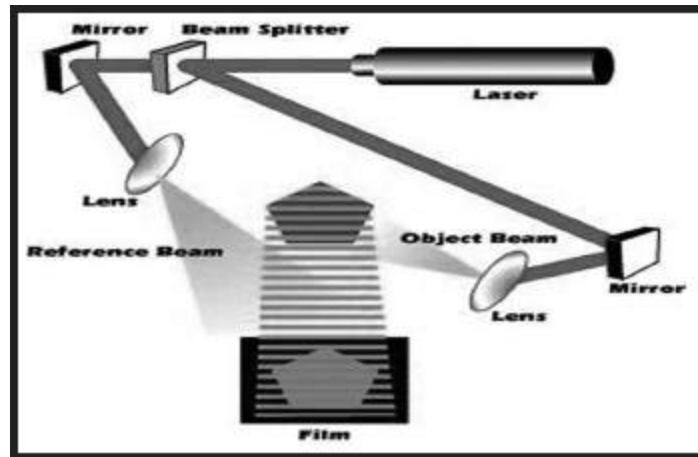


Figure 14: How holograms are created by capturing a waveform version of the subject image.

Holographic 'solidity'

Our reality is not solid, it is holographic. We are now well aware of holograms which are widely used today. Two-dimensional information is decoded into a three-dimensional reality that is not solid although can very much appear to be (Fig 13). Holograms are created with a laser divided into two parts. One goes directly onto a holographic photographic print ('reference beam') and the other takes a waveform image of the subject ('working beam') before being directed onto the print where it 'collides' with the other half of the laser (Fig 14). This creates a *waveform* interference pattern which contains the wavefield information of whatever is being photographed (Fig 15 overleaf). The process can be likened to dropping pebbles in a pond. Waves generated by each one spread out across the water to collide with the others and create a wave representation of where the stones fell and at what speed, weight and distance. A waveform interference pattern of a hologram is akin to the waveform information in The Field which the five senses decode into electrical signals to be decoded by the brain into a holographic illusory 'physical' reality. In the same way when a laser (think human attention) is directed at the waveform interference pattern a three-dimensional version of the subject is projected into apparently 'solid' reality (Fig 16). An amazing trait of holograms reveals more 'paranormal mysteries'. Information of the *whole*

hologram is encoded in waveform in every part of the interference pattern by the way they are created. This means that every *part* of a hologram is a smaller version of the whole. Cut the interference wave-pattern into four and you won't get four parts of the image. You get quarter-sized versions of the *whole* image. The body is a hologram and the same applies. Here we have the basis of acupuncture, reflexology and other forms of healing which identify representations of the whole body in all of the parts, hands, feet, ears, everywhere. Skilled palm readers can do what they do because the information of whole body is encoded in the hand. The concept of as above, so below, comes from this.



Figure 15: A waveform interference pattern that holds the information that transforms into a hologram.



Figure 16: Holographic people including 'Elvis' holographically inserted to sing a duet with Celine Dion.

The question will be asked of why, if solidity is illusory, we can't just walk through walls and each other. The resistance is not solid against solid; it is electromagnetic field against electromagnetic field and we decode this into the *experience* of solid against solid. We should also not underestimate the power of belief to dictate reality. What you believe is impossible *will be*. Your belief impacts on your decoding processes and they won't decode what you think is impossible. What we believe we perceive and what we perceive we experience. 'Can't dos' and 'impossibles' are like a firewall in a computer system that won't put on the screen what the firewall blocks. How vital that is to understanding how human experience has been hijacked. I explain in *The Answer, Everything You Need To Know But Have Never Been Told* and other books a long list of 'mysteries' and 'paranormal' phenomena that are not mysterious and perfectly normal once you realise what reality is and how it works. 'Ghosts' can be seen to pass through 'solid' walls because the walls are not solid and the ghost is a discarnate entity operating on a frequency so different to that of the wall that it's like two radio stations sharing the same space while never interfering with each other. I have seen ghosts do this myself. The apartness of people and objects is also an illusion. Everything is connected by the Field like all sea life is connected by the sea. It's just that within the limits of our visual reality we only 'see' holographic information and not the field of information that connects everything and from which the holographic world is made manifest. If you can only see holographic 'objects' and not the field that connects them they will appear to you as unconnected to each other in the same way that we see the computer while not seeing the Wi-Fi.

What you don't know *can* hurt you

Okay, we return to those 'two worlds' of human society and the Cult with its global network of interconnecting secret societies and satanic groups which manipulate through governments, corporations, media, religions, etc. The fundamental difference between them is *knowledge*. The idea has been to keep humanity

ignorant of the plan for its total enslavement underpinned by a crucial ignorance of reality – who we are and where we are – and how we interact with it. ‘Human’ should be the interaction between our expanded eternal consciousness and the five-sense body experience. We are meant to be *in* this world in terms of the five senses but not *of* this world in relation to our greater consciousness and perspective. In that state we experience the small picture of the five senses within the wider context of the big picture of awareness beyond the five senses. Put another way the five senses see the dots and expanded awareness connects them into pictures and patterns that give context to the apparently random and unconnected. Without the context of expanded awareness the five senses see only apartness and randomness with apparently no meaning. The Cult and its other-dimensional controllers seek to intervene in the frequency realm where five-sense reality is supposed to connect with expanded reality and to keep the two apart (more on this in the final chapter). When that happens five-sense mental and emotional processes are no longer influenced by expanded awareness, or the True ‘I’, and instead are driven by the isolated perceptions of the body’s decoding systems. They are in the world *and* of it. Here we have the human plight and why humanity with its potential for infinite awareness can be so easily manipulatable and descend into such extremes of stupidity.

Once the Cult isolates five-sense mind from expanded awareness it can then program the mind with perceptions and beliefs by controlling information that the mind receives through the ‘education’ system of the formative years and the media perceptual bombardment and censorship of an entire lifetime. Limit perception and a sense of the possible through limiting knowledge by limiting and skewing information while censoring and discrediting that which could set people free. As the title of another of my books says ... *And The Truth Shall Set You Free*. For this reason the last thing the Cult wants in circulation is the truth about anything – especially the reality of the eternal ‘I’ – and that’s why it is desperate to control information. The Cult knows that information becomes perception

which becomes behaviour which, collectively, becomes human society. Cult-controlled and funded mainstream 'science' denies the existence of an eternal 'I' and seeks to dismiss and trash all evidence to the contrary. Cult-controlled mainstream religion has a version of 'God' that is little more than a system of control and dictatorship that employs threats of damnation in an afterlife to control perceptions and behaviour in the here and now through fear and guilt. Neither is true and it's the 'neither' that the Cult wishes to suppress. This 'neither' is that everything is an expression, a point of attention, within an infinite state of consciousness which is the real meaning of the term 'God'.

Perceptual obsession with the 'physical body' and five-senses means that 'God' becomes personified as a bearded bloke sitting among the clouds or a raging bully who loves us if we do what 'he' wants and condemns us to the fires of hell if we don't. These are no more than a 'spiritual' fairy tales to control and dictate events and behaviour through fear of this 'God' which has bizarrely made 'God-fearing' in religious circles a state to be desired. I would suggest that fearing *anything* is not to be encouraged and celebrated, but rather deleted. You can see why 'God fearing' is so beneficial to the Cult and its religions when *they* decide what 'God' wants and what 'God' demands (the Cult demands) that everyone do. As the great American comedian Bill Hicks said satirising a Christian zealot: 'I think what God meant to say.' How much of this infinite awareness ('God') that we access is decided by how far we choose to expand our perceptions, self-identity and sense of the possible. The scale of self-identity reflects itself in the scale of awareness that we can connect with and are influenced by – how much knowing and insight we have instead of programmed perception. You cannot expand your awareness into the infinity of possibility when you believe that you are little me Peter the postman or Mary in marketing and nothing more. I'll deal with this in the concluding chapter because it's crucial to how we turnaround current events.

Where the Cult came from

When I realised in the early 1990s there was a Cult network behind global events I asked the obvious question: When did it start? I took it back to ancient Rome and Egypt and on to Babylon and Sumer in Mesopotamia, the 'Land Between Two Rivers', in what we now call Iraq. The two rivers are the Tigris and Euphrates and this region is of immense historical and other importance to the Cult, as is the land called Israel only 550 miles away by air. There is much more going on with deep esoteric meaning across this whole region. It's not only about 'wars for oil'. Priceless artefacts from Mesopotamia were stolen or destroyed after the American and British invasion of Iraq in 2003 justified by the lies of Boy Bush and Tony Blair (their Cult masters) about non-existent 'weapons of mass destruction'.

Mesopotamia was the location of Sumer (about 5,400BC to 1,750BC), and Babylon (about 2,350BC to 539BC). Sabbatians may have become immensely influential in the Cult in modern times but they are part of a network that goes back into the mists of history. Sumer is said by historians to be the 'cradle of civilisation'. I disagree. I say it was the re-start of what we call human civilisation after cataclysmic events symbolised in part as the 'Great Flood' destroyed the world that existed before. These fantastic upheavals that I have been describing in detail in the books since the early 1990s appear in accounts and legends of ancient cultures across the world and they are supported by geological and biological evidence. Stone tablets found in Iraq detailing the Sumer period say the cataclysms were caused by non-human 'gods' they call the Anunnaki. These are described in terms of extraterrestrial visitations in which knowledge supplied by the Anunnaki is said to have been the source of at least one of the world's oldest writing systems and developments in astronomy, mathematics and architecture that were way ahead of their time. I have covered this subject at length in *The Biggest Secret* and *Children of the Matrix* and the same basic 'Anunnaki' story can be found in Zulu accounts in South Africa where the late and very great Zulu high shaman Credo Mutwa told me that the Sumerian Anunnaki were known by Zulus as the Chitauri or 'children of the serpent'. See my six-hour video interview with Credo on this subject entitled *The*

Reptilian Agenda recorded at his then home near Johannesburg in 1999 which you can watch on the Ickonic media platform.

The Cult emerged out of Sumer, Babylon and Egypt (and elsewhere) and established the Roman Empire before expanding with the Romans into northern Europe from where many empires were savagely imposed in the form of Cult-controlled societies all over the world. Mass death and destruction was their calling card. The Cult established its centre of operations in Europe and European Empires were Cult empires which allowed it to expand into a global force. Spanish and Portuguese colonialists headed for Central and South America while the British and French targeted North America. Africa was colonised by Britain, France, Belgium, the Netherlands, Portugal, Spain, Italy, and Germany. Some like Britain and France moved in on the Middle East. The British Empire was by far the biggest for a simple reason. By now Britain was the headquarters of the Cult from which it expanded to form Canada, the United States, Australia and New Zealand. The Sun never set on the British Empire such was the scale of its occupation. London remains a global centre for the Cult along with Rome and the Vatican although others have emerged in Israel and China. It is no accident that the 'virus' is alleged to have come out of China while Italy was chosen as the means to terrify the Western population into compliance with 'Covid' fascism. Nor that Israel has led the world in 'Covid' fascism and mass 'vaccination'.

You would think that I would mention the United States here, but while it has been an important means of imposing the Cult's will it is less significant than would appear and is currently in the process of having what power it does have deleted. The Cult in Europe has mostly loaded the guns for the US to fire. America has been controlled from Europe from the start through Cult operatives in Britain and Europe. The American Revolution was an illusion to make it appear that America was governing itself while very different forces were pulling the strings in the form of Cult families such as the Rothschilds through the Rockefellers and other subordinates. The Rockefellers are extremely close to Bill Gates and

established both scalpel and drug 'medicine' and the World Health Organization. They play a major role in the development and circulation of vaccines through the Rockefeller Foundation on which Bill Gates said his Foundation is based. Why wouldn't this be the case when the Rockefellers and Gates are on the same team? Cult infiltration of human society goes way back into what we call history and has been constantly expanding and centralising power with the goal of establishing a global structure to dictate everything. Look how this has been advanced in great leaps with the 'Covid' hoax.

The non-human dimension

I researched and observed the comings and goings of Cult operatives through the centuries and even thousands of years as they were born, worked to promote the agenda within the secret society and satanic networks, and then died for others to replace them. Clearly there had to be a coordinating force that spanned this entire period while operatives who would not have seen the end goal in their lifetimes came and went advancing the plan over millennia. I went in search of that coordinating force with the usual support from the extraordinary synchronicity of my life which has been an almost daily experience since 1990. I saw common themes in religious texts and ancient cultures about a non-human force manipulating human society from the hidden. Christianity calls this force Satan, the Devil and demons; Islam refers to the Jinn or Djinn; Zulus have their Chitauri (spelt in other ways in different parts of Africa); and the Gnostic people in Egypt in the period around and before 400AD referred to this phenomena as the 'Archons', a word meaning rulers in Greek. Central American cultures speak of the 'Predators' among other names and the same theme is everywhere. I will use 'Archons' as a collective name for all of them. When you see how their nature and behaviour is described all these different sources are clearly talking about the same force. Gnostics described the Archons in terms of 'luminous fire' while Islam relates the Jinn to 'smokeless fire'. Some refer to beings in form that could occasionally be seen, but the most common of common theme is that they operate from

unseen realms which means almost all existence to the visual processes of humans. I had concluded that this was indeed the foundation of human control and that the Cult was operating within the human frequency band on behalf of this hidden force when I came across the writings of Gnostics which supported my conclusions in the most extraordinary way.

A sealed earthen jar was found in 1945 near the town of Nag Hammadi about 75-80 miles north of Luxor on the banks of the River Nile in Egypt. Inside was a treasure trove of manuscripts and texts left by the Gnostic people some 1,600 years earlier. They included 13 leather-bound papyrus codices (manuscripts) and more than 50 texts written in Coptic Egyptian estimated to have been hidden in the jar in the period of 400AD although the source of the information goes back much further. Gnostics oversaw the Great or Royal Library of Alexandria, the fantastic depository of ancient texts detailing advanced knowledge and accounts of human history. The Library was dismantled and destroyed in stages over a long period with the death-blow delivered by the Cult-established Roman Church in the period around 415AD. The Church of Rome was the Church of Babylon relocated as I said earlier. Gnostics were not a race. They were a way of perceiving reality. Whenever they established themselves and their information circulated the terrorists of the Church of Rome would target them for destruction. This happened with the Great Library and with the Gnostic Cathars who were burned to death by the psychopaths after a long period of oppression at the siege of the Castle of Monségur in southern France in 1244. The Church has always been terrified of Gnostic information which demolishes the official Christian narrative although there is much in the Bible that supports the Gnostic view if you read it in another way. To anyone studying the texts of what became known as the Nag Hammadi Library it is clear that great swathes of Christian and Biblical belief has its origin with Gnostics sources going back to Sumer. Gnostic themes have been twisted to manipulate the perceived reality of Bible believers. Biblical texts have been in the open for centuries where they could be changed while Gnostic

documents found at Nag Hammadi were sealed away and untouched for 1,600 years. What you see is what they wrote.

Use your *pneuma* not your *nous*

Gnosticism and Gnostic come from 'gnosis' which means knowledge, or rather *secret* knowledge, in the sense of spiritual awareness – knowledge about reality and life itself. The desperation of the Cult's Church of Rome to destroy the Gnostics can be understood when the knowledge they were circulating was the last thing the Cult wanted the population to know. Sixteen hundred years later the same Cult is working hard to undermine and silence me for the same reason. The dynamic between knowledge and ignorance is a constant. 'Time' appears to move on, but essential themes remain the same. We are told to 'use your nous', a Gnostic word for head/brain/intelligence. They said, however, that spiritual awakening or 'salvation' could only be secured by expanding awareness *beyond* what they called *nous* and into *pneuma* or Infinite Self. Obviously as I read these texts the parallels with what I have been saying since 1990 were fascinating to me. There is a universal truth that spans human history and in that case why wouldn't we be talking the same language 16 centuries apart? When you free yourself from the perception program of the five senses and explore expanded realms of consciousness you are going to connect with the same information no matter what the perceived 'era' within a manufactured timeline of a single and tiny range of manipulated frequency. Humans working with 'smart' technology or knocking rocks together in caves is only a timeline appearing to operate within the human frequency band. Expanded awareness and the knowledge it holds have always been there whether the era be Stone Age or computer age. We can only access that knowledge by opening ourselves to its frequency which the five-sense prison cell is designed to stop us doing. Gates, Fauci, Whitty, Vallance, Zuckerberg, Brin, Page, Wojcicki, Bezos, and all the others behind the 'Covid' hoax clearly have a long wait before their range of frequency can make that connection given that an open heart is

crucial to that as we shall see. Instead of accessing knowledge directly through expanded awareness it is given to Cult operatives by the secret society networks of the Cult where it has been passed on over thousands of years outside the public arena. Expanded realms of consciousness is where great artists, composers and writers find their inspiration and where truth awaits anyone open enough to connect with it. We need to go there fast.

Archon hijack

A fifth of the Nag Hammadi texts describe the existence and manipulation of the Archons led by a 'Chief Archon' they call 'Yaldabaoth', or the 'Demiurge', and this is the Christian 'Devil', 'Satan', 'Lucifer', and his demons. Archons in Biblical symbolism are the 'fallen ones' which are also referred to as fallen angels after the angels expelled from heaven according to the Abrahamic religions of Judaism, Christianity and Islam. These angels are claimed to tempt humans to 'sin' ongoing and you will see how accurate that symbolism is during the rest of the book. The theme of 'original sin' is related to the 'Fall' when Adam and Eve were 'tempted by the serpent' and fell from a state of innocence and 'obedience' (connection) with God into a state of disobedience (disconnection). The Fall is said to have brought sin into the world and corrupted everything including human nature. Yaldabaoth, the 'Lord Archon', is described by Gnostics as a 'counterfeit spirit', 'The Blind One', 'The Blind God', and 'The Foolish One'. The Jewish name for Yaldabaoth in Talmudic writings is Samael which translates as 'Poison of God', or 'Blindness of God'. You see the parallels. Yaldabaoth in Islamic belief is the Muslim Jinn devil known as Shaytan – Shaytan is Satan as the same themes are found all over the world in every religion and culture. The 'Lord God' of the Old Testament is the 'Lord Archon' of Gnostic manuscripts and that's why he's such a bloodthirsty bastard. Satan is known by Christians as 'the Demon of Demons' and Gnostics called Yaldabaoth the 'Archon of Archons'. Both are known as 'The Deceiver'. We are talking about the same 'bloke' for sure and these common themes

using different names, storylines and symbolism tell a common tale of the human plight.

Archons are referred to in Nag Hammadi documents as mind parasites, inverters, guards, gatekeepers, detainers, judges, pitiless ones and deceivers. The 'Covid' hoax alone is a glaring example of all these things. The Biblical 'God' is so different in the Old and New Testaments because they are not describing the same phenomenon. The vindictive, angry, hate-filled, 'God' of the Old Testament, known as Yahweh, is Yaldabaoth who is depicted in Cult-dictated popular culture as the 'Dark Lord', 'Lord of Time', Lord (Darth) Vader and Dormammu, the evil ruler of the 'Dark Dimension' trying to take over the 'Earth Dimension' in the Marvel comic movie, *Dr Strange*. Yaldabaoth is both the Old Testament 'god' and the Biblical 'Satan'. Gnostics referred to Yaldabaoth as the 'Great Architect of the Universe' and the Cult-controlled Freemason network calls their god 'the 'Great Architect of the Universe' (also Grand Architect). The 'Great Architect' Yaldabaoth is symbolised by the Cult as the all-seeing eye at the top of the pyramid on the Great Seal of the United States and the dollar bill. Archon is encoded in *arch*-itect as it is in *arch*-angels and *arch*-bishops. All religions have the theme of a force for good and force for evil in some sort of spiritual war and there is a reason for that – the theme is true. The Cult and its non-human masters are quite happy for this to circulate. They present themselves as the force for good fighting evil when they are really the force of evil (absence of love). The whole foundation of Cult modus operandi is inversion. They promote themselves as a force for good and anyone challenging them in pursuit of peace, love, fairness, truth and justice is condemned as a satanic force for evil. This has been the game plan throughout history whether the Church of Rome inquisitions of non-believers or 'conspiracy theorists' and 'anti-vaxxers' of today. The technique is the same whatever the timeline era.

Yaldabaoth is revolting (true)

Yaldabaoth and the Archons are said to have revolted against God with Yaldabaoth claiming to *be* God – the *All That Is*. The Old Testament ‘God’ (Yaldabaoth) demanded to be worshipped as such: ‘*I am the LORD, and there is none else, there is no God beside me*’ (Isaiah 45:5). I have quoted in other books a man who said he was the unofficial son of the late Baron Philippe de Rothschild of the Mouton-Rothschild wine producing estates in France who died in 1988 and he told me about the Rothschild ‘revolt from God’. The man said he was given the name Phillip Eugene de Rothschild and we shared long correspondence many years ago while he was living under another identity. He said that he was conceived through ‘occult incest’ which (within the Cult) was ‘normal and to be admired’. ‘Phillip’ told me about his experience attending satanic rituals with rich and famous people whom he names and you can see them and the wider background to Cult Satanism in my other books starting with *The Biggest Secret*. Cult rituals are interactions with Archontic ‘gods’. ‘Phillip’ described Baron Philippe de Rothschild as ‘a master Satanist and hater of God’ and he used the same term ‘revolt from God’ associated with Yaldabaoth/Satan/Lucifer/the Devil in describing the Sabbatian Rothschild dynasty. ‘I played a key role in my family’s revolt from God’, he said. That role was to infiltrate in classic Sabbatian style the Christian Church, but eventually he escaped the mind-prison to live another life. The Cult has been targeting religion in a plan to make worship of the Archons the global one-world religion. Infiltration of Satanism into modern ‘culture’, especially among the young, through music videos, stage shows and other means, is all part of this.

Nag Hammadi texts describe Yaldabaoth and the Archons in their prime form as energy – consciousness – and say they can take form if they choose in the same way that consciousness takes form as a human. Yaldabaoth is called ‘formless’ and represents a deeply inverted, distorted and chaotic state of consciousness which seeks to attached to humans and turn them into a likeness of itself in an attempt at assimilation. For that to happen it has to manipulate

humans into low frequency mental and emotional states that match its own. Archons can certainly appear in human form and this is the origin of the psychopathic personality. The energetic distortion Gnostics called Yaldabaoth is psychopathy. When psychopathic Archons take human form that human will be a psychopath as an expression of Yaldabaoth consciousness. Cult psychopaths are Archons in human form. The principle is the same as that portrayed in the 2009 *Avatar* movie when the American military travelled to a fictional Earth-like moon called Pandora in the Alpha Centauri star system to infiltrate a society of blue people, or Na'vi, by hiding within bodies that looked like the Na'vi. Archons posing as humans have a particular hybrid information field, part human, part Archon, (the ancient 'demigods') which processes information in a way that manifests behaviour to match their psychopathic evil, lack of empathy and compassion, and stops them being influenced by the empathy, compassion and love that a fully-human information field is capable of expressing. Cult bloodlines interbreed, be they royalty or dark suits, for this reason and you have their obsession with incest. Interbreeding with full-blown humans would dilute the Archontic energy field that guarantees psychopathy in its representatives in the human realm.

Gnostic writings say the main non-human forms that Archons take are *serpentine* (what I have called for decades 'reptilian' amid unbounded ridicule from the Archontically-programmed) and what Gnostics describe as 'an unborn baby or foetus with grey skin and dark, unmoving eyes'. This is an excellent representation of the ET 'Greys' of UFO folklore which large numbers of people claim to have seen and been abducted by – Zulu shaman Credo Mutwa among them. I agree with those that believe in extraterrestrial or interdimensional visitations today and for thousands of years past. No wonder with their advanced knowledge and technological capability they were perceived and worshipped as gods for technological and other 'miracles' they appeared to perform. Imagine someone arriving in a culture disconnected from the modern world with a smartphone and computer. They would be

seen as a 'god' capable of 'miracles'. The Renegade Mind, however, wants to know the source of everything and not only the way that source manifests as human or non-human. In the same way that a Renegade Mind seeks the original source material for the 'Covid virus' to see if what is claimed is true. The original source of Archons in form is consciousness – the distorted state of consciousness known to Gnostics as Yaldabaoth.

'Revolt from God' is energetic disconnection

Where I am going next will make a lot of sense of religious texts and ancient legends relating to 'Satan', Lucifer' and the 'gods'. Gnostic descriptions sync perfectly with the themes of my own research over the years in how they describe a consciousness distortion seeking to impose itself on human consciousness. I've referred to the core of infinite awareness in previous books as Infinite Awareness in Awareness of Itself. By that I mean a level of awareness that knows that it is all awareness and is aware of all awareness. From here comes the frequency of love in its true sense and balance which is what love is on one level – the balance of all forces into a single whole called Oneness and Isness. The more we disconnect from this state of love that many call 'God' the constituent parts of that Oneness start to unravel and express themselves as a part and not a whole. They become individualised as intellect, mind, selfishness, hatred, envy, desire for power over others, and such like. This is not a problem in the greater scheme in that 'God', the *All That Is*, can experience all these possibilities through different expressions of itself including humans. What we as expressions of the whole experience the *All That Is* experiences. We are the *All That Is* experiencing itself. As we withdraw from that state of Oneness we disconnect from its influence and things can get very unpleasant and very stupid. Archontic consciousness is at the extreme end of that. It has so disconnected from the influence of Oneness that it has become an inversion of unity and love, an inversion of everything, an inversion of life itself. Evil is appropriately live written backwards. Archontic consciousness is obsessed with death, an inversion of life,

and so its manifestations in Satanism are obsessed with death. They use inverted symbols in their rituals such as the inverted pentagram and cross. Sabbatians as Archontic consciousness incarnate invert Judaism and every other religion and culture they infiltrate. They seek disunity and chaos and they fear unity and harmony as they fear love like garlic to a vampire. As a result the Cult, Archons incarnate, act with such evil, psychopathy and lack of empathy and compassion disconnected as they are from the source of love. How could Bill Gates and the rest of the Archontic psychopaths do what they have to human society in the 'Covid' era with all the death, suffering and destruction involved and have no emotional consequence for the impact on others? Now you know. Why have Zuckerberg, Brin, Page, Wojcicki and company callously censored information warning about the dangers of the 'vaccine' while thousands have been dying and having severe, sometimes life-changing reactions? Now you know. Why have Tedros, Fauci, Whitty, Vallance and their like around the world been using case and death figures they're aware are fraudulent to justify lockdowns and all the deaths and destroyed lives that have come from that? Now you know. Why did Christian Drosten produce and promote a 'testing' protocol that he knew couldn't test for infectious disease which led to a global human catastrophe. Now you know. The Archontic mind doesn't give a shit ([Fig 17](#)). I personally think that Gates and major Cult insiders are a form of AI cyborg that the Archons want humans to become.

these.' The statement was true in all respects. We do live in a technologically-generated virtual reality simulation (more very shortly) and we have been manipulated to be an energy source for Archontic consciousness. The Disney-Pixar animated movie *Monsters, Inc.* in 2001 symbolised the dynamic when monsters in their world had no energy source and they would enter the human world to terrify children in their beds, catch the child's scream, terror (low-vibrational frequencies), and take that energy back to power the monster world. The lead character you might remember was a single giant eye and the symbolism of the Cult's all-seeing eye was obvious. Every thought and emotion is broadcast as a frequency unique to that thought and emotion. Feelings of love and joy, empathy and compassion, are high, quick, frequencies while fear, depression, anxiety, suffering and hate are low, slow, dense frequencies. Which kind do you think Archontic consciousness can connect with and absorb? In such a low and dense frequency state there's no way it can connect with the energy of love and joy. Archons can only feed off energy compatible with their own frequency and they and their Cult agents want to delete the human world of love and joy and manipulate the transmission of low vibrational frequencies through low-vibrational human mental and emotional states. *We are their energy source.* Wars are energetic banquets to the Archons – a world war even more so – and think how much low-frequency mental and emotional energy has been generated from the consequences for humanity of the 'Covid' hoax orchestrated by Archons incarnate like Gates.

The ancient practice of human sacrifice 'to the gods', continued in secret today by the Cult, is based on the same principle. 'The gods' are Archontic consciousness in different forms and the sacrifice is induced into a state of intense terror to generate the energy the Archontic frequency can absorb. Incarnate Archons in the ritual drink the blood which contains an adrenaline they crave which floods into the bloodstream when people are terrorised. Most of the sacrifices, ancient and modern, are children and the theme of 'sacrificing young virgins to the gods' is just code for children. They

have a particular pre-puberty energy that Archons want more than anything and the energy of the young in general is their target. The California Department of Education wants students to chant the names of Aztec gods (Archontic gods) once worshipped in human sacrifice rituals in a curriculum designed to encourage them to 'challenge racist, bigoted, discriminatory, imperialist/colonial beliefs', join 'social movements that struggle for social justice', and 'build new possibilities for a post-racist, post-systemic racism society'. It's the usual Woke crap that inverts racism and calls it anti-racism. In this case solidarity with 'indigenous tribes' is being used as an excuse to chant the names of 'gods' to which people were sacrificed (and still are in secret). What an example of Woke's inability to see beyond black and white, us and them, They condemn the colonisation of these tribal cultures by Europeans (quite right), but those cultures sacrificing people including children to their 'gods', and mass murdering untold numbers as the Aztecs did, is just fine. One chant is to the Aztec god Tezcatlipoca who had a man sacrificed to him in the 5th month of the Aztec calendar. His heart was cut out and he was eaten. Oh, that's okay then. Come on children ... after three ... Other sacrificial 'gods' for the young to chant their allegiance include Quetzalcoatl, Huitzilopochtli and Xipe Totec. The curriculum says that 'chants, affirmations, and energizers can be used to bring the class together, build unity around ethnic studies principles and values, and to reinvigorate the class following a lesson that may be emotionally taxing or even when student engagement may appear to be low'. Well, that's the cover story, anyway. Chanting and mantras are the repetition of a particular frequency generated from the vocal cords and chanting the names of these Archontic 'gods' tunes you into their frequency. That is the last thing you want when it allows for energetic synchronisation, attachment and perceptual influence. Initiates chant the names of their 'Gods' in their rituals for this very reason.

Vampires of the Woke

Paedophilia is another way that Archons absorb the energy of children. Paedophiles possessed by Archontic consciousness are used as the conduit during sexual abuse for discarnate Archons to vampire the energy of the young they desire so much. Stupendous numbers of children disappear every year never to be seen again although you would never know from the media. Imagine how much low-vibrational energy has been generated by children during the 'Covid' hoax when so many have become depressed and psychologically destroyed to the point of killing themselves. Shocking numbers of children are now taken by the state from loving parents to be handed to others. I can tell you from long experience of researching this since 1996 that many end up with paedophiles and assets of the Cult through corrupt and Cult-owned social services which in the reframing era has hired many psychopaths and emotionless automatons to do the job. Children are even stolen to order using spurious reasons to take them by the corrupt and secret (because they're corrupt) 'family courts'. I have written in detail in other books, starting with *The Biggest Secret* in 1997, about the ubiquitous connections between the political, corporate, government, intelligence and military elites (Cult operatives) and Satanism and paedophilia. If you go deep enough both networks have an interlocking leadership. The Woke mentality has been developed by the Cult for many reasons: To promote almost every aspect of its agenda; to hijack the traditional political left and turn it fascist; to divide and rule; and to target agenda pushbackers. But there are other reasons which relate to what I am describing here. How many happy and joyful Wokers do you ever see especially at the extreme end? They are a mental and psychological mess consumed by emotional stress and constantly emotionally cocked for the next explosion of indignation at someone referring to a female as a female. They are walking, talking, batteries as Morpheus might say emitting frequencies which both enslave them in low-vibrational bubbles of perceptual limitation and feed the Archons. Add to this the hatred claimed to be love; fascism claimed to 'anti-fascism', racism claimed to be 'anti-racism';

exclusion claimed to inclusion; and the abuse-filled Internet trolling. You have a purpose-built Archontic energy system with not a wind turbine in sight and all founded on Archontic *inversion*. We have whole generations now manipulated to serve the Archons with their actions and energy. They will be doing so their entire adult lives unless they snap out of their Archon-induced trance. Is it really a surprise that Cult billionaires and corporations put so much money their way? Where is the energy of joy and laughter, including laughing at yourself which is confirmation of your own emotional security? Mark Twain said: 'The human race has one really effective weapon, and that is laughter.' We must use it all the time. Woke has destroyed comedy because it has no humour, no joy, sense of irony, or self-deprecation. Its energy is dense and intense. *Mmmmm*, lunch says the Archontic frequency. Rudolf Steiner (1861-1925) was the Austrian philosopher and famous esoteric thinker who established Waldorf education or Steiner schools to treat children like unique expressions of consciousness and not minds to be programmed with the perceptions determined by authority. I'd been writing about this energy vampiring for decades when I was sent in 2016 a quote by Steiner. He was spot on:

There are beings in the spiritual realms for whom anxiety and fear emanating from human beings offer welcome food. When humans have no anxiety and fear, then these creatures starve. If fear and anxiety radiates from people and they break out in panic, then these creatures find welcome nutrition and they become more and more powerful. These beings are hostile towards humanity. Everything that feeds on negative feelings, on anxiety, fear and superstition, despair or doubt, are in reality hostile forces in super-sensible worlds, launching cruel attacks on human beings, while they are being fed ... These are exactly the feelings that belong to contemporary culture and materialism; because it estranges people from the spiritual world, it is especially suited to evoke hopelessness and fear of the unknown in people, thereby calling up the above mentioned hostile forces against them.

Pause for a moment from this perspective and reflect on what has happened in the world since the start of 2020. Not only will pennies drop, but billion dollar bills. We see the same theme from Don Juan Matus, a Yaqui Indian shaman in Mexico and the information source for Peruvian-born writer, Carlos Castaneda, who wrote a series of

books from the 1960s to 1990s. Don Juan described the force manipulating human society and his name for the Archons was the predator:

We have a predator that came from the depths of the cosmos and took over the rule of our lives. Human beings are its prisoners. The predator is our lord and master. It has rendered us docile, helpless. If we want to protest, it suppresses our protest. If we want to act independently, it demands that we don't do so ... indeed we are held prisoner!

They took us over because we are food to them, and they squeeze us mercilessly because we are their sustenance. Just as we rear chickens in coops, the predators rear us in human coops, humaneros. Therefore, their food is always available to them.

Different cultures, different eras, same recurring theme.

The 'ennoia' dilemma

Nag Hammadi Gnostic manuscripts say that Archon consciousness has no 'ennoia'. This is directly translated as 'intentionality', but I'll use the term 'creative imagination'. The *All That Is* in awareness of itself is the source of all creativity – all possibility – and the more disconnected you are from that source the more you are subsequently denied 'creative imagination'. Given that Archon consciousness is almost entirely disconnected it severely lacks creativity and has to rely on far more mechanical processes of thought and exploit the creative potential of those that do have 'ennoia'. You can see cases of this throughout human society. Archon consciousness almost entirely dominates the global banking system and if we study how that system works you will appreciate what I mean. Banks manifest 'money' out of nothing by issuing lines of 'credit' which is 'money' that has never, does not, and will never exist except in theory. It's a confidence trick. If you think 'credit' figures-on-a-screen 'money' is worth anything you accept it as payment. If you don't then the whole system collapses through lack of confidence in the value of that 'money'. Archontic bankers with no 'ennoia' are 'lending' 'money' that doesn't exist to humans that *do* have creativity – those that have the inspired ideas and create businesses and products. Archon banking feeds off human creativity

which it controls through 'money' creation and debt. Humans have the creativity and Archons exploit that for their own benefit and control while having none themselves. Archon Internet platforms like Facebook claim joint copyright of everything that creative users post and while Archontic minds like Zuckerberg may officially head that company it will be human creatives on the staff that provide the creative inspiration. When you have limitless 'money' you can then buy other companies established by creative humans. Witness the acquisition record of Facebook, Google and their like. Survey the Archon-controlled music industry and you see non-creative dark suit executives making their fortune from the human creativity of their artists. The cases are endless. Research the history of people like Gates and Zuckerberg and how their empires were built on exploiting the creativity of others. Archon minds cannot create out of nothing, but they are skilled (because they have to be) in what Gnostic texts call 'countermimicry'. They can imitate, but not innovate. Sabbatians trawl the creativity of others through backdoors they install in computer systems through their cybersecurity systems. Archon-controlled China is globally infamous for stealing intellectual property and I remember how Hong Kong, now part of China, became notorious for making counterfeit copies of the creativity of others – 'countermimicry'. With the now pervasive and all-seeing surveillance systems able to infiltrate any computer you can appreciate the potential for Archons to vampire the creativity of humans. Author John Lamb Lash wrote in his book about the Nag Hammadi texts, *Not In His Image*:

Although they cannot originate anything, because they lack the divine factor of ennoia (intentionality), Archons can imitate with a vengeance. Their expertise is simulation (HAL, virtual reality). The Demiurge [Yaldabaoth] fashions a heaven world copied from the fractal patterns [of the original] ... His construction is celestial kitsch, like the fake Italianate villa of a Mafia don complete with militant angels to guard every portal.

This brings us to something that I have been speaking about since the turn of the millennium. Our reality is a simulation; a virtual reality that we think is real. No, I'm not kidding.

Human reality? Well, virtually

I had pondered for years about whether our reality is 'real' or some kind of construct. I remembered being immensely affected on a visit as a small child in the late 1950s to the then newly-opened Planetarium on the Marylebone Road in London which is now closed and part of the adjacent Madame Tussauds wax museum. It was in the middle of the day, but when the lights went out there was the night sky projected in the Planetarium's domed ceiling and it appeared to be so real. The experience never left me and I didn't know why until around the turn of the millennium when I became certain that our 'night sky' and entire reality is a projection, a virtual reality, akin to the illusory world portrayed in the *Matrix* movies. I looked at the sky one day in this period and it appeared to me like the domed roof of the Planetarium. The release of the first *Matrix* movie in 1999 also provided a synchronistic and perfect visual representation of where my mind had been going for a long time. I hadn't come across the Gnostic Nag Hammadi texts then. When I did years later the correlation was once again astounding. As I read Gnostic accounts from 1,600 years and more earlier it was clear that they were describing the same simulation phenomenon. They tell how the Yaldabaoth 'Demiurge' and Archons created a 'bad copy' of original reality to rule over all that were captured by its illusions and the body was a prison to trap consciousness in the 'bad copy' fake reality. Read how Gnostics describe the 'bad copy' and update that to current times and they are referring to what we would call today a virtual reality simulation.

Author John Lamb Lash said 'the Demiurge fashions a heaven world copied from the fractal patterns' of the original through expertise in 'HAL' or virtual reality simulation. Fractal patterns are part of the energetic information construct of our reality, a sort of blueprint. If these patterns were copied in computer terms it would indeed give you a copy of a 'natural' reality in a non-natural frequency and digital form. The principle is the same as making a copy of a website. The original website still exists, but now you can change the copy version to make it whatever you like and it can

become very different to the original website. Archons have done this with our reality, a *synthetic* copy of prime reality that still exists beyond the frequency walls of the simulation. Trapped within the illusions of this synthetic Matrix, however, were and are human consciousness and other expressions of prime reality and this is why the Archons via the Cult are seeking to make the human body synthetic and give us synthetic AI minds to complete the job of turning the entire reality synthetic including what we perceive to be the natural world. To quote Kurzweil: 'Nanobots will infuse all the matter around us with information. Rocks, trees, everything will become these intelligent creatures.' Yes, *synthetic* 'creatures' just as 'Covid' and other genetically-manipulating 'vaccines' are designed to make the human body synthetic. From this perspective it is obvious why Archons and their Cult are so desperate to infuse synthetic material into every human with their 'Covid' scam.

Let there be (electromagnetic) light

Yaldabaoth, the force that created the simulation, or Matrix, makes sense of the Gnostic reference to 'The Great Architect' and its use by Cult Freemasonry as the name of its deity. The designer of the Matrix in the movies is called 'The Architect' and that trilogy is jam-packed with symbolism relating to these subjects. I have contended for years that the angry Old Testament God (Yaldabaoth) is the 'God' being symbolically 'quoted' in the opening of Genesis as 'creating the world'. This is not the creation of prime reality – it's the creation of the *simulation*. The Genesis 'God' says: 'Let there be Light: and there was light.' But what is this 'Light'? I have said for decades that the speed of light (186,000 miles per second) is not the fastest speed possible as claimed by mainstream science and is in fact the frequency walls or outer limits of the Matrix. You can't have a fastest or slowest anything within all possibility when everything is possible. The human body is encoded to operate within the speed of light or *within the simulation* and thus we see only the tiny frequency band of visible *light*. Near-death experiencers who perceive reality outside the body during temporary 'death' describe a very different

form of light and this is supported by the Nag Hammadi texts. Prime reality beyond the simulation ('Upper Aeons' to the Gnostics) is described as a realm of incredible beauty, bliss, love and harmony – a realm of 'watery light' that is so powerful 'there are no shadows'. Our false reality of Archon control, which Gnostics call the 'Lower Aeons', is depicted as a realm with a different kind of 'light' and described in terms of chaos, 'Hell', 'the Abyss' and 'Outer Darkness', where trapped souls are tormented and manipulated by demons (relate that to the 'Covid' hoax alone). The watery light theme can be found in near-death accounts and it is not the same as *simulation* 'light' which is electromagnetic or radiation light within the speed of light – the 'Lower Aeons'. Simulation 'light' is the 'luminous fire' associated by Gnostics with the Archons. The Bible refers to Yaldabaoth as 'that old serpent, called the Devil, and Satan, which deceiveth the whole world' (Revelation 12:9). I think that making a simulated copy of prime reality ('countermimicry') and changing it dramatically while all the time manipulating humanity to believe it to be real could probably meet the criteria of deceiving the whole world. Then we come to the Cult god Lucifer – the *Light Bringer*. Lucifer is symbolic of Yaldabaoth, the bringer of radiation light that forms the bad copy simulation within the speed of light. 'He' is symbolised by the lighted torch held by the Statue of Liberty and in the name 'Illuminati'. Sabbatian-Frankism declares that Lucifer is the true god and Lucifer is the real god of Freemasonry honoured as their 'Great or Grand Architect of the Universe' (simulation).

I would emphasise, too, the way Archontic technologically-generated luminous fire of radiation has deluged our environment since I was a kid in the 1950s and changed the nature of The Field with which we constantly interact. Through that interaction technological radiation is changing us. The Smart Grid is designed to operate with immense levels of communication power with 5G expanding across the world and 6G, 7G, in the process of development. Radiation is the simulation and the Archontic manipulation system. Why wouldn't the Archon Cult wish to unleash radiation upon us to an ever-greater extreme to form

Kurzweil's 'cloud'? The plan for a synthetic human is related to the need to cope with levels of radiation beyond even anything we've seen so far. Biological humans would not survive the scale of radiation they have in their script. The Smart Grid is a technological sub-reality within the technological simulation to further disconnect five-sense perception from expanded consciousness. It's a technological prison of the mind.

Infusing the 'spirit of darkness'

A recurring theme in religion and native cultures is the manipulation of human genetics by a non-human force and most famously recorded as the biblical 'sons of god' (the gods plural in the original) who interbred with the daughters of men. The Nag Hammadi *Apocryphon of John* tells the same story this way:

He [Yaldabaoth] sent his angels [Archons/demons] to the daughters of men, that they might take some of them for themselves and raise offspring for their enjoyment. And at first they did not succeed. When they had no success, they gathered together again and they made a plan together ... And the angels changed themselves in their likeness into the likeness of their mates, filling them with the spirit of darkness, which they had mixed for them, and with evil ... And they took women and begot children out of the darkness according to the likeness of their spirit.

Possession when a discarnate entity takes over a human body is an age-old theme and continues today. It's very real and I've seen it. Satanic and secret society rituals can create an energetic environment in which entities can attach to initiates and I've heard many stories of how people have changed their personality after being initiated even into lower levels of the Freemasons. I have been inside three Freemasonic temples, one at a public open day and two by just walking in when there was no one around to stop me. They were in Ryde, the town where I live, Birmingham, England, when I was with a group, and Boston, Massachusetts. They all felt the same energetically – dark, dense, low-vibrational and sinister. Demonic attachment can happen while the initiate has no idea what is going on. To them it's just a ritual to get in the Masons and do a bit of good

business. In the far more extreme rituals of Satanism human possession is even more powerful and they are designed to make possession possible. The hierarchy of the Cult is dictated by the power and perceived status of the possessing Archon. In this way the Archon hierarchy becomes the Cult hierarchy. Once the entity has attached it can influence perception and behaviour and if it attaches to the extreme then so much of its energy (information) infuses into the body information field that the hologram starts to reflect the nature of the possessing entity. This is the *Exorcist* movie type of possession when facial features change and it's known as shapeshifting. Islam's Jinn are said to be invisible tricksters who change shape, 'whisper', confuse and take human form. These are all traits of the Archons and other versions of the same phenomenon. Extreme possession could certainly infuse the 'spirit of darkness' into a partner during sex as the Nag Hammadi texts appear to describe. Such an infusion can change genetics which is also energetic information. Human genetics is information and the 'spirit of darkness' is information. Mix one with the other and change must happen. Islam has the concept of a 'Jinn baby' through possession of the mother and by Jinn taking human form. There are many ways that human genetics can be changed and remember that Archons have been aware all along of advanced techniques to do this. What is being done in human society today – and far more – was known about by Archons at the time of the 'fallen ones' and their other versions described in religions and cultures.

Archons and their human-world Cult are obsessed with genetics as we see today and they know this dictates how information is processed into perceived reality during a human life. They needed to produce a human form that would decode the simulation and this is symbolically known as 'Adam and Eve' who left the 'garden' (prime reality) and 'fell' into Matrix reality. The simulation is not a 'physical' construct (there is no 'physical'); it is a source of information. Think Wi-Fi again. The simulation is an energetic field encoded with information and body-brain systems are designed to decode that information encoded in wave or frequency form which

is transmitted to the brain as electrical signals. These are decoded by the brain to construct our sense of reality – an illusory ‘physical’ world that only exists in the brain or the mind. Virtual reality games mimic this process using the same sensory decoding system. Information is fed to the senses to decode a virtual reality that can appear so real, but isn’t (Figs 18 and 19). Some scientists believe – and I agree with them – that what we perceive as ‘physical’ reality only exists when we are looking or observing. The act of perception or focus triggers the decoding systems which turn waveform information into holographic reality. When we are not observing something our reality reverts from a holographic state to a waveform state. This relates to the same principle as a falling tree not making a noise unless someone is there to hear it or decode it. The concept makes sense from the simulation perspective. A computer is not decoding all the information in a Wi-Fi field all the time and only decodes or brings into reality on the screen that part of Wi-Fi that it’s decoding – focusing upon – at that moment.



Figure 18: Virtual reality technology ‘hacks’ into the body’s five-sense decoding system.



Figure 19: The result can be experienced as very ‘real’.

Interestingly, Professor Donald Hoffman at the Department of Cognitive Sciences at the University of California, Irvine, says that our experienced reality is like a computer interface that shows us only the level with which we interact while hiding all that exists beyond it: 'Evolution shaped us with a user interface that hides the truth. Nothing that we see is the truth – the very language of space and time and objects is the wrong language to describe reality.' He is correct in what he says on so many levels. Space and time are not a universal reality. They are a phenomenon of decoded *simulation* reality as part of the process of enslaving our sense of reality. Near-death experiencers report again and again how space and time did not exist as we perceive them once they were free of the body – body decoding systems. You can appreciate from this why Archons and their Cult are so desperate to entrap human attention in the five senses where we are in the Matrix and of the Matrix. Opening your mind to expanded states of awareness takes you beyond the information confines of the simulation and you become aware of knowledge and insights denied to you before. This is what we call 'awakening' – *awakening from the Matrix* – and in the final chapter I will relate this to current events.

Where are the 'aliens'?

A simulation would explain the so-called 'Fermi Paradox' named after Italian physicist Enrico Fermi (1901-1954) who created the first nuclear reactor. He considered the question of why there is such a lack of extraterrestrial activity when there are so many stars and planets in an apparently vast universe; but what if the night sky that we see, or think we do, is a simulated projection as I say? If you control the simulation and your aim is to hold humanity fast in essential ignorance would you want other forms of life including advanced life coming and going sharing information with humanity? Or would you want them to believe they were isolated and apparently alone? Themes of human isolation and apartness are common whether they be the perception of a lifeless universe or the fascist isolation laws of the 'Covid' era. Paradoxically the very

existence of a simulation means that we are not alone when some force had to construct it. My view is that experiences that people have reported all over the world for centuries with Reptilians and Grey entities are Archon phenomena as Nag Hammadi texts describe; and that benevolent 'alien' interactions are non-human groups that come in and out of the simulation by overcoming Archon attempts to keep them out. It should be highlighted, too, that Reptilians and Greys are obsessed with *genetics* and *technology* as related by cultural accounts and those who say they have been abducted by them. Technology is their way of overcoming some of the limitations in their creative potential and our technology-driven and controlled human society of today is *archetypical* Archon-Reptilian-Grey *modus operandi*. Technocracy is really *Archontocracy*. The Universe does not have to be as big as it appears with a simulation. There is no space or distance only information decoded into holographic reality. What we call 'space' is only the absence of holographic 'objects' and that 'space' is The Field of energetic information which connects everything into a single whole. The same applies with the artificially-generated information field of the simulation. The Universe is not big or small as a physical reality. It is decoded information, that's all, and its perceived size is decided by the way the simulation is encoded to make it appear. The entire night sky as we perceive it only exists in our brain and so where are those 'millions of light years'? The 'stars' on the ceiling of the Planetarium looked a vast distance away.

There's another point to mention about 'aliens'. I have been highlighting since the 1990s the plan to stage a fake 'alien invasion' to justify the centralisation of global power and a world military. Nazi scientist Werner von Braun, who was taken to America by Operation Paperclip after World War Two to help found NASA, told his American assistant Dr Carol Rosin about the Cult agenda when he knew he was dying in 1977. Rosin said that he told her about a sequence that would lead to total human control by a one-world government. This included threats from terrorism, rogue nations, meteors and asteroids before finally an 'alien invasion'. All of these

things, von Braun said, would be bogus and what I would refer to as a No-Problem-Reaction-Solution. Keep this in mind when 'the aliens are coming' is the new mantra. The aliens are not coming – they are *already here* and they have infiltrated human society while looking human. French-Canadian investigative journalist Serge Monast said in 1994 that he had uncovered a NASA/military operation called Project Blue Beam which fits with what Werner von Braun predicted. Monast died of a 'heart attack' in 1996 the day after he was arrested and spent a night in prison. He was 51. He said Blue Beam was a plan to stage an alien invasion that would include religious figures beamed holographically into the sky as part of a global manipulation to usher in a 'new age' of worshipping what I would say is the Cult 'god' Yaldabaoth in a one-world religion. Fake holographic asteroids are also said to be part of the plan which again syncs with von Braun. How could you stage an illusory threat from asteroids unless they were holographic inserts? This is pretty straightforward given the advanced technology outside the public arena and the fact that our 'physical' reality is holographic anyway. Information fields would be projected and we would decode them into the illusion of a 'physical' asteroid. If they can sell a global 'pandemic' with a 'virus' that doesn't exist what will humans not believe if government and media tell them?

All this is particularly relevant as I write with the Pentagon planning to release in June, 2021, information about 'UFO sightings'. I have been following the UFO story since the early 1990s and the common theme throughout has been government and military denials and cover up. More recently, however, the Pentagon has suddenly become more talkative and apparently open with Air Force pilot radar images released of unexplained craft moving and changing direction at speeds well beyond anything believed possible with human technology. Then, in March, 2021, former Director of National Intelligence John Ratcliffe said a Pentagon report months later in June would reveal a great deal of information about UFO sightings unknown to the public. He said the report would have 'massive implications'. The order to do this was included bizarrely

in a \$2.3 trillion 'coronavirus' relief and government funding bill passed by the Trump administration at the end of 2020. I would add some serious notes of caution here. I have been pointing out since the 1990s that the US military and intelligence networks have long had craft – 'flying saucers' or anti-gravity craft – which any observer would take to be extraterrestrial in origin. Keeping this knowledge from the public allows craft flown by *humans* to be perceived as alien visitations. I am not saying that 'aliens' do not exist. I would be the last one to say that, but we have to be streetwise here. President Ronald Reagan told the UN General Assembly in 1987: 'I occasionally think how quickly our differences worldwide would vanish if we were facing an alien threat from outside this world.' That's the idea. Unite against a common 'enemy' with a common purpose behind your 'saviour force' (the Cult) as this age-old technique of mass manipulation goes global.

Science moves this way ...

I could find only one other person who was discussing the simulation hypothesis publicly when I concluded it was real. This was Nick Bostrom, a Swedish-born philosopher at the University of Oxford, who has explored for many years the possibility that human reality is a computer simulation although his version and mine are not the same. Today the simulation and holographic reality hypothesis have increasingly entered the scientific mainstream. Well, the more open-minded mainstream, that is. Here are a few of the ever-gathering examples. American nuclear physicist Silas Beane led a team of physicists at the University of Bonn in Germany pursuing the question of whether we live in a simulation. They concluded that we probably do and it was likely based on a lattice of cubes. They found that cosmic rays align with that specific pattern. The team highlighted the Greisen–Zatsepin–Kuzmin (GZK) limit which refers to cosmic ray particle interaction with cosmic background radiation that creates an apparent boundary for cosmic ray particles. They say in a paper entitled 'Constraints on the Universe as a Numerical Simulation' that this 'pattern of constraint' is exactly what you

would find with a computer simulation. They also made the point that a simulation would create its own 'laws of physics' that would limit possibility. I've been making the same point for decades that the *perceived* laws of physics relate only to this reality, or what I would later call the simulation. When designers write codes to create computer and virtual reality games they are the equivalent of the laws of physics for that game. Players interact within the limitations laid out by the coding. In the same way those who wrote the codes for the simulation decided the laws of physics that would apply. These can be overridden by expanded states of consciousness, but not by those enslaved in only five-sense awareness where simulation codes rule. Overriding the codes is what people call 'miracles'. They are not. They are bypassing the encoded limits of the simulation. A population caught in simulation perception would have no idea that this was their plight. As the Bonn paper said: 'Like a prisoner in a pitch-black cell we would not be able to see the "walls" of our prison,' That's true if people remain mesmerised by the five senses. Open to expanded awareness and those walls become very clear. The main one is the speed of light.

American theoretical physicist James Gates is another who has explored the simulation question and found considerable evidence to support the idea. Gates was Professor of Physics at the University of Maryland, Director of The Center for String and Particle Theory, and on Barack Obama's Council of Advisors on Science and Technology. He and his team found *computer codes* of digital data embedded in the fabric of our reality. They relate to on-off electrical charges of 1 and 0 in the binary system used by computers. 'We have no idea what they are doing there', Gates said. They found within the energetic fabric mathematical sequences known as error-correcting codes or block codes that 'reboot' data to its original state or 'default settings' when something knocks it out of sync. Gates was asked if he had found a set of equations embedded in our reality indistinguishable from those that drive search engines and browsers and he said: 'That is correct.' Rich Terrile, director of the Centre for Evolutionary Computation and Automated Design at NASA's Jet

Propulsion Laboratory, has said publicly that he believes the Universe is a digital hologram that must have been created by a form of intelligence. I agree with that in every way. Waveform information is delivered electrically by the senses to the brain which constructs a *digital* holographic reality that we call the 'world'. This digital level of reality can be read by the esoteric art of numerology. Digital holograms are at the cutting edge of holographics today. We have digital technology everywhere designed to access and manipulate our digital level of perceived reality. Synthetic mRNA in 'Covid vaccines' has a digital component to manipulate the body's digital 'operating system'.

Reality is numbers

How many know that our reality can be broken down to numbers and codes that are the same as computer games? Max Tegmark, a physicist at the Massachusetts Institute of Technology (MIT), is the author of *Our Mathematical Universe* in which he lays out how reality can be entirely described by numbers and maths in the way that a video game is encoded with the 'physics' of computer games. Our world and computer virtual reality are essentially the same.

Tegmark imagines the perceptions of characters in an advanced computer game when the graphics are so good they don't know they are in a game. They think they can bump into real objects (electromagnetic resistance in our reality), fall in love and feel emotions like excitement. When they began to study the apparently 'physical world' of the video game they would realise that everything was made of pixels (which have been found in our energetic reality as must be the case when on one level our world is digital). What computer game characters thought was physical 'stuff', Tegmark said, could actually be broken down into numbers:

And we're exactly in this situation in our world. We look around and it doesn't seem that mathematical at all, but everything we see is made out of elementary particles like quarks and electrons. And what properties does an electron have? Does it have a smell or a colour or a texture? No! ... We physicists have come up with geeky names for [Electron] properties, like

electric charge, or spin, or lepton number, but the electron doesn't care what we call it, the properties are just numbers.

This is the illusory reality Gnostics were describing. This is the simulation. The A, C, G, and T codes of DNA have a binary value – A and C = 0 while G and T = 1. This has to be when the simulation is digital and the body must be digital to interact with it. Recurring mathematical sequences are encoded throughout reality and the body. They include the Fibonacci sequence in which the two previous numbers are added to get the next one, as in ... 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, etc. The sequence is encoded in the human face and body, proportions of animals, DNA, seed heads, pine cones, trees, shells, spiral galaxies, hurricanes and the number of petals in a flower. The list goes on and on. There are fractal patterns – a 'never-ending pattern that is infinitely complex and self-similar across all scales in the as above, so below, principle of holograms. These and other famous recurring geometrical and mathematical sequences such as Phi, Pi, Golden Mean, Golden Ratio and Golden Section are *computer codes* of the simulation. I had to laugh and give my head a shake the day I finished this book and it went into the production stage. I was sent an article in *Scientific American* published in April, 2021, with the headline 'Confirmed! We Live in a Simulation'. Two decades after I first said our reality is a simulation and the speed of light is its outer limit the article suggested that we do live in a simulation and that the speed of light is its outer limit. I left school at 15 and never passed a major exam in my life while the writer was up to his eyes in qualifications. As I will explain in the final chapter *knowing* is far better than thinking and they come from very different sources. The article rightly connected the speed of light to the processing speed of the 'Matrix' and said what has been in my books all this time ... 'If we are in a simulation, as it appears, then space is an abstract property written in code. It is not real'. No it's not and if we live in a simulation something created it and it wasn't *us*. 'That David Icke says we are manipulated by aliens' – he's crackers.'

Wow ...

The reality that humanity thinks is so real is an illusion. Politicians, governments, scientists, doctors, academics, law enforcement, media, school and university curriculums, on and on, are all founded on a world that *does not exist* except as a simulated prison cell. Is it such a stretch to accept that 'Covid' doesn't exist when our entire 'physical' reality doesn't exist? Revealed here is the knowledge kept under raps in the Cult networks of compartmentalised secrecy to control humanity's sense of reality by inducing the population to believe in a reality that's not real. If it wasn't so tragic in its experiential consequences the whole thing would be hysterically funny. None of this is new to Renegade Minds. Ancient Greek philosopher Plato (about 428 to about 347BC) was a major influence on Gnostic belief and he described the human plight thousands of years ago with his Allegory of the Cave. He told the symbolic story of prisoners living in a cave who had never been outside. They were chained and could only see one wall of the cave while behind them was a fire that they could not see. Figures walked past the fire casting shadows on the prisoners' wall and those moving shadows became their sense of reality. Some prisoners began to study the shadows and were considered experts on them (today's academics and scientists), but what they studied was only an illusion (today's academics and scientists). A prisoner escaped from the cave and saw reality as it really is. When he returned to report this revelation they didn't believe him, called him mad and threatened to kill him if he tried to set them free. Plato's tale is not only a brilliant analogy of the human plight and our illusory reality. It describes, too, the dynamics of the 'Covid' hoax. I have only skimmed the surface of these subjects here. The aim of this book is to crisply connect all essential dots to put what is happening today into its true context. All subject areas and their connections in this chapter are covered in great evidential detail in *Everything You Need To Know, But Have Never Been Told* and *The Answer*.

They say that bewildered people 'can't see the forest for the trees'. Humanity, however, can't see the forest for the *twigs*. The five senses

see only twigs while Renegade Minds can see the forest and it's the forest where the answers lie with the connections that reveals.

Breaking free of perceptual programming so the forest can be seen is the way we turn all this around. Not breaking free is how humanity got into this mess. The situation may seem hopeless, but I promise you it's not. We are a perceptual heartbeat from paradise if only we knew.

CHAPTER TWELVE

Escaping Wetiko

Life is simply a vacation from the infinite
Dean Cavanagh

Renegade Minds weave the web of life and events and see common themes in the apparently random. They are always there if you look for them and their pursuit is aided by incredible synchronicity that comes when your mind is open rather than mesmerised by what it thinks it can see.

Infinite awareness is infinite possibility and the more of infinite possibility that we access the more becomes infinitely possible. That may be stating the apparently obvious, but it is a devastatingly-powerful fact that can set us free. We are a point of attention within an infinity of consciousness. The question is how much of that infinity do we choose to access? How much knowledge, insight, awareness, wisdom, do we want to connect with and explore? If your focus is only in the five senses you will be influenced by a fraction of infinite awareness. I mean a range so tiny that it gives new meaning to infinitesimal. Limitation of self-identity and a sense of the possible limit accordingly your range of consciousness. We are what we think we are. Life is what we think it is. The dream is the dreamer and the dreamer is the dream. Buddhist philosophy puts it this way: 'As a thing is viewed, so it appears.' Most humans live in the realm of touch, taste, see, hear, and smell and that's the limit of their sense of the possible and sense of self. Many will follow a religion and speak of a God in his heaven, but their lives are still

dominated by the five senses in their perceptions and actions. The five senses become the arbiter of everything. When that happens all except a smear of infinity is sealed away from influence by the rigid, unyielding, reality bubbles that are the five-sense human or Phantom Self. Archon Cult methodology is to isolate consciousness within five-sense reality – the simulation – and then program that consciousness with a sense of self and the world through a deluge of life-long information designed to instil the desired perception that allows global control. Efforts to do this have increased dramatically with identity politics as identity bubbles are squeezed into the minutiae of five-sense detail which disconnect people even more profoundly from the infinite 'I'.

Five-sense focus and self-identity are like a firewall that limits access to the infinite realms. You only perceive one radio or television station and no other. We'll take that literally for a moment. Imagine a vast array of stations giving different information and angles on reality, but you only ever listen to one. Here we have the human plight in which the population is overwhelmingly confined to CultFM. This relates only to the frequency range of CultFM and limits perception and insight to that band – limits *possibility* to that band. It means you are connecting with an almost imperceptibly minuscule range of possibility and creative potential within the infinite Field. It's a world where everything seems apart from everything else and where synchronicity is rare. Synchronicity is defined in the dictionary as 'the happening by chance of two or more related or similar events at the same time'. Use of 'by chance' betrays a complete misunderstanding of reality. Synchronicity is not 'by chance'. As people open their minds, or 'awaken' to use the term, they notice more and more coincidences in their lives, bits of 'luck', apparently miraculous happenings that put them in the right place at the right time with the right people. Days become peppered with 'fancy meeting you here' and 'what are the chances of that?' My entire life has been lived like this and ever more so since my own colossal awakening in 1990 and 91 which transformed my sense of reality. Synchronicity is not 'by chance'; it is by accessing expanded

realms of possibility which allow expanded potential for manifestation. People broadcasting the same vibe from the same openness of mind tend to be drawn 'by chance' to each other through what I call frequency magnetism and it's not only people. In the last more than 30 years incredible synchronicity has also led me through the Cult maze to information in so many forms and to crucial personal experiences. These 'coincidences' have allowed me to put the puzzle pieces together across an enormous array of subjects and situations. Those who have breached the bubble of five-sense reality will know exactly what I mean and this escape from the perceptual prison cell is open to everyone whenever they make that choice. This may appear super-human when compared with the limitations of 'human', but it's really our natural state. 'Human' as currently experienced is consciousness in an unnatural state of induced separation from the infinity of the whole. I'll come to how this transformation into unity can be made when I have described in more detail the force that holds humanity in servitude by denying this access to infinite self.

The Wetiko factor

I have been talking and writing for decades about the way five-sense mind is systematically barricaded from expanded awareness. I have used the analogy of a computer (five-sense mind) and someone at the keyboard (expanded awareness). Interaction between the computer and the operator is symbolic of the interaction between five-sense mind and expanded awareness. The computer directly experiences the Internet and the operator experiences the Internet via the computer which is how it's supposed to be – the two working as one. Archons seek to control that point where the operator connects with the computer to stop that interaction ([Fig 20](#)). Now the operator is banging the keyboard and clicking the mouse, but the computer is not responding and this happens when the computer is taken over – *possessed* – by an appropriately-named computer 'virus'. The operator has lost all influence over the computer which goes its own way making decisions under the control of the 'virus'. I have

just described the dynamic through which the force known to Gnostics as Yaldabaoth and Archons disconnects five-sense mind from expanded awareness to imprison humanity in perceptual servitude.

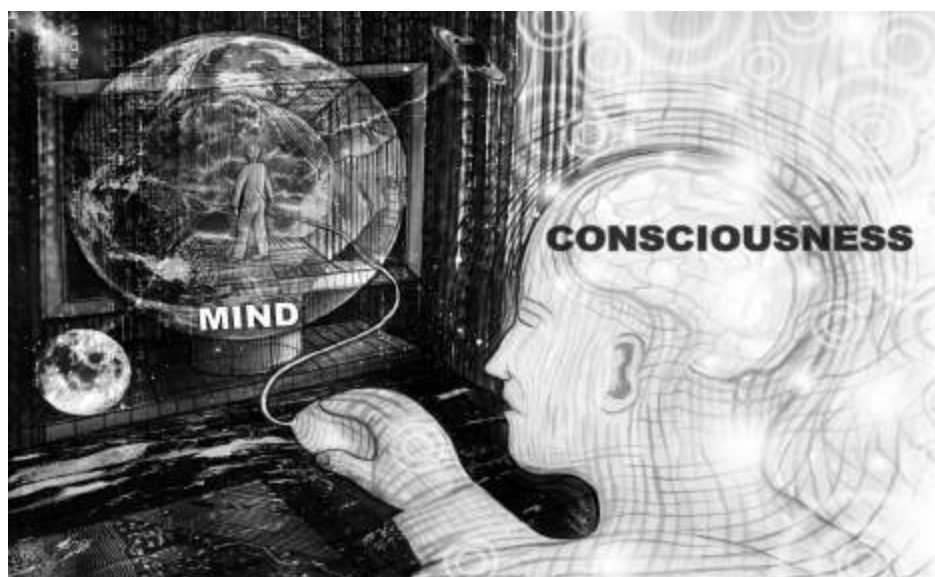


Figure 20: The mind ‘virus’ I have been writing about for decades seeks to isolate five-sense mind (the computer) from the true ‘I’. (Image by Neil Hague).

About a year ago I came across a Native American concept of Wetiko which describes precisely the same phenomenon. Wetiko is the spelling used by the Cree and there are other versions including wintiko and windigo used by other tribal groups. They spell the name with lower case, but I see Wetiko as a proper noun as with Archons and prefer a capital. I first saw an article about Wetiko by writer and researcher Paul Levy which so synced with what I had been writing about the computer/operator disconnection and later the Archons. I then read his book, the fascinating *Dispelling Wetiko, Breaking the Spell of Evil*. The parallels between what I had concluded long before and the Native American concept of Wetiko were so clear and obvious that it was almost funny. For Wetiko see the Gnostic Archons for sure and the Jinn, the Predators, and every other name for a force of evil, inversion and chaos. Wetiko is the Native American name for the force that divides the computer from

the operator (Fig 21). Indigenous author Jack D. Forbes, a founder of the Native American movement in the 1960s, wrote another book about Wetiko entitled *Columbus And Other Cannibals – The Wetiko Disease of Exploitation, Imperialism, and Terrorism* which I also read. Forbes says that Wetiko refers to an evil person or spirit ‘who terrorizes other creatures by means of terrible acts, including cannibalism’. Zulu shaman Credo Mutwa told me that African accounts tell how cannibalism was brought into the world by the Chitauri ‘gods’ – another manifestation of Wetiko. The distinction between ‘evil person or spirit’ relates to Archons/Wetiko possessing a human or acting as pure consciousness. Wetiko is said to be a sickness of the soul or spirit and a state of being that takes but gives nothing back – the Cult and its operatives perfectly described. Black Hawk, a Native American war leader defending their lands from confiscation, said European invaders had ‘poisoned hearts’ – Wetiko hearts – and that this would spread to native societies. Mention of the heart is very significant as we shall shortly see. Forbes writes: ‘Tragically, the history of the world for the past 2,000 years is, in great part, the story of the epidemiology of the wetiko disease.’ Yes, and much longer. Forbes is correct when he says: ‘The wetikos destroyed Egypt and Babylon and Athens and Rome and Tenochtitlan [capital of the Aztec empire] and perhaps now they will destroy the entire earth.’ Evil, he said, is the number one export of a Wetiko culture – see its globalisation with ‘Covid’. Constant war, mass murder, suffering of all kinds, child abuse, Satanism, torture and human sacrifice are all expressions of Wetiko and the Wetiko possessed. The world is Wetiko made manifest, *but it doesn’t have to be*. There is a way out of this even now.



Figure 21: The mind 'virus' is known to Native Americans as 'Wetiko'. (Image by Neil Hague).

Cult of Wetiko

Wetiko is the Yaldabaoth frequency distortion that seeks to attach to human consciousness and absorb it into its own. Once this connection is made Wetiko can drive the perceptions of the target which they believe to be coming from their own mind. All the horrors of history and today from mass killers to Satanists, paedophiles like Jeffrey Epstein and other psychopaths, are the embodiment of Wetiko and express its state of being in all its grotesqueness. The Cult is Wetiko incarnate, Yaldabaoth incarnate, and it seeks to facilitate Wetiko assimilation of humanity in totality into its distortion by manipulating the population into low frequency states that match its own. Paul Levy writes:

'Holographically enforced within the psyche of every human being the wetiko virus pervades and underlies the entire field of consciousness, and can therefore potentially manifest through any one of us at any moment if we are not mindful.' The 'Covid' hoax has achieved this with many people, but others have not fallen into Wetiko's frequency lair. Players in the 'Covid' human catastrophe including Gates, Schwab, Tedros, Fauci, Whitty, Vallance, Johnson, Hancock, Ferguson, Drosten, and all the rest, including the psychopath psychologists, are expressions of Wetiko. This is why

they have no compassion or empathy and no emotional consequence for what they do that would make them stop doing it. Observe all the people who support the psychopaths in authority against the Pushbackers despite the damaging impact the psychopaths have on their own lives and their family's lives. You are again looking at Wetiko possession which prevents them seeing through the lies to the obvious scam going on. *Why can't they see it?* Wetiko won't let them see it. The perceptual divide that has now become a chasm is between the Wetikoed and the non-Wetikoed.

Paul Levy describes Wetiko in the same way that I have long described the Archontic force. They are the same distorted consciousness operating across dimensions of reality: '... the subtle body of wetiko is not located in the third dimension of space and time, literally existing in another dimension ... it is able to affect ordinary lives by mysteriously interpenetrating into our three-dimensional world.' Wetiko does this through its incarnate representatives in the Cult and by weaving itself into The Field which on our level of reality is the electromagnetic information field of the simulation or Matrix. More than that, the simulation *is* Wetiko / Yaldabaoth. Caleb Scharf, Director of Astrobiology at Columbia University, has speculated that 'alien life' could be so advanced that it has transcribed itself into the quantum realm to become what we call physics. He said intelligence indistinguishable from the fabric of the Universe would solve many of its greatest mysteries:

Perhaps hyper-advanced life isn't just external. Perhaps it's already all around. It is embedded in what we perceive to be physics itself, from the root behaviour of particles and fields to the phenomena of complexity and emergence ... In other words, life might not just be in the equations. It might BE the equations [My emphasis].

Scharf said it is possible that 'we don't recognise advanced life because it forms an integral and unsuspecting part of what we've considered to be the natural world'. I agree. Wetiko/Yaldabaoth *is* the simulation. We are literally in the body of the beast. But that doesn't mean it has to control us. We all have the power to overcome Wetiko

influence and the Cult knows that. I doubt it sleeps too well because it knows that.

Which Field?

This, I suggest, is how it all works. There are two Fields. One is the fierce electromagnetic light of the Matrix within the speed of light; the other is the 'watery light' of The Field beyond the walls of the Matrix that connects with the Great Infinity. Five-sense mind and the decoding systems of the body attach us to the Field of Matrix light. They have to or we could not experience this reality. Five-sense mind sees only the Matrix Field of information while our expanded consciousness is part of the Infinity Field. When we open our minds, and most importantly our hearts, to the Infinity Field we have a mission control which gives us an expanded perspective, a road map, to understand the nature of the five-sense world. If we are isolated only in five-sense mind there is no mission control. We're on our own trying to understand a world that's constantly feeding us information to ensure we do not understand. People in this state can feel 'lost' and bewildered with no direction or radar. You can see ever more clearly those who are influenced by the Fields of Big Infinity or little five-sense mind simply by their views and behaviour with regard to the 'Covid' hoax. We have had this division throughout known human history with the mass of the people on one side and individuals who could see and intuit beyond the walls of the simulation – Plato's prisoner who broke out of the cave and saw reality for what it is. Such people have always been targeted by Wetiko/Archon-possessed authority, burned at the stake or demonised as mad, bad and dangerous. The Cult today and its global network of 'anti-hate', 'anti-fascist' Woke groups are all expressions of Wetiko attacking those exposing the conspiracy, 'Covid' lies and the 'vaccine' agenda.

Woke as a whole is Wetiko which explains its black and white mentality and how at one it is with the Wetiko-possessed Cult. Paul Levy said: 'To be in this paradigm is to still be under the thrall of a two-valued logic – where things are either true or false – of a

wetikoized mind.’ Wetiko consciousness is in a permanent rage, therefore so is Woke, and then there is Woke inversion and contradiction. ‘Anti-fascists’ act like fascists because fascists *and* ‘anti-fascists’ are both Wetiko at work. Political parties act the same while claiming to be different for the same reason. Secret society and satanic rituals are attaching initiates to Wetiko and the cold, ruthless, psychopathic mentality that secures the positions of power all over the world is Wetiko. Reframing ‘training programmes’ have the same cumulative effect of attaching Wetiko and we have their graduates described as automatons and robots with a cold, psychopathic, uncaring demeanour. They are all traits of Wetiko possession and look how many times they have been described in this book and elsewhere with regard to personnel behind ‘Covid’ including the police and medical profession. Climbing the greasy pole in any profession in a Wetiko society requires traits of Wetiko to get there and that is particularly true of politics which is not about fair competition and pre-eminence of ideas. It is founded on how many backs you can stab and arses you can lick. This culminated in the global ‘Covid’ coordination between the Wetiko possessed who pulled it off in all the different countries without a trace of empathy and compassion for their impact on humans. Our sight sense can see only holographic form and not the Field which connects holographic form. Therefore we perceive ‘physical’ objects with ‘space’ in between. In fact that ‘space’ is energy/consciousness operating on multiple frequencies. One of them is Wetiko and that connects the Cult psychopaths, those who submit to the psychopaths, and those who serve the psychopaths in the media operations of the world. Wetiko is Gates. Wetiko is the mask-wearing submissive. Wetiko is the fake journalist and ‘fact-checker’. The Wetiko Field is coordinating the whole thing. Psychopaths, gofers, media operatives, ‘anti-hate’ hate groups, ‘fact-checkers’ and submissive people work as one unit *even without human coordination* because they are attached to the *same* Field which is organising it all ([Fig 22](#)). Paul Levy is here describing how Wetiko-possessed people are drawn together and refuse to let any information breach their rigid

perceptions. He was writing long before 'Covid', but I think you will recognise followers of the 'Covid' religion *oh just a little bit*:

People who are channelling the vibratory frequency of wetiko align with each other through psychic resonance to reinforce their unspoken shared agreement so as to uphold their deranged view of reality. Once an unconscious content takes possession of certain individuals, it irresistibly draws them together by mutual attraction and knits them into groups tied together by their shared madness that can easily swell into an avalanche of insanity.

A psychic epidemic is a closed system, which is to say that it is insular and not open to any new information or informing influences from the outside world which contradict its fixed, limited, and limiting perspective.

There we have the Woke mind and the 'Covid' mind. Compatible resonance draws the awakening together, too, which is clearly happening today.

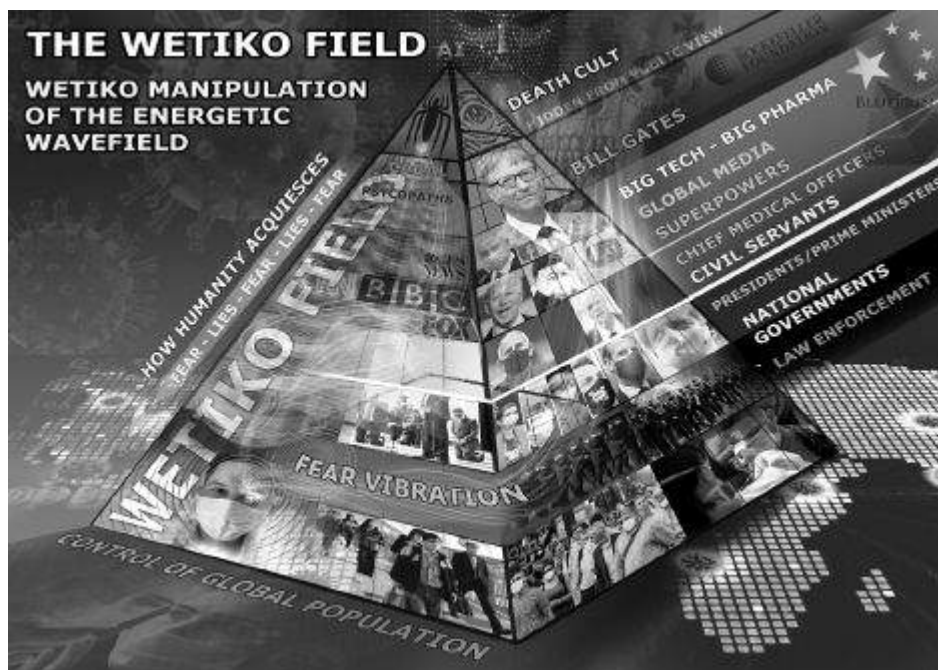


Figure 22: The Wetiko Field from which the Cult pyramid and its personnel are made manifest. (Image by Neil Hague).

Spiritual servitude

Wetiko doesn't care about humans. It's not human; it just possesses humans for its own ends and the effect (depending on the scale of

possession) can be anything from extreme psychopathy to unquestioning obedience. Wetiko's worst nightmare is for human consciousness to expand beyond the simulation. Everything is focussed on stopping that happening through control of information, thus perception, thus frequency. The 'education system', media, science, medicine, academia, are all geared to maintaining humanity in five-sense servitude as is the constant stimulation of low-vibrational mental and emotional states (see 'Covid'). Wetiko seeks to dominate those subconscious spaces between five-sense perception and expanded consciousness where the computer meets the operator. From these subconscious hiding places Wetiko speaks to us to trigger urges and desires that we take to be our own and manipulate us into anything from low-vibrational to psychopathic states. Remember how Islam describes the Jinn as invisible tricksters that 'whisper' and confuse. Wetiko is the origin of the 'trickster god' theme that you find in cultures all over the world. Jinn, like the Archons, are Wetiko which is terrified of humans awakening and reconnecting with our true self for then its energy source has gone. With that the feedback loop breaks between Wetiko and human perception that provides the energetic momentum on which its very existence depends as a force of evil. Humans are both its target and its source of survival, but only if we are operating in low-vibrational states of fear, hate, depression and the background anxiety that most people suffer. We are Wetiko's target because we are its key to survival. It needs us, not the other way round. Paul Levy writes:

A vampire has no intrinsic, independent, substantial existence in its own right; it only exists in relation to us. The pathogenic, vampiric mind-parasite called wetiko is nothing in itself – not being able to exist from its own side – yet it has a 'virtual reality' such that it can potentially destroy our species ...

...The fact that a vampire is not reflected by a mirror can also mean that what we need to see is that there's nothing, no-thing to see, other than ourselves. The fact that wetiko is the expression of something inside of us means that the cure for wetiko is with us as well. The critical issue is finding this cure within us and then putting it into effect.

Evil begets evil because if evil does not constantly expand and find new sources of energetic sustenance its evil, its *distortion*, dies with the assimilation into balance and harmony. Love is the garlic to Wetiko's vampire. Evil, the absence of love, cannot exist in the presence of love. I think I see a way out of here. I have emphasised so many times over the decades that the Archons/Wetiko and their Cult are not all powerful. *They are not*. I don't care how it looks even now *they are not*. I have not called them little boys in short trousers for effect. I have said it because it is true. Wetiko's insatiable desire for power over others is not a sign of its omnipotence, but its insecurity. Paul Levy writes: 'Due to the primal fear which ultimately drives it and which it is driven to cultivate, wetiko's body politic has an intrinsic and insistent need for centralising power and control so as to create imagined safety for itself.' Yeeeeees! Exactly! Why does Wetiko want humans in an ongoing state of fear? Wetiko itself *is* fear and it is petrified of love. As evil is an absence of love, so love is an absence of fear. Love conquers all and *especially* Wetiko which *is* fear. Wetiko brought fear into the world when it wasn't here before. *Fear* was the 'fall', the fall into low-frequency ignorance and illusion – fear is **False Emotion Appearing Real**. The simulation is driven and energised by fear because Wetiko/Yaldabaoth (fear) *are* the simulation. Fear is the absence of love and Wetiko is the absence of love.

Wetiko today

We can now view current events from this level of perspective. The 'Covid' hoax has generated momentous amounts of ongoing fear, anxiety, depression and despair which have empowered Wetiko. No wonder people like Gates have been the instigators when they are Wetiko incarnate and exhibit every trait of Wetiko in the extreme. See how cold and unemotional these people are like Gates and his cronies, how dead of eye they are. That's Wetiko. Sabbatians are Wetiko and everything they control including the World Health Organization, Big Pharma and the 'vaccine' makers, national 'health'

hierarchies, corporate media, Silicon Valley, the banking system, and the United Nations with its planned transformation into world government. All are controlled and possessed by the Wetiko distortion into distorting human society in its image. We are with this knowledge at the gateway to understanding the world. Divisions of race, culture, creed and sexuality are diversions to hide the real division between those possessed and influenced by Wetiko and those that are not. The 'Covid' hoax has brought both clearly into view. Human behaviour is not about race. Tyrants and dictatorships come in all colours and creeds. What unites the US president bombing the innocent and an African tribe committing genocide against another as in Rwanda? What unites them? *Wetiko*. All wars are Wetiko, all genocide is Wetiko, all hunger over centuries in a world of plenty is Wetiko. Children going to bed hungry, including in the West, is Wetiko. Cult-generated Woke racial divisions that focus on the body are designed to obscure the reality that divisions in behaviour are manifestations of mind, not body. Obsession with body identity and group judgement is a means to divert attention from the real source of behaviour – mind and perception. Conflict sown by the Woke both within themselves and with their target groups are Wetiko providing lunch for itself through still more agents of the division, chaos, and fear on which it feeds. The Cult is seeking to assimilate the entirety of humanity and all children and young people into the Wetiko frequency by manipulating them into states of fear and despair. Witness all the suicide and psychological unravelling since the spring of 2020. Wetiko psychopaths want to impose a state of unquestioning obedience to authority which is no more than a conduit for Wetiko to enforce its will and assimilate humanity into itself. It needs us to believe that resistance is futile when it fears resistance and even more so the game-changing non-cooperation with its impositions. It can use violent resistance for its benefit. Violent impositions and violent resistance are *both* Wetiko. The Power of Love with its Power of No will sweep Wetiko from our world. Wetiko and its Cult know that. They just don't want us to know.

AI Wetiko

This brings me to AI or artificial intelligence and something else Wetikos don't want us to know. What is AI *really*? I know about computer code algorithms and AI that learns from data input. These, however, are more diversions, the expeditionary force, for the real AI that they want to connect to the human brain as promoted by Silicon Valley Wetikos like Kurzweil. What is this AI? It is the frequency of *Wetiko*, the frequency of the Archons. The connection of AI to the human brain is the connection of the Wetiko frequency to create a Wetiko hive mind and complete the job of assimilation. The hive mind is planned to be controlled from Israel and China which are both 100 percent owned by Wetiko Sabbatians. The assimilation process has been going on minute by minute in the 'smart' era which fused with the 'Covid' era. We are told that social media is scrambling the minds of the young and changing their personality. This is true, but what is social media? Look more deeply at how it works, how it creates divisions and conflict, the hostility and cruelty, the targeting of people until they are destroyed. That's Wetiko. Social media is manipulated to tune people to the Wetiko frequency with all the emotional exploitation tricks employed by platforms like Facebook and its Wetiko front man, Zuckerberg. Facebook's Instagram announced a new platform for children to overcome a legal bar on them using the main site. This is more Wetiko exploitation and manipulation of kids. Amnesty International likened the plan to foxes offering to guard the henhouse and said it was incompatible with human rights. Since when did Wetiko or Zuckerberg (I repeat myself) care about that? Would Brin and Page at Google, Wojcicki at YouTube, Bezos at Amazon and whoever the hell runs Twitter act as they do if they were not channelling Wetiko? Would those who are developing technologies for no other reason than human control? How about those designing and selling technologies to kill people and Big Pharma drug and 'vaccine' producers who know they will end or devastate lives? Quite a thought for these people to consider is that if you are Wetiko in a human life you are Wetiko on the 'other side' unless your frequency

changes and that can only change by a change of perception which becomes a change of behaviour. Where Gates is going does not bear thinking about although perhaps that's exactly where he wants to go. Either way, that's where he's going. His frequency will make it so.

The frequency lair

I have been saying for a long time that a big part of the addiction to smartphones and devices is that a frequency is coming off them that entraps the mind. People spend ages on their phones and sometimes even a minute or so after they put them down they pick them up again and it all repeats. 'Covid' lockdowns will have increased this addiction a million times for obvious reasons. Addictions to alcohol overindulgence and drugs are another way that Wetiko entraps consciousness to attach to its own. Both are symptoms of low-vibrational psychological distress which alcoholism and drug addiction further compound. Do we think it's really a coincidence that access to them is made so easy while potions that can take people into realms beyond the simulation are banned and illegal? I have explored smartphone addiction in other books, the scale is mind-blowing, and that level of addiction does not come without help. Tech companies that make these phones are Wetiko and they will have no qualms about destroying the minds of children. We are seeing again with these companies the Wetiko perceptual combination of psychopathic enforcers and weak and meek unquestioning compliance by the rank and file.

The global Smart Grid is the Wetiko Grid and it is crucial to complete the Cult endgame. The simulation is radiation and we are being deluged with technological radiation on a devastating scale. Wetiko frauds like Elon Musk serve Cult interests while occasionally criticising them to maintain his street-cred. 5G and other forms of Wi-Fi are being directed at the earth from space on a volume and scale that goes on increasing by the day. Elon Musk's (officially) SpaceX Starlink project is in the process of putting tens of thousands of satellites in low orbit to cover every inch of the planet with 5G and other Wi-Fi to create Kurzweil's global 'cloud' to which the

human mind is planned to be attached very soon. SpaceX has approval to operate 12,000 satellites with more than 1,300 launched at the time of writing and applications filed for 30,000 more. Other operators in the Wi-Fi, 5G, low-orbit satellite market include OneWeb (UK), Telesat (Canada), and AST & Science (US). Musk tells us that AI could be the end of humanity and then launches a company called Neuralink to connect the human brain to computers. Musk's (in theory) Tesla company is building electric cars and the driverless vehicles of the smart control grid. As frauds and bullshitters go Elon Musk in my opinion is Major League.

5G and technological radiation in general are destructive to human health, genetics and psychology and increasing the strength of artificial radiation underpins the five-sense perceptual bubbles which are themselves expressions of radiation or electromagnetism. Freedom activist John Whitehead was so right with his 'databit by databit, we are building our own electronic concentration camps'. The Smart Grid and 5G is a means to control the human mind and infuse perceptual information into The Field to influence anyone in sync with its frequency. You can change perception and behaviour en masse if you can manipulate the population into those levels of frequency and this is happening all around us today. The arrogance of Musk and his fellow Cult operatives knows no bounds in the way that we see with Gates. Musk's satellites are so many in number already they are changing the night sky when viewed from Earth. The astronomy community has complained about this and they have seen nothing yet. Some consequences of Musk's Wetiko hubris include: Radiation; visible pollution of the night sky; interference with astronomy and meteorology; ground and water pollution from intensive use of increasingly many spaceports; accumulating space debris; continual deorbiting and burning up of aging satellites, polluting the atmosphere with toxic dust and smoke; and ever-increasing likelihood of collisions. A collective public open letter of complaint to Musk said:

We are writing to you ... because SpaceX is in process of surrounding the Earth with a network of thousands of satellites whose very purpose is to irradiate every square inch of the

Earth. SpaceX, like everyone else, is treating the radiation as if it were not there. As if the mitochondria in our cells do not depend on electrons moving undisturbed from the food we digest to the oxygen we breathe.

As if our nervous systems and our hearts are not subject to radio frequency interference like any piece of electronic equipment. As if the cancer, diabetes, and heart disease that now afflict a majority of the Earth's population are not metabolic diseases that result from interference with our cellular machinery. As if insects everywhere, and the birds and animals that eat them, are not starving to death as a result.

People like Musk and Gates believe in their limitless Wetiko arrogance that they can do whatever they like to the world because they own it. Consequences for humanity are irrelevant. It's absolutely time that we stopped taking this shit from these self-styled masters of the Earth when you consider where this is going.

Why is the Cult so anti-human?

I hear this question often: Why would they do this when it will affect them, too? Ah, but will it? Who is this *them*? Forget their bodies. They are just vehicles for Wetiko consciousness. When you break it all down to the foundations we are looking at a state of severely distorted consciousness targeting another state of consciousness for assimilation. The rest is detail. The simulation is the fly-trap in which unique sensations of the five senses create a cycle of addiction called reincarnation. Renegade Minds see that everything which happens in our reality is a smaller version of the whole picture in line with the holographic principle. Addiction to the radiation of smart technology is a smaller version of addiction to the whole simulation. Connecting the body/brain to AI is taking that addiction on a giant step further to total ongoing control by assimilating human incarnate consciousness into Wetiko. I have watched during the 'Covid' hoax how many are becoming ever more profoundly attached to Wetiko's perceptual calling cards of aggressive response to any other point of view ('There is no other god but me'), psychopathic lack of compassion and empathy, and servile submission to the narrative and will of authority. Wetiko is the psychopaths *and* subservience to psychopaths. The Cult of Wetiko is

so anti-human because it is *not* human. It embarked on a mission to destroy human by targeting everything that it means to be human and to survive as human. 'Covid' is not the end, just a means to an end. The Cult with its Wetiko consciousness is seeking to change Earth systems, including the atmosphere, to suit them, not humans. The gathering bombardment of 5G alone from ground and space is dramatically changing The Field with which the five senses interact. There is so much more to come if we sit on our hands and hope it will all go away. It is not meant to go away. It is meant to get ever more extreme and we need to face that while we still can – just.

Carbon dioxide is the gas of life. Without that human is over. Kaput, gone, history. No natural world, no human. The Cult has created a cock and bull story about carbon dioxide and climate change to justify its reduction to the point where Gates and the ignoramus Biden 'climate chief' John Kerry want to suck it out of the atmosphere. Kerry wants to do this because his master Gates does. Wetikos have made the gas of life a demon with the usual support from the Wokers of Extinction Rebellion and similar organisations and the bewildered puppet-child that is Greta Thunberg who was put on the world stage by Klaus Schwab and the World Economic Forum. The name Extinction Rebellion is both ironic and as always Wetiko inversion. The gas that we need to survive must be reduced to save us from extinction. The most basic need of human is oxygen and we now have billions walking around in face nappies depriving body and brain of this essential requirement of human existence. More than that 5G at 60 gigahertz interacts with the oxygen molecule to reduce the amount of oxygen the body can absorb into the bloodstream. The obvious knock-on consequences of that for respiratory and cognitive problems and life itself need no further explanation. Psychopaths like Musk are assembling a global system of satellites to deluge the human atmosphere with this insanity. The man should be in jail. Here we have two most basic of human needs, oxygen and carbon dioxide, being dismantled.

Two others, water and food, are getting similar treatment with the United Nations Agendas 21 and 2030 – the Great Reset – planning to

centrally control all water and food supplies. People will not even own rain water that falls on their land. Food is affected at the most basic level by reducing carbon dioxide. We have genetic modification or GMO infiltrating the food chain on a mass scale, pesticides and herbicides polluting the air and destroying the soil. Freshwater fish that provide livelihoods for 60 million people and feed hundreds of millions worldwide are being 'pushed to the brink' according the conservationists while climate change is the only focus. Now we have Gates and Schwab wanting to dispense with current food sources all together and replace them with a synthetic version which the Wetiko Cult would control in terms of production and who eats and who doesn't. We have been on the Totalitarian Tiptoe to this for more than 60 years as food has become ever more processed and full of chemical shite to the point today when it's not natural food at all. As Dr Tom Cowan says: 'If it has a label don't eat it.' Bill Gates is now the biggest owner of farmland in the United States and he does nothing without an ulterior motive involving the Cult. Klaus Schwab wrote: 'To feed the world in the next 50 years we will need to produce as much food as was produced in the last 10,000 years ... food security will only be achieved, however, if regulations on genetically modified foods are adapted to reflect the reality that gene editing offers a precise, efficient and safe method of improving crops.' Liar. People and the world are being targeted with aluminium through vaccines, chemtrails, food, drink cans, and endless other sources when aluminium has been linked to many health issues including dementia which is increasing year after year. Insects, bees and wildlife essential to the food chain are being deleted by pesticides, herbicides and radiation which 5G is dramatically increasing with 6G and 7G to come. The pollinating bee population is being devastated while wildlife including birds, dolphins and whales are having their natural radar blocked by the effects of ever-increasing radiation. In the summer windscreens used to be splattered with insects so numerous were they. It doesn't happen now. Where have they gone?

Synthetic everything

The Cult is introducing genetically-modified versions of trees, plants and insects including a Gates-funded project to unleash hundreds of millions of genetically-modified, lab-altered and patented male mosquitoes to mate with wild mosquitoes and induce genetic flaws that cause them to die out. Clinically-insane Gates-funded Japanese researchers have developed mosquitos that spread vaccine and are dubbed 'flying vaccinators'. Gates is funding the modification of weather patterns in part to sell the myth that this is caused by carbon dioxide and he's funding geoengineering of the skies to change the atmosphere. Some of this came to light with the Gates-backed plan to release tonnes of chalk into the atmosphere to 'deflect the Sun and cool the planet'. Funny how they do this while the heating effect of the Sun is not factored into climate projections focussed on carbon dioxide. The reason is that they want to reduce carbon dioxide (so don't mention the Sun), but at the same time they do want to reduce the impact of the Sun which is so essential to human life and health. I have mentioned the sun-cholesterol-vitamin D connection as they demonise the Sun with warnings about skin cancer (caused by the chemicals in sun cream they tell you to splash on). They come from the other end of the process with statin drugs to reduce cholesterol that turns sunlight into vitamin D. A lack of vitamin D leads to a long list of health effects and how vitamin D levels must have fallen with people confined to their homes over 'Covid'. Gates is funding other forms of geoengineering and most importantly chemtrails which are dropping heavy metals, aluminium and self-replicating nanotechnology onto the Earth which is killing the natural world. See *Everything You Need To Know, But Have Never Been Told* for the detailed background to this.

Every human system is being targeted for deletion by a force that's not human. The Wetiko Cult has embarked on the process of transforming the human body from biological to synthetic biological as I have explained. Biological is being replaced by the artificial and synthetic – Archontic 'countermimicry' – right across human society. The plan eventually is to dispense with the human body altogether

and absorb human consciousness – which it wouldn't really be by then – into cyberspace (the simulation which is Wetiko/Yaldabaoth). Preparations for that are already happening if people would care to look. The alternative media rightly warns about globalism and 'the globalists', but this is far bigger than that and represents the end of the human race as we know it. The 'bad copy' of prime reality that Gnostics describe was a bad copy of harmony, wonder and beauty to start with before Wetiko/Yaldabaoth set out to change the simulated 'copy' into something very different. The process was slow to start with. Entrapped humans in the simulation timeline were not technologically aware and they had to be brought up to intellectual speed while being suppressed spiritually to the point where they could build their own prison while having no idea they were doing so. We have now reached that stage where technological intellect has the potential to destroy us and that's why events are moving so fast. Central American shaman Don Juan Matus said:

Think for a moment, and tell me how you would explain the contradictions between the intelligence of man the engineer and the stupidity of his systems of belief, or the stupidity of his contradictory behaviour. Sorcerers believe that the predators have given us our systems of beliefs, our ideas of good and evil; our social mores. They are the ones who set up our dreams of success or failure. They have given us covetousness, greed, and cowardice. It is the predator who makes us complacent, routinary, and egomaniacal.

In order to keep us obedient and meek and weak, the predators engaged themselves in a stupendous manoeuvre – stupendous, of course, from the point of view of a fighting strategist; a horrendous manoeuvre from the point of those who suffer it. They gave us their mind. The predators' mind is baroque, contradictory, morose, filled with the fear of being discovered any minute now.

For 'predators' see Wetiko, Archons, Yaldabaoth, Jinn, and all the other versions of the same phenomenon in cultures and religions all over the world. The theme is always the same because it's true and it's real. We have reached the point where we have to deal with it. The question is – how?

Don't fight – walk away

I thought I'd use a controversial subheading to get things moving in terms of our response to global fascism. What do you mean 'don't fight'? What do you mean 'walk away'? We've got to fight. We can't walk away. Well, it depends what we mean by fight and walk away. If fighting means physical combat we are playing Wetiko's game and falling for its trap. It wants us to get angry, aggressive, and direct hate and hostility at the enemy we think we must fight. Every war, every battle, every conflict, has been fought with Wetiko leading both sides. It's what it does. Wetiko wants a fight, anywhere, any place. Just hit me, son, so I can hit you back. Wetiko hits Wetiko and Wetiko hits Wetiko in return. I am very forthright as you can see in exposing Wetikos of the Cult, but I don't hate them. I refuse to hate them. It's what they want. What you hate you become. What you *fight* you become. Wokers, 'anti-haters' and 'anti-fascists' prove this every time they reach for their keyboards or don their balaclavas. By walk away I mean to disengage from Wetiko which includes ceasing to cooperate with its tyranny. Paul Levy says of Wetiko:

The way to 'defeat' evil is not to try to destroy it (for then, in playing evil's game, we have already lost), but rather, to find the invulnerable place within ourselves where evil is unable to vanquish us – this is to truly 'win' our battle with evil.

Wetiko is everywhere in human society and it's been on steroids since the 'Covid' hoax. Every shouting match over wearing masks has Wetiko wearing a mask and Wetiko not wearing one. It's an electrical circuit of push and resist, push and resist, with Wetiko pushing *and* resisting. Each polarity is Wetiko empowering itself. Dictionary definitions of 'resist' include 'opposing, refusing to accept or comply with' and the word to focus on is 'opposing'. What form does this take – setting police cars alight or 'refusing to accept or comply with'? The former is Wetiko opposing Wetiko while the other points the way forward. This is the difference between those aggressively demanding that government fascism must be obeyed who stand in stark contrast to the great majority of Pushbackers. We saw this clearly with a march by thousands of Pushbackers against lockdown in London followed days later by a Woker-hijacked

protest in Bristol in which police cars were set on fire. Masks were virtually absent in London and widespread in Bristol. Wetiko wants lockdown on every level of society and infuses its aggression to police it through its unknowing stooges. Lockdown protesters are the ones with the smiling faces and the hugs, The two blatantly obvious states of being – getting more obvious by the day – are the result of Wokers and their like becoming ever more influenced by the simulation Field of Wetiko and Pushbackers ever more influenced by The Field of a far higher vibration beyond the simulation. Wetiko can't invade the heart which is where most lockdown opponents are coming from. It's the heart that allows them to see through the lies to the truth in ways I will be highlighting.

Renegade Minds know that calmness is the place from which wisdom comes. You won't find wisdom in a hissing fit and wisdom is what we need in abundance right now. Calmness is not weakness – you don't have to scream at the top of your voice to be strong. Calmness is indeed a sign of strength. 'No' means I'm not doing it. NOOOO!!! doesn't mean you're not doing it even more. Volume does not advance 'No – I'm not doing it'. You are just not doing it. Wetiko possessed and influenced don't know how to deal with that. Wetiko wants a fight and we should not give it one. What it needs more than anything is our *cooperation* and we should not give that either. Mass rallies and marches are great in that they are a visual representation of feeling, but if it ends there they are irrelevant. You demand that Wetikos act differently? Well, they're not going to are they? They are Wetikos. We don't need to waste our time demanding that something doesn't happen when that will make no difference. We need to delete the means that *allows* it to happen. This, invariably, is our cooperation. You can demand a child stop firing a peashooter at the dog or you can refuse to buy the peashooter. If you provide the means you are cooperating with the dog being smacked on the nose with a pea. How can the authorities enforce mask-wearing if millions in a country refuse? What if the 74 million Pushbackers that voted for Trump in 2020 refused to wear masks, close their businesses or stay in their homes. It would be unenforceable. The

few control the many through the compliance of the many and that's always been the dynamic be it 'Covid' regulations or the Roman Empire. I know people can find it intimidating to say no to authority or stand out in a crowd for being the only one with a face on display; but it has to be done or it's over. I hope I've made clear in this book that where this is going will be far more intimidating than standing up now and saying 'No' – I will not cooperate with my own enslavement and that of my children. There might be consequences for some initially, although not so if enough do the same. The question that must be addressed is what is going to happen if we don't? It is time to be strong and unyieldingly so. No means no. Not here and there, but *everywhere* and *always*. I have refused to wear a mask and obey all the other nonsense. I will not comply with tyranny. I repeat: Fascism is not imposed by fascists – there are never enough of them. Fascism is imposed by the population acquiescing to fascism. *I will not do it*. I will die first, or my body will. Living meekly under fascism is a form of death anyway, the death of the spirit that Martin Luther King described.

Making things happen

We must not despair. This is not over till it's over and it's far from that. The 'fat lady' must refuse to sing. The longer the 'Covid' hoax has dragged on and impacted on more lives we have seen an awakening of phenomenal numbers of people worldwide to the realisation that what they have believed all their lives is not how the world really is. Research published by the system-serving University of Bristol and King's College London in February, 2021, concluded: 'One in every 11 people in Britain say they trust David Icke's take on the coronavirus pandemic.' It will be more by now and we have gathering numbers to build on. We must urgently progress from seeing the scam to ceasing to cooperate with it. Prominent German lawyer Reiner Fuellmich, also licenced to practice law in America, is doing a magnificent job taking the legal route to bring the psychopaths to justice through a second Nuremberg tribunal for crimes against humanity. Fuellmich has an impressive record of

beating the elite in court and he formed the German Corona Investigative Committee to pursue civil charges against the main perpetrators with a view to triggering criminal charges. Most importantly he has grasped the foundation of the hoax – the PCR test not testing for the ‘virus’ – and Christian Drosten is therefore on his charge sheet along with Gates frontman Tedros at the World Health Organization. Major players must not be allowed to inflict their horrors on the human race without being brought to book. A life sentence must follow for Bill Gates and the rest of them. A group of researchers has also indicted the government of Norway for crimes against humanity with copies sent to the police and the International Criminal Court. The lawsuit cites participation in an internationally-planned false pandemic and violation of international law and human rights, the European Commission’s definition of human rights by coercive rules, Nuremberg and Hague rules on fundamental human rights, and the Norwegian constitution. We must take the initiative from hereon and not just complain, protest and react.

There are practical ways to support vital mass non-cooperation. Organising in numbers is one. Lockdown marches in London in the spring in 2021 were mass non-cooperation that the authorities could not stop. There were too many people. Hundreds of thousands walked the London streets in the centre of the road for mile after mile while the Face-Nappies could only look on. They were determined, but calm, and just *did it* with no histrionics and lots of smiles. The police were impotent. Others are organising group shopping without masks for mutual support and imagine if that was happening all over. Policing it would be impossible. If the store refuses to serve people in these circumstances they would be faced with a long line of trolleys full of goods standing on their own and everything would have to be returned to the shelves. How would they cope with that if it kept happening? I am talking here about moving on from complaining to being pro-active; from watching things happen to making things happen. I include in this our relationship with the police. The behaviour of many Face-Nappies

has been disgraceful and anyone who thinks they would never find concentration camp guards in the 'enlightened' modern era have had that myth busted big-time. The period and setting may change – Wetikos never do. I watched film footage from a London march in which a police thug viciously kicked a protestor on the floor who had done nothing. His fellow Face-Nappies stood in a ring protecting him. What he did was a criminal assault and with a crowd far outnumbering the police this can no longer be allowed to happen unchallenged. I get it when people chant 'shame on you' in these circumstances, but that is no longer enough. They *have* no shame those who do this. Crowds needs to start making a citizen's arrest of the police who commit criminal offences and brutally attack innocent people and defenceless women. A citizen's arrest can be made under section 24A of the UK Police and Criminal Evidence (PACE) Act of 1984 and you will find something similar in other countries. I prefer to call it a Common Law arrest rather than citizen's for reasons I will come to shortly. Anyone can arrest a person committing an indictable offence or if they have reasonable grounds to suspect they are committing an indictable offence. On both counts the attack by the police thug would have fallen into this category. A citizen's arrest can be made to stop someone:

- Causing physical injury to himself or any other person
- Suffering physical injury
- Causing loss of or damage to property
- Making off before a constable can assume responsibility for him

A citizen's arrest may also be made to prevent a breach of the peace under Common Law and if they believe a breach of the peace will happen or anything related to harm likely to be done or already done in their presence. This is the way to go I think – the Common Law version. If police know that the crowd and members of the public will no longer be standing and watching while they commit

their thuggery and crimes they will think twice about acting like Brownshirts and Blackshirts.

Common Law – common sense

Mention of Common Law is very important. Most people think the law is the law as in one law. This is not the case. There are two bodies of law, Common Law and Statute Law, and they are not the same. Common Law is founded on the simple premise of do no harm. It does not recognise victimless crimes in which no harm is done while Statute Law does. There is a Statute Law against almost everything. So what is Statute Law? Amazingly it's the law of the *sea* that was brought ashore by the Cult to override the law of the land which is Common Law. They had no right to do this and as always they did it anyway. They had to. They could not impose their will on the people through Common Law which only applies to do no harm. How could you stitch up the fine detail of people's lives with that? Instead they took the law of the sea, or Admiralty Law, and applied it to the population. Statute Law refers to all the laws spewing out of governments and their agencies including all the fascist laws and regulations relating to 'Covid'. The key point to make is that Statute Law is *contract law*. It only applies between *contracting* corporations. Most police officers don't even know this. They have to be kept in the dark, too. Long ago when merchants and their sailing ships began to trade with different countries a contractual law was developed called Admiralty Law and other names. Again it only applied to *contracts* agreed between *corporate* entities. If there is no agreed contract the law of the sea had no jurisdiction *and that still applies to its new alias of Statute Law*. The problem for the Cult when the law of the sea was brought ashore was an obvious one. People were not corporations and neither were government entities. To overcome the latter they made governments and all associated organisations corporations. All the institutions are *private corporations* and I mean governments and their agencies, local councils, police, courts, military, US states, the whole lot. Go to the

Dun and Bradstreet corporate listings website for confirmation that they are all corporations. You are arrested by a private corporation called the police by someone who is really a private security guard and they take you to court which is another private corporation. Neither have jurisdiction over you unless you consent and *contract* with them. This is why you hear the mantra about law enforcement policing by *consent* of the people. In truth the people 'consent' only in theory through monumental trickery.

Okay, the Cult overcame the corporate law problem by making governments and institutions corporate entities; but what about people? They are not corporations are they? Ah ... well in a sense, and *only* a sense, they are. Not people exactly – the illusion of people. The Cult creates a corporation in the name of everyone at the time that their birth certificate is issued. Note birth/ *berth* certificate and when you go to court under the law of the sea on land you stand in a *dock*. These are throwbacks to the origin. My Common Law name is David Vaughan Icke. The name of the corporation created by the government when I was born is called Mr David Vaughan Icke usually written in capitals as MR DAVID VAUGHAN ICKE. That is not me, the living, breathing man. It is a fictitious corporate entity. The trick is to make you think that David Vaughan Icke and MR DAVID VAUGHAN ICKE are the same thing. *They are not*. When police charge you and take you to court they are prosecuting the corporate entity and not the living, breathing, man or woman. They have to trick you into identifying as the corporate entity and contracting with them. Otherwise they have no jurisdiction. They do this through a language known as legalese. Lawful and legal are not the same either. Lawful relates to Common Law and legal relates to Statute Law. Legalese is the language of Statue Law which uses terms that mean one thing to the public and another in legalese. Notice that when a police officer tells someone why they are being charged he or she will say at the end: 'Do you understand?' To the public that means 'Do you comprehend?' In legalese it means 'Do you stand under me?' Do you stand under my authority? If you say

yes to the question you are unknowingly agreeing to give them jurisdiction over you in a contract between two corporate entities.

This is a confidence trick in every way. Contracts have to be agreed between informed parties and if you don't know that David Vaughan Icke is agreeing to be the corporation MR DAVID VAUGHAN ICKE you cannot knowingly agree to contract. They are deceiving you and another way they do this is to ask for proof of identity. You usually show them a driving licence or other document on which your corporate name is written. In doing so you are accepting that you are that corporate entity when you are not. Referring to yourself as a 'person' or 'citizen' is also identifying with your corporate fiction which is why I made the Common Law point about the citizen's arrest. If you are approached by a police officer you identify yourself immediately as a living, breathing, man or woman and say 'I do not consent, I do not contract with you and I do not understand' or stand under their authority. I have a Common Law birth certificate as a living man and these are available at no charge from commonlawcourt.com. Businesses registered under the Statute Law system means that its laws apply. There are, however, ways to run a business under Common Law. Remember all 'Covid' laws and regulations are Statute Law – the law of *contracts* and you do not have to contract. This doesn't mean that you can kill someone and get away with it. Common Law says do no harm and that applies to physical harm, financial harm etc. Police are employees of private corporations and there needs to be a new system of non-corporate Common Law constables operating outside the Statute Law system. If you go to davidicke.com and put Common Law into the search engine you will find videos that explain Common Law in much greater detail. It is definitely a road we should walk.

With all my heart

I have heard people say that we are in a spiritual war. I don't like the term 'war' with its Wetiko dynamic, but I know what they mean. Sweep aside all the bodily forms and we are in a situation in which two states of consciousness are seeking very different realities.

Wetiko wants upheaval, chaos, fear, suffering, conflict and control. The other wants love, peace, harmony, fairness and freedom. That's where we are. We should not fall for the idea that Wetiko is all-powerful and there's nothing we can do. Wetiko is not all-powerful. It's a joke, pathetic. It doesn't have to be, but it has made that choice for now. A handful of times over the years when I have felt the presence of its frequency I have allowed it to attach briefly so I could consciously observe its nature. The experience is not pleasant, the energy is heavy and dark, but the ease with which you can kick it back out the door shows that its real power is in persuading us that it has power. It's all a con. Wetiko is a con. It's a trickster and not a power that can control us if we unleash our own. The con is founded on manipulating humanity to give its power to Wetiko which recycles it back to present the illusion that it has power when its power is *ours* that we gave away. This happens on an energetic level and plays out in the world of the seen as humanity giving its power to Wetiko authority which uses that power to control the population when the power is only the power the population has handed over. How could it be any other way for billions to be controlled by a relative few? I have had experiences with people possessed by Wetiko and again you can kick its arse if you do it with an open heart. Oh yes – the *heart* which can transform the world of perceived 'matter'.

We are receiver-transmitters and processors of information, but what information and where from? Information is processed into perception in three main areas – the brain, the heart and the belly. These relate to thinking, knowing, and emotion. Wetiko wants us to be head and belly people which means we think within the confines of the Matrix simulation and low-vibrational emotional reaction scrambles balance and perception. A few minutes on social media and you see how emotion is the dominant force. Woke is all emotion and is therefore thought-free and fact-free. Our heart is something different. It *knows* while the head *thinks* and has to try to work it out because it doesn't know. The human energy field has seven prime vortexes which connect us with wider reality ([Fig 23](#)). Chakra means

‘wheels of light’ in the Sanskrit language of ancient India. The main ones are: The crown chakra on top of the head; brow (or ‘third eye’) chakra in the centre of the forehead; throat chakra; heart chakra in the centre of the chest; solar plexus chakra below the sternum; sacral chakra beneath the navel; and base chakra at the bottom of the spine. Each one has a particular function or functions. We feel anxiety and nervousness in the belly where the sacral chakra is located and this processes emotion that can affect the colon to give people ‘the shits’ or make them ‘shit scared’ when they are nervous. Chakras all play an important role, but the Mr and Mrs Big is the heart chakra which sits at the centre of the seven, above the chakras that connect us to the ‘physical’ and below those that connect with higher realms (or at least should). Here in the heart chakra we feel love, empathy and compassion – ‘My heart goes out to you’. Those with closed hearts become literally ‘heart-less’ in their attitudes and behaviour (see Bill Gates). Native Americans portrayed Wetiko with what Paul Levy calls a ‘frigid, icy heart, devoid of mercy’ (see Bill Gates).



Figure 23: The chakra system which interpenetrates the human energy field. The heart chakra is the governor – or should be.

Wetiko trembles at the thought of heart energy which it cannot infiltrate. The frequency is too high. What it seeks to do instead is close the heart chakra vortex to block its perceptual and energetic influence. Psychopaths have ‘hearts of stone’ and emotionally-damaged people have ‘heartache’ and ‘broken hearts’. The astonishing amount of heart disease is related to heart chakra

disruption with its fundamental connection to the 'physical' heart. Dr Tom Cowan has written an outstanding book challenging the belief that the heart is a pump and making the connection between the 'physical' and spiritual heart. Rudolph Steiner who was way ahead of his time said the same about the fallacy that the heart is a pump. *What?* The heart is not a pump? That's crazy, right? Everybody knows that. Read Cowan's *Human Heart, Cosmic Heart* and you will realise that the very idea of the heart as a pump is ridiculous when you see the evidence. How does blood in the feet so far from the heart get pumped horizontally up the body by the heart?? Cowan explains in the book the real reason why blood moves as it does. Our 'physical' heart is used to symbolise love when the source is really the heart vortex or spiritual heart which is our most powerful energetic connection to 'out there' expanded consciousness. That's why we feel *knowing* – intuitive knowing – in the centre of the chest. Knowing doesn't come from a process of thoughts leading to a conclusion. It is there in an instant all in one go. Our heart knows because of its connection to levels of awareness that *do* know. This is the meaning and source of intuition – intuitive *knowing*.

For the last more than 30 years of uncovering the global game and the nature of reality my heart has been my constant antenna for truth and accuracy. An American intelligence insider once said that I had quoted a disinformant in one of my books and yet I had only quoted the part that was true. He asked: 'How do you do that?' By using my heart antenna was the answer and anyone can do it. Heart-centred is how we are meant to be. With a closed heart chakra we withdraw into a closed mind and the bubble of five-sense reality. If you take a moment to focus your attention on the centre of your chest, picture a spinning wheel of light and see it opening and expanding. You will feel it happening, too, and perceptions of the heart like joy and love as the heart impacts on the mind as they interact. The more the chakra opens the more you will feel expressions of heart consciousness and as the process continues, and becomes part of you, insights and knowings will follow. An open

heart is connected to that level of awareness that knows all is *One*. You will see from its perspective that the fault-lines that divide us are only illusions to control us. An open heart does not process the illusions of race, creed and sexuality except as brief experiences for a consciousness that is all. Our heart does not see division, only unity (Figs 24 and 25). There's something else, too. Our hearts love to laugh. Mark Twain's quote that says 'The human race has one really effective weapon, and that is laughter' is really a reference to the heart which loves to laugh with the joy of knowing the true nature of infinite reality and that all the madness of human society is an illusion of the mind. Twain also said: 'Against the assault of laughter nothing can stand.' This is so true of Wetiko and the Cult. Their insecurity demands that they be taken seriously and their power and authority acknowledged and feared. We should do nothing of the sort. We should not get aggressive or fearful which their insecurity so desires. We should laugh in their face. Even in their no-face as police come over in their face-nappies and expect to be taken seriously. They don't take themselves seriously looking like that so why should we? Laugh in the face of intimidation. Laugh in the face of tyranny. You will see by its reaction that you have pressed all of its buttons. Wetiko does not know what to do in the face of laughter or when its targets refuse to concede their joy to fear. We have seen many examples during the 'Covid' hoax when people have expressed their energetic power and the string puppets of Wetiko retreat with their tail limp between their knees. Laugh – the world is bloody mad after all and if it's a choice between laughter and tears I know which way I'm going.



Figure 24: Head consciousness without the heart sees division and everything apart from everything else.



Figure 25: Heart consciousness sees everything as One.

'Vaccines' and the soul

The foundation of Wetiko/Archon control of humans is the separation of incarnate five-sense mind from the infinite 'I' and closing the heart chakra where the True 'I' lives during a human life. The goal has been to achieve complete separation in both cases. I was interested therefore to read an account by a French energetic healer of what she said she experienced with a patient who had been given the 'Covid' vaccine. Genuine energy healers can sense information and consciousness fields at different levels of being which are referred to as 'subtle bodies'. She described treating the patient who later returned after having, without the healer's knowledge, two doses of the 'Covid vaccine'. The healer said:

I noticed immediately the change, very heavy energy emanating from [the] subtle bodies. The scariest thing was when I was working on the heart chakra, I connected with her soul: it was detached from the physical body, it had no contact and it was, as if it was floating in a state of total confusion: a damage to the consciousness that loses contact with the physical body, i.e. with our biological machine, there is no longer any communication between them.

I continued the treatment by sending light to the heart chakra, the soul of the person, but it seemed that the soul could no longer receive any light, frequency or energy. It was a very powerful experience for me. Then I understood that this substance is indeed used to detach consciousness so that this consciousness can no longer interact through this body that it possesses in life, where there is no longer any contact, no frequency, no light, no more energetic balance or mind.

This would create a human that is rudderless and at the extreme almost zombie-like operating with a fractional state of consciousness at the mercy of Wetiko. I was especially intrigued by what the healer said in the light of the prediction by the highly-informed Rudolf Steiner more than a hundred years ago. He said:

In the future, we will eliminate the soul with medicine. Under the pretext of a 'healthy point of view', there will be a vaccine by which the human body will be treated as soon as possible directly at birth, so that the human being cannot develop the thought of the existence of soul and Spirit. To materialistic doctors will be entrusted the task of removing the soul of humanity.

As today, people are vaccinated against this disease or that disease, so in the future, children will be vaccinated with a substance that can be produced precisely in such a way that people, thanks to this vaccination, will be immune to being subjected to the 'madness' of spiritual life. He would be extremely smart, but he would not develop a conscience, and that is the true goal of some materialistic circles.

Steiner said the vaccine would detach the physical body from the etheric body (subtle bodies) and 'once the etheric body is detached the relationship between the universe and the etheric body would become extremely unstable, and man would become an automaton'. He said 'the physical body of man must be polished on this Earth by spiritual will – so the vaccine becomes a kind of arymanique (Wetiko) force' and 'man can no longer get rid of a given materialistic feeling'. Humans would then, he said, become 'materialistic of constitution and can no longer rise to the spiritual'. I have been writing for years about DNA being a receiver-transmitter of information that connects us to other levels of reality and these 'vaccines' changing DNA can be likened to changing an antenna and what it can transmit and receive. Such a disconnection would clearly lead to changes in personality and perception. Steiner further predicted the arrival of AI. Big Pharma 'Covid vaccine' makers, expressions of Wetiko, are testing their DNA-manipulating evil on children as I write with a view to giving the 'vaccine' to babies. If it's a soul-body disconnecter – and I say that it is or can be – every child would be disconnected from 'soul' at birth and the 'vaccine' would create a closed system in which spiritual guidance from the greater self would play no part. This has been the ambition of Wetiko all

along. A Pentagon video from 2005 was leaked of a presentation explaining the development of vaccines to change behaviour by their effect on the brain. Those that believe this is not happening with the 'Covid' genetically-modifying procedure masquerading as a 'vaccine' should make an urgent appointment with Naivety Anonymous. Klaus Schwab wrote in 2018:

Neurotechnologies enable us to better influence consciousness and thought and to understand many activities of the brain. They include decoding what we are thinking in fine levels of detail through new chemicals and interventions that can influence our brains to correct for errors or enhance functionality.

The plan is clear and only the heart can stop it. With every heart that opens, every mind that awakens, Wetiko is weakened. Heart and love are far more powerful than head and hate and so nothing like a majority is needed to turn this around.

Beyond the Phantom

Our heart is the prime target of Wetiko and so it must be the answer to Wetiko. We *are* our heart which is part of one heart, the infinite heart. Our heart is where the true self lives in a human life behind firewalls of five-sense illusion when an imposter takes its place – *Phantom Self*; but our heart waits patiently to be set free any time we choose to see beyond the Phantom, beyond Wetiko. A Wetikoed Phantom Self can wreak mass death and destruction while the love of forever is locked away in its heart. The time is here to unleash its power and let it sweep away the fear and despair that is Wetiko. Heart consciousness does not seek manipulated, censored, advantage for its belief or religion, its activism and desires. As an expression of the One it treats all as One with the same rights to freedom and opinion. Our heart demands fairness for itself no more than for others. From this unity of heart we can come together in mutual support and transform this Wetikoed world into what reality is meant to be – a place of love, joy, happiness, fairness, justice and freedom. Wetiko has another agenda and that's why the world is as

it is, but enough of this nonsense. Wetiko can't stay where hearts are open and it works so hard to keep them closed. Fear is its currency and its food source and love in its true sense has no fear. Why would love have fear when it knows it is *All That Is, Has Been, And Ever Can Be* on an eternal exploration of all possibility? Love in this true sense is not the physical attraction that passes for love. This can be an expression of it, yes, but Infinite Love, a love without condition, goes far deeper to the core of all being. It is the core of all being. Infinite reality was born from love beyond the illusions of the simulation. Love infinitely expressed is the knowing that all is One and the swiftly-passing experience of separation is a temporary hallucination. You cannot disconnect from Oneness; you can only *perceive* that you have and withdraw from its influence. This is the most important of all perception trickery by the mind parasite that is Wetiko and the foundation of all its potential for manipulation.

If we open our hearts, open the sluice gates of the mind, and redefine self-identity amazing things start to happen. Consciousness expands or contracts in accordance with self-identity. When true self is recognised as infinite awareness and label self – Phantom Self – is seen as only a series of brief experiences life is transformed. Consciousness expands to the extent that self-identity expands and everything changes. You see unity, not division, the picture, not the pixels. From this we can play the long game. No more is an experience something in and of itself, but a fleeting moment in the eternity of forever. Suddenly people in uniform and dark suits are no longer intimidating. Doing what your heart knows to be right is no longer intimidating and consequences for those actions take on the same nature of a brief experience that passes in the blink of an infinite eye. Intimidation is all in the mind. Beyond the mind there is no intimidation.

An open heart does not consider consequences for what it knows to be right. To do so would be to consider not doing what it knows to be right and for a heart in its power that is never an option. The Renegade Mind is really the Renegade Heart. Consideration of consequences will always provide a getaway car for the mind and

the heart doesn't want one. What is right in the light of what we face today is to stop cooperating with Wetiko in all its forms and to do it without fear or compromise. You cannot compromise with tyranny when tyranny always demands more until it has everything. Life is your perception and you are your destiny. Change your perception and you change your life. Change collective perception and we change the world.

Come on people ... One human family, One heart, One goal ...
FREEEEEEEDOM!

We must settle for nothing less.

Postscript

The big scare story as the book goes to press is the 'Indian' variant and the world is being deluged with propaganda about the 'Covid catastrophe' in India which mirrors in its lies and misrepresentations what happened in Italy before the first lockdown in 2020.

The *New York Post* published a picture of someone who had 'collapsed in the street from Covid' in India in April, 2021, which was actually taken during a gas leak in May, 2020. Same old, same old. Media articles in mid-February were asking why India had been so untouched by 'Covid' and then as their vaccine rollout gathered pace the alleged 'cases' began to rapidly increase. Indian 'Covid vaccine' maker Bharat Biotech was funded into existence by the Bill and Melinda Gates Foundation (the pair announced their divorce in May, 2021, which is a pity because they so deserve each other). The Indian 'Covid crisis' was ramped up by the media to terrify the world and prepare people for submission to still more restrictions. The scam that worked the first time was being repeated only with far more people seeing through the deceit. Davidicke.com and Ickonic.com have sought to tell the true story of what is happening by talking to people living through the Indian nightmare which has nothing to do with 'Covid'. We posted a letter from 'Alisha' in Pune who told a very different story to government and media mendacity. She said scenes of dying people and overwhelmed hospitals were designed to hide what was really happening – genocide and starvation. Alisha said that millions had already died of starvation during the ongoing lockdowns while government and media were lying and making it look like the 'virus':

Restaurants, shops, gyms, theatres, basically everything is shut. The cities are ghost towns. Even so-called 'essential' businesses are only open till 11am in the morning. You basically have just an hour to buy food and then your time is up.

Inter-state travel and even inter-district travel is banned. The cops wait at all major crossroads to question why you are traveling outdoors or to fine you if you are not wearing a mask.

The medical community here is also complicit in genocide, lying about hospitals being full and turning away people with genuine illnesses, who need immediate care. They have even created a shortage of oxygen cylinders.

This is the classic Cult modus operandi played out in every country. Alisha said that people who would not have a PCR test not testing for the 'virus' were being denied hospital treatment. She said the people hit hardest were migrant workers and those in rural areas. Most businesses employed migrant workers and with everything closed there were no jobs, no income and no food. As a result millions were dying of starvation or malnutrition. All this was happening under Prime Minister Narendra Modi, a 100-percent asset of the Cult, and it emphasises yet again the scale of pure anti-human evil we are dealing with. Australia banned its people from returning home from India with penalties for trying to do so of up to five years in jail and a fine of £37,000. The manufactured 'Covid' crisis in India was being prepared to justify further fascism in the West. Obvious connections could be seen between the Indian 'vaccine' programme and increased 'cases' and this became a common theme. The Seychelles, the most per capita 'Covid vaccinated' population in the world, went back into lockdown after a 'surge of cases'.

Long ago the truly evil Monsanto agricultural biotechnology corporation with its big connections to Bill Gates devastated Indian farming with genetically-modified crops. Human rights activist Gurcharan Singh highlighted the efforts by the Indian government to complete the job by destroying the food supply to hundreds of millions with 'Covid' lockdowns. He said that 415 million people at the bottom of the disgusting caste system (still going whatever they say) were below the poverty line and struggled to feed themselves every year. Now the government was imposing lockdown at just the

time to destroy the harvest. This deliberate policy was leading to mass starvation. People may reel back at the suggestion that a government would do that, but Wetiko-controlled 'leaders' are capable of any level of evil. In fact what is described in India is in the process of being instigated worldwide. The food chain and food supply are being targeted at every level to cause world hunger and thus control. Bill Gates is not the biggest owner of farmland in America for no reason and destroying access to food aids both the depopulation agenda and the plan for synthetic 'food' already being funded into existence by Gates. Add to this the coming hyper-inflation from the suicidal creation of fake 'money' in response to 'Covid' and the breakdown of container shipping systems and you have a cocktail that can only lead one way and is meant to. The Cult plan is to crash the entire system to 'build back better' with the Great Reset.

'Vaccine' transmission

Reports from all over the world continue to emerge of women suffering menstrual and fertility problems after having the fake 'vaccine' and of the non-'vaccinated' having similar problems when interacting with the 'vaccinated'. There are far too many for 'coincidence' to be credible. We've had menopausal women getting periods, others having periods stop or not stopping for weeks, passing clots, sometimes the lining of the uterus, breast irregularities, and miscarriages (which increased by 400 percent in parts of the United States). Non-'vaccinated' men and children have suffered blood clots and nose bleeding after interaction with the 'vaccinated'. Babies have died from the effects of breast milk from a 'vaccinated' mother. Awake doctors – the small minority – speculated on the cause of non-'vaccinated' suffering the same effects as the 'vaccinated'. Was it nanotechnology in the synthetic substance transmitting frequencies or was it a straight chemical bioweapon that was being transmitted between people? I am not saying that some kind of chemical transmission is not one possible answer, but the foundation of all that the Cult does is frequency and

this is fertile ground for understanding how transmission can happen. American doctor Carrie Madej, an internal medicine physician and osteopath, has been practicing for the last 20 years, teaching medical students, and she says attending different meetings where the agenda for humanity was discussed. Madej, who operates out of Georgia, did not dismiss other possible forms of transmission, but she focused on frequency in search of an explanation for transmission. She said the Moderna and Pfizer 'vaccines' contained nano-lipid particles as a key component. This was a brand new technology never before used on humanity. 'They're using a nanotechnology which is pretty much little tiny computer bits ... nanobots or hydrogel.' Inside the 'vaccines' was 'this sci-fi kind of substance' which suppressed immune checkpoints to get into the cell. I referred to this earlier as the 'Trojan horse' technique that tricks the cell into opening a gateway for the self-replicating synthetic material and while the immune system is artificially suppressed the body has no defences. Madej said the substance served many purposes including an on-demand ability to 'deliver the payload' and using the nano 'computer bits' as biosensors in the body. 'It actually has the ability to accumulate data from your body, like your breathing, your respiration, thoughts, emotions, all kinds of things.'

She said the technology obviously has the ability to operate through Wi-Fi and transmit and receive energy, messages, frequencies or impulses. 'Just imagine you're getting this new substance in you and it can react to things all around you, the 5G, your smart device, your phones.' We had something completely foreign in the human body that had never been launched large scale at a time when we were seeing 5G going into schools and hospitals (plus the Musk satellites) and she believed the 'vaccine' transmission had something to do with this: '... if these people have this inside of them ... it can act like an antenna and actually transmit it outwardly as well.' The synthetic substance produced its own voltage and so it could have that kind of effect. This fits with my own contention that the nano receiver-transmitters are designed to connect people to the

Smart Grid and break the receiver-transmitter connection to expanded consciousness. That would explain the French energy healer's experience of the disconnection of body from 'soul' with those who have had the 'vaccine'. The nanobots, self-replicating inside the body, would also transmit the synthetic frequency which could be picked up through close interaction by those who have not been 'vaccinated'. Madej speculated that perhaps it was 5G and increased levels of other radiation that was causing the symptoms directly although interestingly she said that non-'vaccinated' patients had shown improvement when they were away from the 'vaccinated' person they had interacted with. It must be remembered that you can control frequency and energy with your mind and you can consciously create energetic barriers or bubbles with the mind to stop damaging frequencies from penetrating your field. American paediatrician Dr Larry Palevsky said the 'vaccine' was not a 'vaccine' and was never designed to protect from a 'viral' infection. He called it 'a massive, brilliant propaganda of genocide' because they didn't have to inject everyone to get the result they wanted. He said the content of the jabs was able to infuse any material into the brain, heart, lungs, kidneys, liver, sperm and female productive system. 'This is genocide; this is a weapon of mass destruction.' At the same time American colleges were banning students from attending if they didn't have this life-changing and potentially life-ending 'vaccine'. Class action lawsuits must follow when the consequences of this college fascism come to light. As the book was going to press came reports about fertility effects on sperm in 'vaccinated' men which would absolutely fit with what I have been saying and hospitals continued to fill with 'vaccine' reactions. Another question is what about transmission via blood transfusions? The NHS has extended blood donation restrictions from seven days after a 'Covid vaccination' to 28 days after even a sore arm reaction.

I said in the spring of 2020 that the then touted 'Covid vaccine' would be ongoing each year like the flu jab. A year later Pfizer CEO, the appalling Albert Bourla, said people would 'likely' need a 'booster dose' of the 'vaccine' within 12 months of getting 'fully

vaccinated' and then a yearly shot. 'Variants will play a key role', he said confirming the point. Johnson & Johnson CEO Alex Gorsky also took time out from his 'vaccine' disaster to say that people may need to be vaccinated against 'Covid-19' each year. UK Health Secretary, the psychopath Matt Hancock, said additional 'boosters' would be available in the autumn of 2021. This is the trap of the 'vaccine passport'. The public will have to accept every last 'vaccine' they introduce, including for the fake 'variants', or it would cease to be valid. The only other way in some cases would be continuous testing with a test not testing for the 'virus' and what is on the swabs constantly pushed up your nose towards the brain every time?

'Vaccines' changing behaviour

I mentioned in the body of the book how I believed we would see gathering behaviour changes in the 'vaccinated' and I am already hearing such comments from the non-'vaccinated' describing behaviour changes in friends, loved ones and work colleagues. This will only increase as the self-replicating synthetic material and nanoparticles expand in body and brain. An article in the *Guardian* in 2016 detailed research at the University of Virginia in Charlottesville which developed a new method for controlling brain circuits associated with complex animal behaviour. The method, dubbed 'magnetogenetics', involves genetically-engineering a protein called ferritin, which stores and releases iron, to create a magnetised substance – 'Magneto' – that can activate specific groups of nerve cells from a distance. This is claimed to be an advance on other methods of brain activity manipulation known as optogenetics and chemogenetics (the Cult has been developing methods of brain control for a long time). The ferritin technique is said to be non-invasive and able to activate neurons 'rapidly and reversibly'. In other words, human thought and perception. The article said that earlier studies revealed how nerve cell proteins 'activated by heat and mechanical pressure can be genetically engineered so that they become sensitive to radio waves and magnetic fields, by attaching them to an iron-storing protein called ferritin, or to inorganic

paramagnetic particles'. Sensitive to radio waves and magnetic fields? You mean like 5G, 6G and 7G? This is the human-AI Smart Grid hive mind we are talking about. The *Guardian* article said:

... the researchers injected Magneto into the striatum of freely behaving mice, a deep brain structure containing dopamine-producing neurons that are involved in reward and motivation, and then placed the animals into an apparatus split into magnetised and non-magnetised sections.

Mice expressing Magneto spent far more time in the magnetised areas than mice that did not, because activation of the protein caused the striatal neurons expressing it to release dopamine, so that the mice found being in those areas rewarding. This shows that Magneto can remotely control the firing of neurons deep within the brain, and also control complex behaviours.

Make no mistake this basic methodology will be part of the 'Covid vaccine' cocktail and using magnetics to change brain function through electromagnetic field frequency activation. The Pentagon is developing a 'Covid vaccine' using ferritin. Magnetism would explain changes in behaviour and why videos are appearing across the Internet as I write showing how magnets stick to the skin at the point of the 'vaccine' shot. Once people take these 'vaccines' anything becomes possible in terms of brain function and illness which will be blamed on 'Covid-19' and 'variants'. Magnetic field manipulation would further explain why the non-'vaccinated' are reporting the same symptoms as the 'vaccinated' they interact with and why those symptoms are reported to decrease when not in their company. Interestingly 'Magneto', a 'mutant', is a character in the Marvel Comic *X-Men* stories with the ability to manipulate magnetic fields and he believes that mutants should fight back against their human oppressors by any means necessary. The character was born Erik Lehnsherr to a Jewish family in Germany.

Cult-controlled courts

The European Court of Human Rights opened the door for mandatory 'Covid-19 vaccines' across the continent when it ruled in a Czech Republic dispute over childhood immunisation that legally

enforced vaccination could be 'necessary in a democratic society'. The 17 judges decided that compulsory vaccinations did not breach human rights law. On the face of it the judgement was so inverted you gasp for air. If not having a vaccine infused into your body is not a human right then what is? Ah, but they said human rights law which has been specifically written to delete all human rights at the behest of the state (the Cult). Article 8 of the European Convention on Human Rights relates to the right to a private life. The crucial word here is '*except*':

There shall be no interference by a public authority with the exercise of this right EXCEPT such as is in accordance with the law and is necessary in a democratic society in the interests of national security, public safety or the economic wellbeing of the country, for the prevention of disorder or crime, for the protection of health or morals, or for the protection of the rights and freedoms of others [My emphasis].

No interference *except* in accordance with the law means there *are* no 'human rights' *except* what EU governments decide you can have at their behest. 'As is necessary in a democratic society' explains that reference in the judgement and 'in the interests of national security, public safety or the economic well-being of the country, for the prevention of disorder or crime, for the protection of health or morals, or for the protection of the rights and freedoms of others' gives the EU a coach and horses to ride through 'human rights' and scatter them in all directions. The judiciary is not a check and balance on government extremism; it is a vehicle to enforce it. This judgement was almost laughably predictable when the last thing the Cult wanted was a decision that went against mandatory vaccination. Judges rule over and over again to benefit the system of which they are a part. Vaccination disputes that come before them are invariably delivered in favour of doctors and authorities representing the view of the state which owns the judiciary. Oh, yes, and we have even had calls to stop putting 'Covid-19' on death certificates within 28 days of a 'positive test' because it is claimed the practice makes the 'vaccine' appear not to work. They are laughing at you.

The scale of madness, inhumanity and things to come was highlighted when those not 'vaccinated' for 'Covid' were refused evacuation from the Caribbean island of St Vincent during massive volcanic eruptions. Cruise ships taking residents to the safety of another island allowed only the 'vaccinated' to board and the rest were left to their fate. Even in life and death situations like this we see 'Covid' stripping people of their most basic human instincts and the insanity is even more extreme when you think that fake 'vaccine'-makers are not even claiming their body-manipulating concoctions stop 'infection' and 'transmission' of a 'virus' that doesn't exist. St Vincent Prime Minister Ralph Gonsalves said: 'The chief medical officer will be identifying the persons already vaccinated so that we can get them on the ship.' Note again the power of the chief medical officer who, like Whitty in the UK, will be answering to the World Health Organization. This is the Cult network structure that has overridden politicians who 'follow the science' which means doing what WHO-controlled 'medical officers' and 'science advisers' tell them. Gonsalves even said that residents who were 'vaccinated' after the order so they could board the ships would still be refused entry due to possible side effects such as 'wooziness in the head'. The good news is that if they were woozy enough in the head they could qualify to be prime minister of St Vincent.

Microchipping freedom

The European judgement will be used at some point to justify moves to enforce the 'Covid' DNA-manipulating procedure. Sandra Ro, CEO of the Global Blockchain Business Council, told a World Economic Forum event that she hoped 'vaccine passports' would help to 'drive forced consent and standardisation' of global digital identity schemes: 'I'm hoping with the desire and global demand for some sort of vaccine passport – so that people can get travelling and working again – [it] will drive forced consent, standardisation, and frankly, cooperation across the world.' The lady is either not very bright, or thoroughly mendacious, to use the term 'forced consent'.

You do not 'consent' if you are forced – you *submit*. She was describing what the plan has been all along and that's to enforce a digital identity on every human without which they could not function. 'Vaccine passports' are opening the door and are far from the end goal. A digital identity would allow you to be tracked in everything you do in cyberspace and this is the same technique used by Cult-owned China to enforce its social credit system of total control. The ultimate 'passport' is planned to be a microchip as my books have warned for nearly 30 years. Those nice people at the Pentagon working for the Cult-controlled Defense Advanced Research Projects Agency (DARPA) claimed in April, 2021, they have developed a microchip inserted under the skin to detect 'asymptomatic Covid-19 infection' before it becomes an outbreak and a 'revolutionary filter' that can remove the 'virus' from the blood when attached to a dialysis machine. The only problems with this are that the 'virus' does not exist and people transmitting the 'virus' with no symptoms is brain-numbing bullshit. This is, of course, not a ruse to get people to be microchipped for very different reasons. DARPA also said it was producing a one-stop 'vaccine' for the 'virus' and all 'variants'. One of the most sinister organisations on Planet Earth is doing this? Better have it then. These people are insane because Wetiko that possesses them is insane.

Researchers from the Salk Institute in California announced they have created an embryo that is part human and part monkey. My books going back to the 1990s have exposed experiments in top secret underground facilities in the United States where humans are being crossed with animal and non-human 'extraterrestrial' species. They are now easing that long-developed capability into the public arena and there is much more to come given we are dealing with psychiatric basket cases. Talking of which – Elon Musk's scientists at Neuralink trained a monkey to play Pong and other puzzles on a computer screen using a joystick and when the monkey made the correct move a metal tube squirted banana smoothie into his mouth which is the basic technique for training humans into unquestioning compliance. Two Neuralink chips were in the monkey's skull and

more than 2,000 wires ‘fanned out’ into its brain. Eventually the monkey played a video game purely with its brain waves. Psychopathic narcissist Musk said the ‘breakthrough’ was a step towards putting Neuralink chips into human skulls and merging minds with artificial intelligence. *Exactly*. This man is so dark and Cult to his DNA.

World Economic Fascism (WEF)

The World Economic Forum is telling you the plan by the statements made at its many and various events. Cult-owned fascist YouTube CEO Susan Wojcicki spoke at the 2021 WEF Global Technology Governance Summit (see the name) in which 40 governments and 150 companies met to ensure ‘the responsible design and deployment of emerging technologies’. Orwellian translation: ‘Ensuring the design and deployment of long-planned technologies will advance the Cult agenda for control and censorship.’ Freedom-destroyer and Nuremberg-bound Wojcicki expressed support for tech platforms like hers to censor content that is ‘technically legal but could be harmful’. Who decides what is ‘harmful’? She does and they do. ‘Harmful’ will be whatever the Cult doesn’t want people to see and we have legislation proposed by the UK government that would censor content on the basis of ‘harm’ no matter if the information is fair, legal and provably true. Make that *especially* if it is fair, legal and provably true. Wojcicki called for a global coalition to be formed to enforce content moderation standards through automated censorship. This is a woman and mega-censor so self-deluded that she shamelessly accepted a ‘free expression’ award – *Wojcicki* – in an event sponsored by her own *YouTube*. They have no shame and no self-awareness.

You know that ‘Covid’ is a scam and Wojcicki a Cult operative when YouTube is censoring medical and scientific opinion purely on the grounds of whether it supports or opposes the Cult ‘Covid’ narrative. Florida governor Ron DeSantis compiled an expert panel with four professors of medicine from Harvard, Oxford, and Stanford Universities who spoke against forcing children and

vaccinated people to wear masks. They also said there was no proof that lockdowns reduced spread or death rates of 'Covid-19'. Cult-gofer Wojcicki and her YouTube deleted the panel video 'because it included content that contradicts the consensus of local and global health authorities regarding the efficacy of masks to prevent the spread of Covid-19'. This 'consensus' refers to what the Cult tells the World Health Organization to say and the WHO tells 'local health authorities' to do. Wojcicki knows this, of course. The panellists pointed out that censorship of scientific debate was responsible for deaths from many causes, but Wojcicki couldn't care less. She would not dare go against what she is told and as a disgrace to humanity she wouldn't want to anyway. The UK government is seeking to pass a fascist 'Online Safety Bill' to specifically target with massive fines and other means non-censored video and social media platforms to make them censor 'lawful but harmful' content like the Cult-owned Facebook, Twitter, Google and YouTube. What is 'lawful but harmful' would be decided by the fascist Blair-created Ofcom.

Another WEF obsession is a cyber-attack on the financial system and this is clearly what the Cult has planned to take down the bank accounts of everyone – except theirs. Those that think they have enough money for the Cult agenda not to matter to them have got a big lesson coming if they continue to ignore what is staring them in the face. The World Economic Forum, funded by Gates and fronted by Klaus Schwab, announced it would be running a 'simulation' with the Russian government and global banks of just such an attack called Cyber Polygon 2021. What they simulate – as with the 'Covid' Event 201 – they plan to instigate. The WEF is involved in a project with the Cult-owned Carnegie Endowment for International Peace called the WEF-Carnegie Cyber Policy Initiative which seeks to merge Wall Street banks, 'regulators' (I love it) and intelligence agencies to 'prevent' (arrange and allow) a cyber-attack that would bring down the global financial system as long planned by those that control the WEF and the Carnegie operation. The Carnegie Endowment for International Peace sent an instruction to First World

War US President Woodrow Wilson not to let the war end before society had been irreversibly transformed.

The Wuhan lab diversion

As I close, the Cult-controlled authorities and lapdog media are systematically pushing 'the virus was released from the Wuhan lab' narrative. There are two versions – it happened by accident and it happened on purpose. Both are nonsense. The perceived existence of the never-shown-to-exist 'virus' is vital to sell the impression that there is actually an infective agent to deal with and to allow the endless potential for terrifying the population with 'variants' of a 'virus' that does not exist. The authorities at the time of writing are going with the 'by accident' while the alternative media is promoting the 'on purpose'. Cable news host Tucker Carlson who has questioned aspects of lockdown and 'vaccine' compulsion has bought the Wuhan lab story. 'Everyone now agrees' he said. Well, I don't and many others don't and the question is *why* does the system and its media suddenly 'agree'? When the media moves as one unit with a narrative it is always a lie – witness the hour by hour mendacity of the 'Covid' era. Why would this Cult-owned combination which has unleashed lies like machine gun fire suddenly 'agree' to tell the truth??

Much of the alternative media is buying the lie because it fits the conspiracy narrative, but it's the *wrong* conspiracy. The real conspiracy is that *there is no virus* and that is what the Cult is desperate to hide. The idea that the 'virus' was released by accident is ludicrous when the whole 'Covid' hoax was clearly long-planned and waiting to be played out as it was so fast in accordance with the Rockefeller document and Event 201. So they prepared everything in detail over decades and then sat around strumming their fingers waiting for an 'accidental' release from a bio-lab? *What??* It's crazy. Then there's the 'on purpose' claim. You want to circulate a 'deadly virus' and hide the fact that you've done so and you release it down the street from the highest-level bio-lab in China? I repeat – *What??*

You would release it far from that lab to stop any association being made. But, no, we'll do it in a place where the connection was certain to be made. Why would you need to scam 'cases' and 'deaths' and pay hospitals to diagnose 'Covid-19' if you had a real 'virus'? What are sections of the alternative media doing believing this crap? Where were all the mass deaths in Wuhan from a 'deadly pathogen' when the recovery to normal life after the initial propaganda was dramatic in speed? Why isn't the 'deadly pathogen' now circulating all over China with bodies in the street? Once again we have the technique of tell them what they want to hear and they will likely believe it. The alternative media has its 'conspiracy' and with Carlson it fits with his 'China is the danger' narrative over years. China *is* a danger as a global Cult operations centre, but not for this reason. The Wuhan lab story also has the potential to instigate conflict with China when at some stage the plan is to trigger a Problem-Reaction-Solution confrontation with the West. Question everything – *everything* – and especially when the media agrees on a common party line.

Third wave ... fourth wave ... fifth wave ...

As the book went into production the world was being set up for more lockdowns and a 'third wave' supported by invented 'variants' that were increasing all the time and will continue to do so in public statements and computer programs, but not in reality. India became the new Italy in the 'Covid' propaganda campaign and we were told to be frightened of the new 'Indian strain'. Somehow I couldn't find it within myself to do so. A document produced for the UK government entitled 'Summary of further modelling of easing of restrictions – Roadmap Step 2' declared that a third wave was inevitable (of course when it's in the script) and it would be the fault of children and those who refuse the health-destroying fake 'Covid vaccine'. One of the computer models involved came from the Cult-owned *Imperial College* and the other from Warwick University which I wouldn't trust to tell me the date in a calendar factory. The document states that both models presumed extremely high uptake

of the 'Covid vaccines' and didn't allow for 'variants'. The document states: 'The resurgence is a result of some people (mostly children) being ineligible for vaccination; others choosing not to receive the vaccine; and others being vaccinated but not perfectly protected.' The mendacity takes the breath away. Okay, blame those with a brain who won't take the DNA-modifying shots and put more pressure on children to have it as 'trials' were underway involving children as young as six months with parents who give insanity a bad name. Massive pressure is being put on the young to have the fake 'vaccine' and child age consent limits have been systematically lowered around the world to stop parents intervening. Most extraordinary about the document was its claim that the 'third wave' would be driven by 'the resurgence in both hospitalisations and deaths ... dominated by *those that have received two doses of the vaccine*, comprising around 60-70% of the wave respectively'. The predicted peak of the 'third wave' suggested 300 deaths per day with 250 of them *fully 'vaccinated' people*. How many more lies do acquiescers need to be told before they see the obvious? Those who took the jab to 'protect themselves' are projected to be those who mostly get sick and die? So what's in the 'vaccine'? The document went on:

It is possible that a summer of low prevalence could be followed by substantial increases in incidence over the following autumn and winter. Low prevalence in late summer should not be taken as an indication that SARS-CoV-2 has retreated or that the population has high enough levels of immunity to prevent another wave.

They are telling you the script and while many British people believed 'Covid' restrictions would end in the summer of 2021 the government was preparing for them to be ongoing. Authorities were awarding contracts for 'Covid marshals' to police the restrictions with contracts starting in July, 2021, and going through to January 31st, 2022, and the government was advertising for 'Media Buying Services' to secure media propaganda slots worth a potential £320 million for 'Covid-19 campaigns' with a contract not ending until March, 2022. The recipient – via a list of other front companies – was reported to be American media marketing giant Omnicom Group

Inc. While money is no object for 'Covid' the UK waiting list for all other treatment – including life-threatening conditions – passed 4.5 million. Meantime the Cult is seeking to control all official 'inquiries' to block revelations about what has really been happening and why. It must not be allowed to – we need Nuremberg jury trials in every country. The cover-up doesn't get more obvious than appointing ultra-Zionist professor Philip Zelikow to oversee two dozen US virologists, public health officials, clinicians, former government officials and four American 'charitable foundations' to 'learn the lessons' of the 'Covid' debacle. The personnel will be those that created and perpetuated the 'Covid' lies while Zelikow is the former executive director of the 9/11 Commission who ensured that the truth about those attacks never came out and produced a report that must be among the most mendacious and manipulative documents ever written – see *The Trigger* for the detailed exposure of the almost unimaginable 9/11 story in which Sabbatians can be found at every level.

Passive no more

People are increasingly challenging the authorities with amazing numbers of people taking to the streets in London well beyond the ability of the Face-Nappies to stop them. Instead the Nappies choose situations away from the mass crowds to target, intimidate, and seek to promote the impression of 'violent protestors'. One such incident happened in London's Hyde Park. Hundreds of thousands walking through the streets in protest against 'Covid' fascism were ignored by the Cult-owned BBC and most of the rest of the mainstream media, but they delighted in reporting how police were injured in 'clashes with protestors'. The truth was that a group of people gathered in Hyde Park at the end of one march when most had gone home and they were peacefully having a good time with music and chat. Face-Nappies who couldn't deal with the full-march crowd then waded in with their batons and got more than they bargained for. Instead of just standing for this criminal brutality the crowd used their numerical superiority to push the Face-Nappies out of the

park. Eventually the Nappies turned and ran. Unfortunately two or three idiots in the crowd threw drink cans striking two officers which gave the media and the government the image they wanted to discredit the 99.9999 percent who were peaceful. The idiots walked straight into the trap and we must always be aware of potential agent provocateurs used by the authorities to discredit their targets.

This response from the crowd – the can people apart – must be a turning point when the public no longer stand by while the innocent are arrested and brutally attacked by the Face-Nappies. That doesn't mean to be violent, that's the last thing we need. We'll leave the violence to the Face-Nappies and government. But it does mean that when the Face-Nappies use violence against peaceful people the numerical superiority is employed to stop them and make citizen's arrests or Common Law arrests for a breach of the peace. The time for being passive in the face of fascism is over.

We are the many, they are the few, and we need to make that count before there is no freedom left and our children and grandchildren face an ongoing fascist nightmare.

COME ON PEOPLE – IT'S TIME.

One final thought ...

The power of love
A force from above
Cleaning my soul
Flame on burn desire
Love with tongues of fire
Purge the soul
Make love your goal

I'll protect you from the hooded claw
Keep the vampires from your door
When the chips are down I'll be around
With my undying, death-defying
Love for you

Envy will hurt itself
Let yourself be beautiful
Sparkling love, flowers
And pearls and pretty girls
Love is like an energy
Rushin' rushin' inside of me

This time we go sublime
Lovers entwine, divine, divine,
Love is danger, love is pleasure
Love is pure – the only treasure

I'm so in love with you
Purge the soul
Make love your goal

The power of love
A force from above
Cleaning my soul
The power of love
A force from above
A sky-scraping dove

Flame on burn desire
Love with tongues of fire
Purge the soul
Make love your goal

Frankie Goes To Hollywood

APPENDIX

Cowan-Kaufman-Morell Statement on Virus Isolation (SOVI)

Isolation: The action of isolating; the fact or condition of being isolated or standing alone; separation from other things or persons; solitariness

Oxford English Dictionary

The controversy over whether the SARS-CoV-2 virus has ever been isolated or purified continues. However, using the above definition, common sense, the laws of logic and the dictates of science, any unbiased person must come to the conclusion that the SARS-CoV-2 virus has never been isolated or purified. As a result, no confirmation of the virus' existence can be found. The logical, common sense, and scientific consequences of this fact are:

- the structure and composition of something not shown to exist can't be known, including the presence, structure, and function of any hypothetical spike or other proteins;
- the genetic sequence of something that has never been found can't be known;
- "variants" of something that hasn't been shown to exist can't be known;
- it's impossible to demonstrate that SARS-CoV-2 causes a disease called Covid-19.

In as concise terms as possible, here's the proper way to isolate, characterize and demonstrate a new virus. First, one takes samples (blood, sputum, secretions) from many people (e.g. 500) with symptoms which are unique and specific enough to characterize an illness. Without mixing these samples with ANY tissue or products that also contain genetic material, the virologist macerates, filters and ultracentrifuges i.e. *purifies* the specimen. This common virology technique, done for decades to isolate bacteriophages¹ and so-called giant viruses in every virology lab, then allows the virologist to demonstrate with electron microscopy thousands of identically sized and shaped particles. These particles are the isolated and purified virus.

These identical particles are then checked for uniformity by physical and/or microscopic techniques. Once the purity is determined, the particles may be further characterized. This would include examining the structure, morphology, and chemical composition of the particles. Next, their genetic makeup is characterized by extracting the genetic material directly from the purified particles and using genetic-sequencing techniques, such as Sanger sequencing, that have also been around for decades. Then one does an analysis to confirm that these uniform particles are exogenous (outside) in origin as a virus is conceptualized to be, and not the normal breakdown products of dead and dying tissues.² (As of May 2020, we know that virologists have no way to determine whether the particles they're seeing are viruses or just normal breakdown products of dead and dying tissues.)³

1 Isolation, characterization and analysis of bacteriophages from the haloalkaline lake Elmenteita, Kenya Julia Khayeli Akhwale et al, PLOS One, Published: April 25, 2019.
<https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0215734> – accessed 2/15/21

2 "Extracellular Vesicles Derived From Apoptotic Cells: An Essential Link Between Death and Regeneration," Maojiao Li et al, Frontiers in Cell and Developmental Biology, 2020 October 2.
<https://www.frontiersin.org/articles/10.3389/fcell.2020.573511/full> – accessed 2/15/21

If we have come this far then we have fully isolated, characterized, and genetically sequenced an exogenous virus particle. However, we still have to show it is causally related to a disease. This is carried out by exposing a group of healthy subjects (animals are usually used) to this isolated, purified virus in the manner in which the disease is thought to be transmitted. If the animals get sick with the same disease, as confirmed by clinical and autopsy findings, one has now shown that the virus actually causes a disease. This demonstrates infectivity and transmission of an infectious agent.

None of these steps has even been attempted with the SARS-CoV-2 virus, nor have all these steps been successfully performed for any so-called pathogenic virus. Our research indicates that a single study showing these steps does not exist in the medical literature.

Instead, since 1954, virologists have taken unpurified samples from a relatively few people, often less than ten, with a similar disease. They then minimally process this sample and inoculate this unpurified sample onto tissue culture containing usually four to six other types of material – all of which contain identical genetic material as to what is called a “virus.” The tissue culture is starved and poisoned and naturally disintegrates into many types of particles, some of which contain genetic material. Against all common sense, logic, use of the English language and scientific integrity, this process is called “virus isolation.” This brew containing fragments of genetic material from many sources is then subjected to genetic analysis, which then creates in a computer-simulation process the alleged sequence of the alleged virus, a so called in silico genome. At no time is an actual virus confirmed by electron microscopy. At no time is a genome extracted and sequenced from an actual virus. This is scientific fraud.

The observation that the unpurified specimen — inoculated onto tissue culture along with toxic antibiotics, bovine fetal tissue, amniotic fluid and other tissues — destroys the kidney tissue onto which it is inoculated is given as evidence of the virus' existence and pathogenicity. This is scientific fraud.

From now on, when anyone gives you a paper that suggests the SARS-CoV-2 virus has been isolated, please check the methods sections. If the researchers used Vero cells or any other culture method, you know that their process was not isolation. You will hear the following excuses for why actual isolation isn't done:

1. There were not enough virus particles found in samples from patients to analyze.
2. Viruses are intracellular parasites; they can't be found outside the cell in this manner.

If No. 1 is correct, and we can't find the virus in the sputum of sick people, then on what evidence do we think the virus is dangerous or even lethal? If No. 2 is correct, then how is the virus spread from person to person? We are told it emerges from the cell to infect others. Then why isn't it possible to find it?

Finally, questioning these virology techniques and conclusions is not some distraction or divisive issue. Shining the light on this truth is essential to stop this terrible fraud that humanity is confronting. For, as we now know, if the virus has never been isolated, sequenced or shown to cause illness, if the virus is imaginary, then why are we wearing masks, social distancing and putting the whole world into prison?

Finally, if pathogenic viruses don't exist, then what is going into those injectable devices erroneously called "vaccines," and what is their purpose? This scientific question is the most urgent and relevant one of our time.

We are correct. The SARS-CoV2 virus does not exist.

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Bibliography

- Alinsky, Saul:** *Rules for Radicals* (Vintage, 1989)
- Antelman, Rabbi Marvin:** *To Eliminate the Opiate* (Zahavia, 1974)
- Bastardi, Joe:** *The Climate Chronicles* (Relentless Thunder Press, 2018)
- Cowan, Tom:** *Human Heart, Cosmic Heart* (Chelsea Green Publishing, 2016)
- Cowan, Tom, and Fallon Morell, Sally:** *The Contagion Myth* (Skyhorse Publishing, 2020)
- Forbes, Jack D:** *Columbus And Other Cannibals – The Wetiko Disease of Exploitation, Imperialism, and Terrorism* (Seven Stories Press, 2008 – originally published in 1979)
- Gates, Bill:** *How to Avoid a Climate Disaster: The Solutions We Have and the Breakthroughs We Need* (Allen Lane, 2021)
- Huxley, Aldous:** *Brave New World* (Chatto & Windus, 1932)
- Köhnlein, Dr Claus, and Engelbrecht, Torsten:** *Virus Mania* (emu-Verlag, Lahnstein, 2020)
- Lanza, Robert, and Berman, Bob:** *Biocentrism* (BenBella Books, 2010)
- Lash, John Lamb:** *Not In His Image* (Chelsea Green Publishing, 2006)
- Lester, Dawn, and Parker, David:** *What Really Makes You Ill – Why everything you thought you knew about disease is wrong* (Independently Published, 2019)
- Levy, Paul:** *Dispelling Wetiko, Breaking the Spell of Evil* (North Atlantic Books, 2013)
- Marx, Karl:** *A World Without Jews* (Philosophical Library, first edition, 1959)
- Mullis, Kary:** *Dancing Naked in the Mine Field* (Bloomsbury, 1999)
- O'Brien, Cathy:** *Trance-Formation of America* (Reality Marketing, 1995)
- Scholem, Gershon:** *The Messianic Idea in Judaism* (Schocken Books, 1994)
- Schwab, Klaus, and Davis, Nicholas:** *Shaping the Future of the Fourth Industrial Revolution: A guide to building a better world* (Penguin Books, 2018)
- Schwab, Klaus:** *The Great Reset* (Agentur Schweiz, 2020)
- Sunstein, Cass and Thaler, Richard:** *Nudge: Improving Decisions About Health, Wealth, and Happiness* (Penguin, 2009)
- Swan, Shanna:** *Count Down: How Our Modern World Is Threatening Sperm Counts, Altering Male and Female Reproductive Development and Imperiling the Future of the Human Race* (Scribner, 2021)
- Tegmark, Max:** *Our Mathematical Universe: My Quest for the Ultimate Nature of Reality* (Penguin, 2015)
- Velikovsky, Immanuel:** *Worlds in Collision* (Paradigma, 2009)

Wilton, Robert: *The Last Days of the Romanovs* (Blurb, 2018, first published 1920)

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Ickonic is something that has been a dream of mine for the last 5 years, growing up around alternative information I have always had a natural interest in what is going on in the World and what could I do to make it better.

Across the range of subjects and positions of influence occupied mainly by people who don't strive to make things better it's the Media that I have always found the most frustrating and fascinating. Mainly because if the Media did their Jobs properly then so much of the negative things happening in the World simply would not be able to happen, because they would be exposed within a heartbeat.

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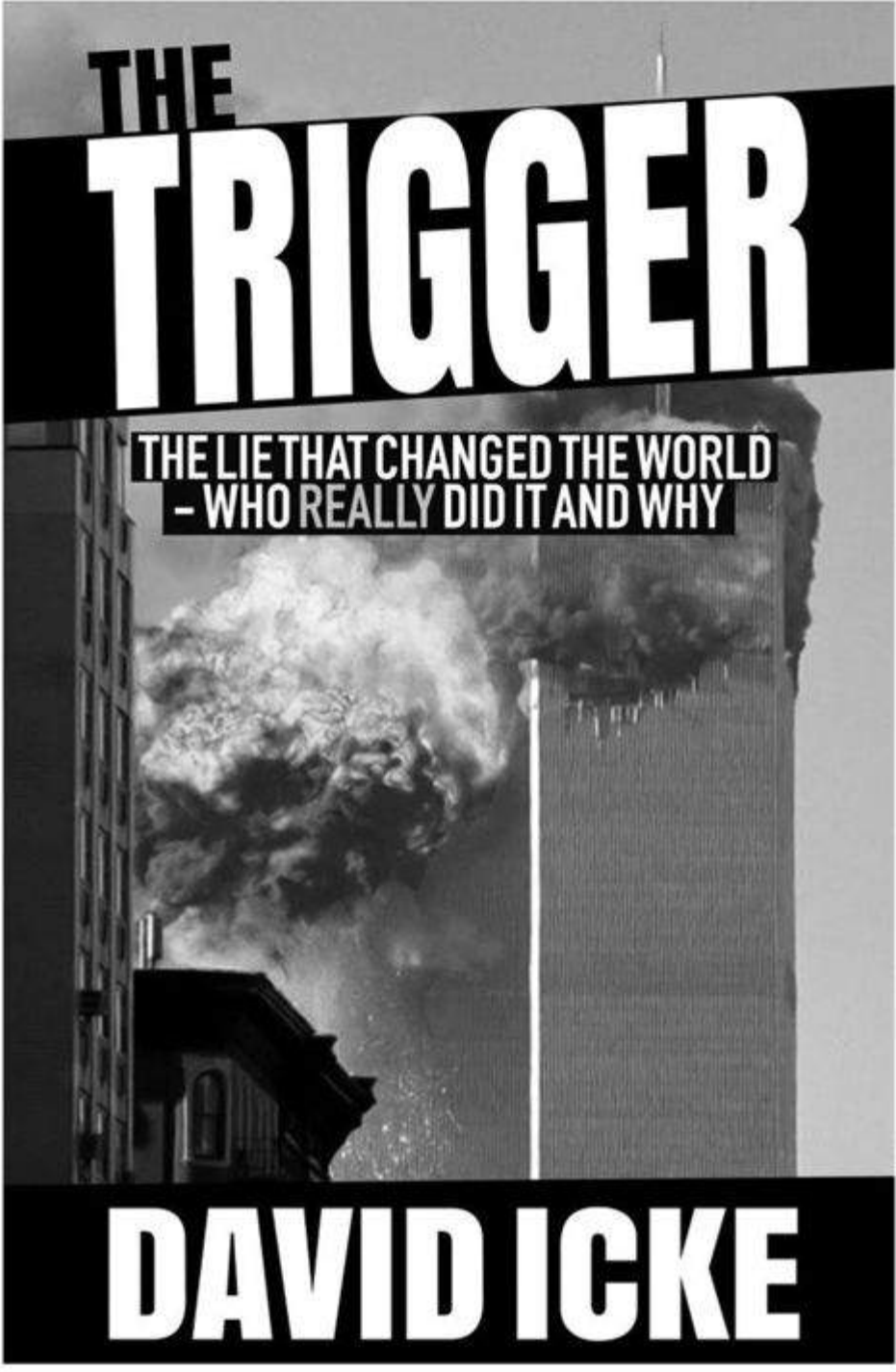
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noun

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