This International Student Edition is for use outside of the U.S.

NINTH EDITION

Digital Electronics

Principles & Applications

McGraw Hill

Roger Tokheim • Patrick E. Hoppe

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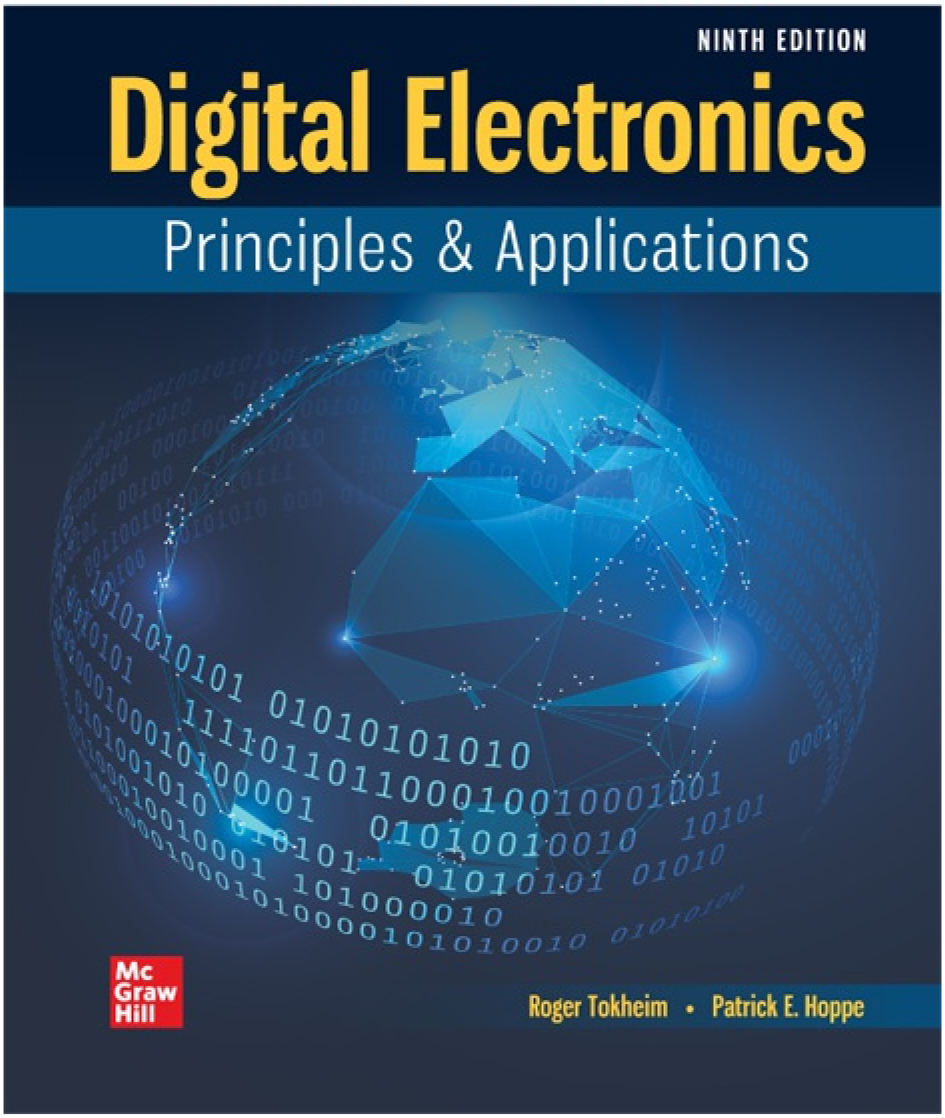
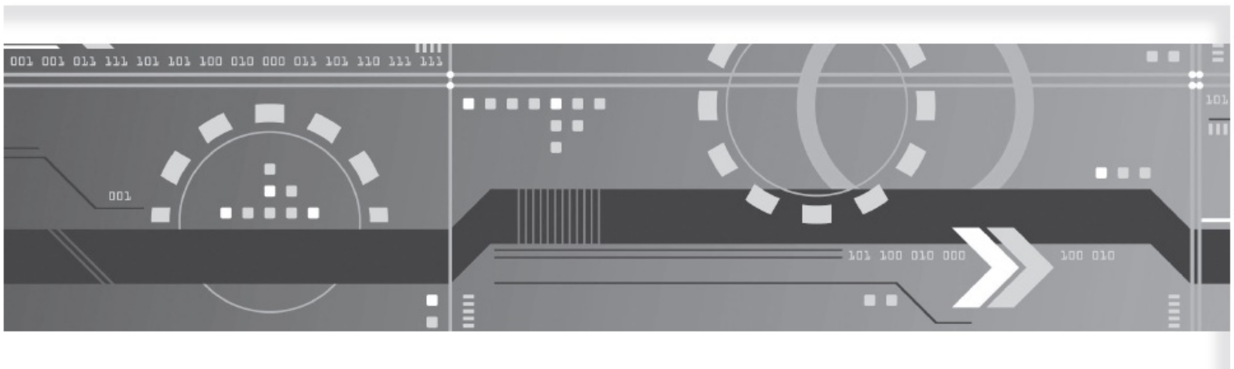


Digital Electronics



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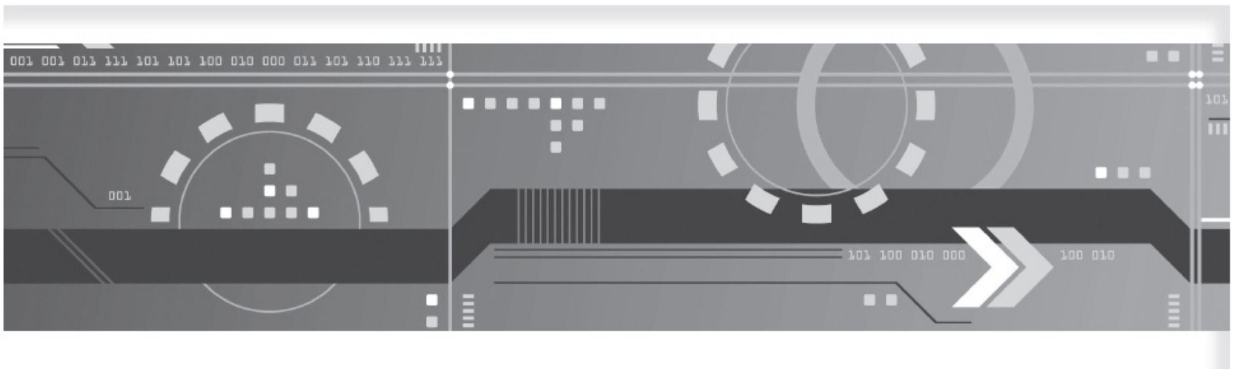

Roger Tokheim

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DIGITAL ELECTRONICS: PRINCIPLES AND APPLICATIONS

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This book is printed on acid-free paper.

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Preface

Digital Electronics: Principles and Applications, ninth edition, is an easy-to-read introductory text for students new to the field of digital electronics. Providing entry-level knowledge and skills for a wide range of occupations is the goal of this textbook and its ancillary materials. Prerequisites are general math and introductory electricity/electronics. Binary math, Boolean concepts, simple programming, and various codes are introduced and explained as needed. Concepts are connected to practical applications, and a systems approach is followed that reflects current practice in industry. Earlier editions of the text have been used successfully in a wide range of programs: electronic technology, electrical trades and apprenticeship training, computer repair, communications electronics, and computer science, to name a few. This concise and practical text can be used in any program needing a quick and readable overview of digital principles.

New to This Edition

Over 100 Multisim simulation files have been developed to bring the examples within these chapters to life. These simulation files can be run within Multisim, to provide students with a firsthand experience with the examples presented in the textbook. Multisim simulation files have also been developed for the laboratory experiments to provide an improved learning experience for the student.

The experiments in the *Experiments Manual* are designed to provide a hands-on learning experience, to reinforce the topics covered in this textbook. The titles of the individual experiments associated with each chapter are listed in a new section, Correlational Experiments, following the summary at the end of each chapter in this textbook. This listing will help the reader identify the experiments in the Experiments Manual associated with the topics covered in each chapter.

Chapter 1

- Expanded the formulas and examples.
- Revised the section on the oscilloscope.

Chapter 2

- Revised and expanded the section on binary to decimal conversion.
- Expanded the Bit, Bytes, Nibbles, and Words section.

Chapter 3

- Revised and expanded the section on the universal NAND gate.
- Added a new section on the use of a NOR gate as a universal gate.
- Revised the coverage of DeMorgan’s theorem.
- Revised the Summary section.

Chapter 4

- Added a new section on Boolean algebra.
- Expanded the coverage of Karnaugh maps.
- Revised the Summary section.

Chapter 5

- Expanded the section on digital IC specifications.
- Added new examples for the calculation of fan-out and power dissipation.

Chapter 6

- Revised the coverage of the ASCII codes.

Chapter 8

- Revised and expanded the section on ripple counters.

Chapter 11

- Revised the coverage of optical storage devices.

Chapter 12

- Introduced a real-time clock IC in the LSI digital clock section.
- Expanded the coverage of distance measurement using ultrasound.

Chapter 13

- Expanded the section on the microcomputer.

Chapter 14

- Revised the coverage of operational amplifiers in D/A conversion.

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Additional Resources

An ***Experiments Manual*** for *Digital Electronics* contains a comprehensive test, a variety of hands-on lab exercises and experiments, and additional problems for each chapter in the textbook.

McGraw-Hill Connect includes comprehensive Multisim files, keyed to circuits found in the ninth edition, and a Multisim primer, which provides a tutorial on the software for new users.

Instructors can access instructor resources on **McGraw-Hill Connect** to find a wide selection of information including:

- An Instructor's Manual that includes a list of the parts and equipment needed to perform lab experiments, learning outcomes for each chapter, answers to chapter review questions and problems, and more.
- PowerPoint presentations that provide comprehensive coverage of the topics in each chapter. A set of questions at the end of each chapter's slide deck provides a review of the topics covered.
- An image library that contains all of the figures presented in this textbook.
- A test bank with questions for each chapter.

Remote Proctoring & Browser-Locking Capabilities

New remote proctoring and browser-locking capabilities, hosted by Proctorio within Connect, provide control of the assessment environment by enabling security options and verifying the identity of the student.

Seamlessly integrated within Connect, these services allow instructors to control students' assessment experience by restricting browser activity, recording students' activity, and verifying students are doing their own work.

Instant and detailed reporting gives instructors an at-a-glance view of potential academic integrity concerns, thereby avoiding personal bias and supporting evidence-based claims.

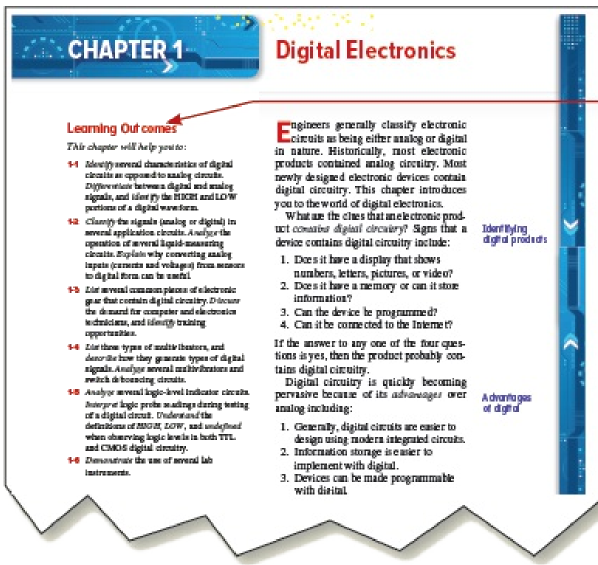
Acknowledgments

Roger Tokheim thanks family members Marshall, Rachael, Dan, Jack, Ben, and Carrie for their help on this project.

Patrick Hoppe would like to thank his wife Rose and the team at McGraw-Hill for their invaluable help on this project: Theresa Collins, Product Development Coordinator; Beth Baugh, Product Developer; Carey Lange, Copy Editor; Sandy Wille and Jane Mohr, Content Project Managers; David Hash, Designer; and Lorraine Buczek, Content Licensing Specialist.

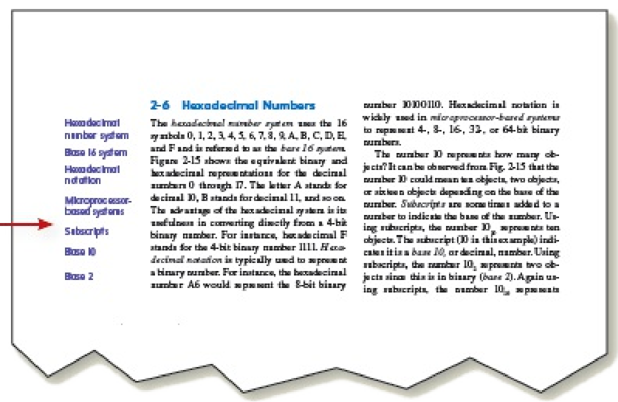
Walkthrough

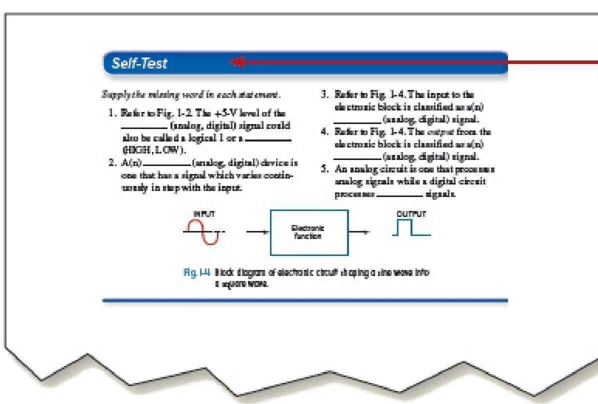
Digital Electronics: Principles and Applications, ninth edition, is designed for a first course in digital electronics. It provides a concise, modern, and practical approach that's suitable for a range of electricity and electronics programs. With its easy-to-read style, numerous full-color illustrations, and accessible math level, the text is ideal for readers who need to learn the essentials of digital electronics and apply them to on-the-job situations.



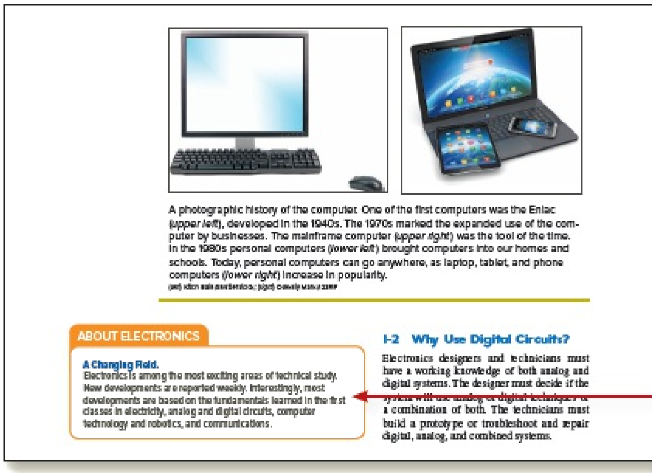
Each chapter begins with a list of ***learning outcomes*** that tell the reader what he or she should expect to accomplish by the end of the chapter. The outcomes are tied to the chapter subsections.

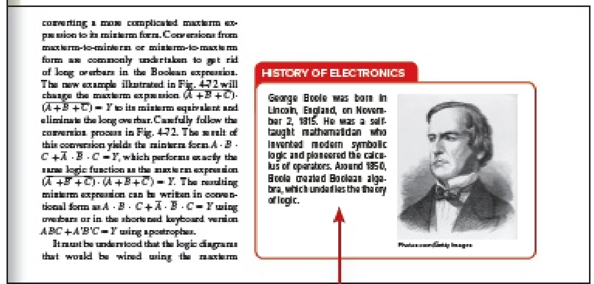
Key terms are carefully defined and explained in the text and listed in the margins so students can easily identify them.



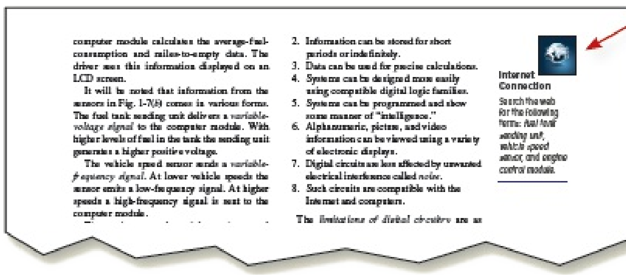


The ***self-tests*** can either help students identify areas that need further study or serve as positive reinforcement for material that students already know. After completing a self-test, students may check their answers in the ***Answers to Self-Tests*** sections at the end of each chapter.

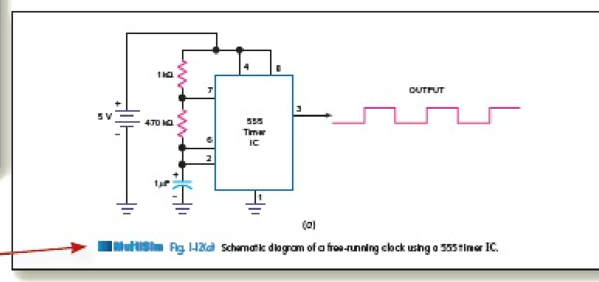




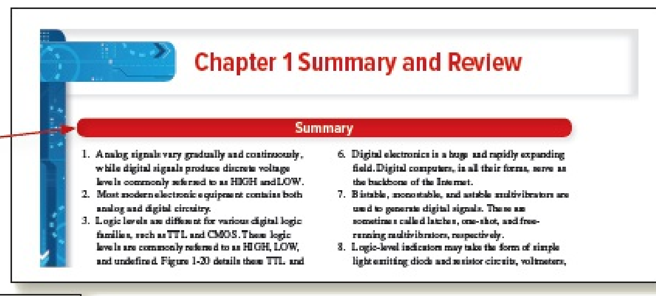
The features ***History of Electronics*** and ***About Electronics*** add depth to the topics and highlight new and interesting technologies or facts.



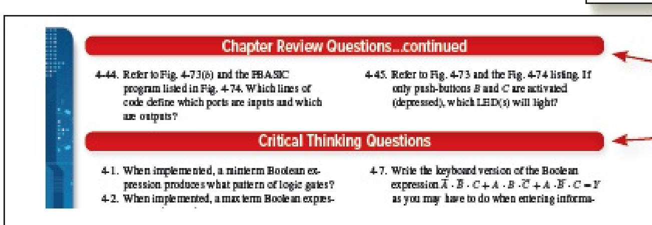
Internet connections encourage students to do online research on certain topics.



Multisim examples and images used throughout this book "bring the material to life" for students. A Multisim icon identifies circuit examples that have associated Multisim simulation files.

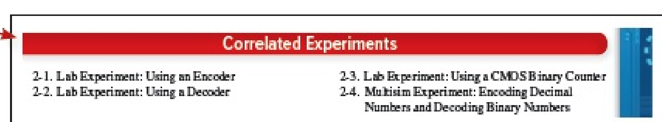


Critical facts and principles are reviewed in the ***Summary and Review*** section at the end of each chapter.



Chapter review questions are found at the end of each chapter, as are ***critical thinking questions***.

Correlated Experiments at the end of each chapter lists experiments in the accompanying ***Experiments Manual*** that provide students hands-on experience working on topics raised the chapter.



About the Author

Over several decades, Roger L. Tokheim has published many textbooks and lab manuals in the areas of digital electronics and microprocessors. His books have been translated into nine languages. He taught technical subjects including electronics for more than 35 years in public schools.

Patrick Hoppe has been the Division Chair for Engineering Technology and lead electronics instructor at Gateway Technical College for the past 21 years. He is also the coauthor of *Electronic Principles*, 9th edition (McGraw-Hill) and its *Experiments Manual*. Pat has received state and national awards for his teaching, including the NISOD Excellence award.

Safety

Electric and electronic circuits can be dangerous. Safe practices are necessary to prevent electrical shock, fires, explosions, mechanical damage, and injuries resulting from the improper use of tools.

Perhaps the greatest hazard is electrical shock. A current through the human body in excess of 10 milliamperes can paralyze the victim and make it impossible to let go of a "live" conductor or component. Ten milliamperes is a rather small amount of current flow: It is only *ten one-thousandths* of an ampere. An ordinary flashlight can provide more than 100 times that amount of current!

Flashlight cells and batteries are safe to handle because the resistance of human skin is normally high enough to keep the current flow very small. For example, touching an ordinary 1.5-V cell produces a current flow in the microampere range (a microampere is one-millionth of an ampere). The amount of current is too small to be noticed.

High voltage, one the other hand, can force enough current through the skin to produce a shock. If the current approaches 100 milliamperes or more, the shock can be fatal. Thus, the danger of shock increases with voltage. Those who work with high voltage must be properly trained and equipped.

When human skin is moist or cut, its resistance to the flow of electricity can drop drastically. When this happens, even moderate voltages may cause a serious shock. Experienced technicians know this, and they also know that so-called low-voltage equipment may have a high-voltage section or two. In other words, they do not practice two methods of working with circuits: one for high voltage and one for low voltage. They follow safe procedures at all times. They do not assume protective devices are working. They do not assume a circuit is off even though the switch is in the OFF position. They know the switch could be defective.

Even a low-voltage, high-current-capacity system like an automotive electrical system can be quite dangerous. Short-circuiting such a system with a ring or metal watchband can cause very severe burns—especially when the ring or band welds to the points being shorted.

As your knowledge and experience grow, you will learn many specific safe procedures for dealing with electricity and electronics. In the meantime:

1. Always follow procedures.
2. Use service manuals as often as possible. They often contain specific safety information. Read, and comply with, all appropriate material safety data sheets.
3. Investigate before you act.
4. When in doubt, *do not act*. Ask your instructor or supervisor.

General Safety Rules for Electricity and Electronics

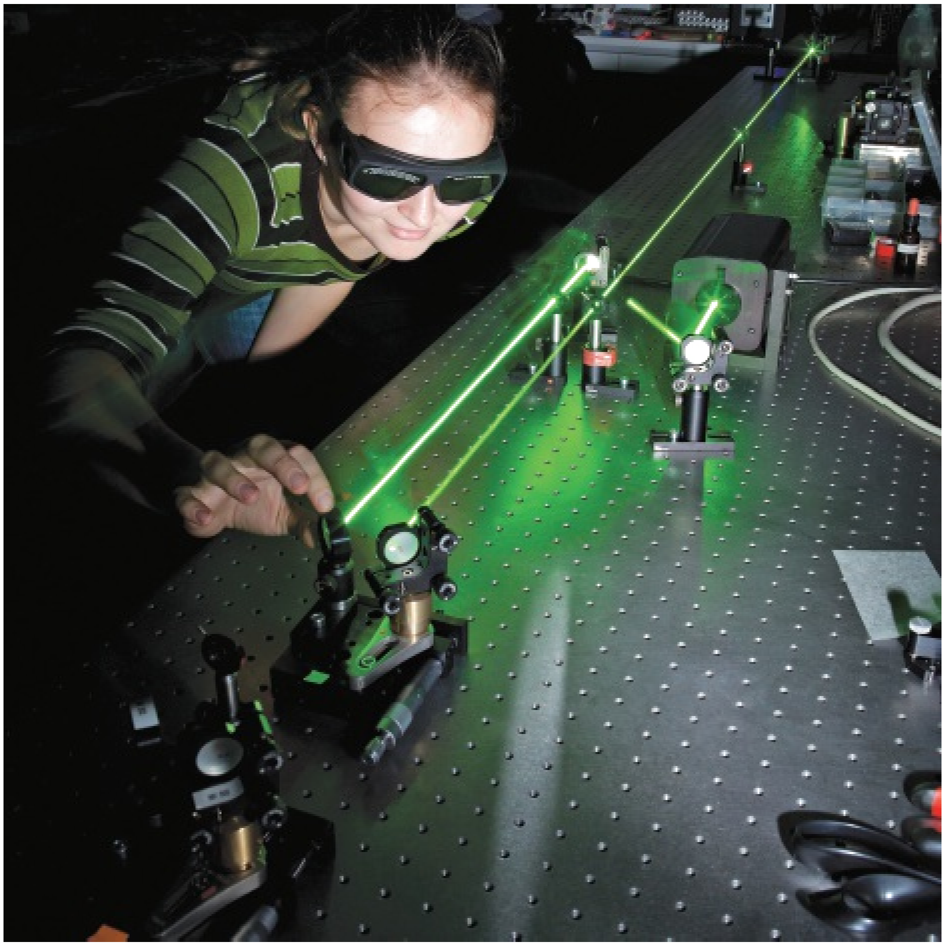
Safe practices will protect you and your fellow workers. Study the following rules. Discuss them with others, and ask your instructor about any you do not understand.

1. Do not work when you are tired or taking medicine that makes you drowsy.
2. Do not work in poor light.
3. Do not work in damp areas or with wet shoes or clothing.
4. Use approved tools, equipment, and protective devices.
5. Avoid wearing rings, bracelets, and similar metal items when working around exposed electric circuits.
6. Never assume that a circuit is off. Double-check it with an instrument that you are sure is operational.
7. Some situations require a "buddy system" to guarantee that power will not be turned on while a

technician is still working on a circuit.

8. Never tamper with or try to override safety devices such as an interlock (a type of switch that automatically removes power when a door is opened or a panel removed).
9. Keep tools and test equipment clean and in good working condition. Replace insulated probes and leads at the first sign of deterioration.
10. Some devices, such as capacitors, can store a *lethal* charge. They may store this charge for long periods of time. You must be certain these devices are discharged before working around them.
11. Do not remove grounds and do not use adapters that defeat the equipment ground. page xvi
12. Use only an approved fire extinguisher for electrical and electronic equipment. Water can conduct electricity and may severely damage equipment. Carbon dioxide (CO_2) or Halotron-type extinguishers are usually preferred. Foam-type extinguishers may also be desired in *some* cases. Commercial fire extinguishers are rated for the type of fires for which they are effective. Use only those rated for the proper working conditions.
13. Follow directions when using solvents and other chemicals. They may be toxic, flammable, or may damage certain materials such as plastics. Always read and follow the appropriate material safety data sheets.
14. A few materials used in electronic equipment are toxic. Examples include tantalum capacitors and beryllium oxide transistor cases. These devices should not be crushed or abraded, and you should wash your hands thoroughly after handling them. Other materials (such as heat shrink tubing) may produce irritating fumes if overheated. Always read and follow the appropriate material safety data sheets.
15. Certain circuit components affect the safe performance of equipment and systems. Use only exact or approved replacement parts.
16. Use protective clothing and safety glasses when handling high-vacuum devices such as picture tubes and cathode-ray tubes.
17. Don’t work on equipment before you know proper procedures and are aware of any potential safety hazards.
18. Many accidents have been caused by people rushing and cutting corners. Take the time required to protect yourself and others. Running, horseplay, and practical jokes are strictly forbidden in shops and laboratories.
19. Never look directly into light emitting diodes or fiber- optic cables; some light sources, although invisible, can cause serious eye damage.

Circuits and equipment must be treated with respect. Learn how they work and the proper way of working on them. Always practice safety. Your health and life depend on it.



Electronics workers use specialized safety knowledge.

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CHAPTER 1 Digital Electronics

Learning Outcomes

This chapter will help you to:

1-1 *Identify* several characteristics of digital circuits as opposed to analog circuits. *Differentiate* between digital and analog signals, and *identify* the HIGH and LOW portions of a digital waveform.

1-2 *Classify* the signals (analog or digital) in several application circuits. *Analyze* the operation of several liquid-measuring circuits. *Explain* why converting analog inputs (currents and voltages) from sensors to digital form can be useful.

1-3 *List* several common pieces of electronic gear that contain digital circuitry. *Discuss* the demand for computer and electronics technicians, and *identify* training opportunities.

1-4 *List* three types of multivibrators, and *describe* how they generate types of digital signals. *Analyze* several multivibrators and switch debouncing circuits.

1-5 *Analyze* several logic-level indicator circuits. *Interpret* logic probe readings during testing of a digital circuit. *Understand* the definitions of *HIGH*, *LOW*, and *undefined* when observing logic levels in both TTL and CMOS digital circuitry.

1-6 *Demonstrate* the use of several lab instruments.

Engineers generally classify electronic circuits as being either analog or digital in nature. Historically, most electronic products contained analog circuitry. Most newly designed electronic devices contain digital circuitry. This chapter introduces you to the world of digital electronics.

What are the clues that an electronic product *contains digital circuitry*? Signs that a device contains digital circuitry include:

Identifying digital products

1. Does it have a display that shows numbers, letters, pictures, or video?
2. Does it have a memory or can it store information?
3. Can the device be programmed?
4. Can it be connected to the Internet?

If the answer to any one of the four questions is yes, then the product probably contains digital circuitry.

Digital circuitry is quickly becoming pervasive because of its *advantages* over analog including:

Advantages of digital

1. Generally, digital circuits are easier to design using modern integrated circuits.
2. Information storage is easier to implement with digital.
3. Devices can be made programmable with digital.
4. More accuracy and precision are possible.
5. Digital circuitry is less affected by unwanted electrical interference called noise.

All persons working in electronics must have knowledge of digital electronic circuits. You will use simple integrated circuits and displays to demonstrate the principles of digital electronics.

1-1 What Is a Digital Signal?

In your experience with electricity and electronics you have probably used analog circuits. The circuit in Fig. 1-1(*a*) puts out an *analog signal* or voltage. As the wiper on the potentiometer is moved upward, the voltage from points *A* to *B gradually* increases. When the wiper is moved downward, the voltage gradually decreases from 5 to 0 volts (V). The waveform diagram in Fig. 1-1(*b*) is a graph of the analog output. On the left side the voltage from *A* to *B* is gradually increasing to 5 V; on the right side the voltage is gradually decreasing to 0 V. By stopping the potentiometer wiper at any midpoint, we can get an output voltage anywhere between 0 and 5 V. An analog device, then, is one that has a signal which *varies continuously* in step with the input.

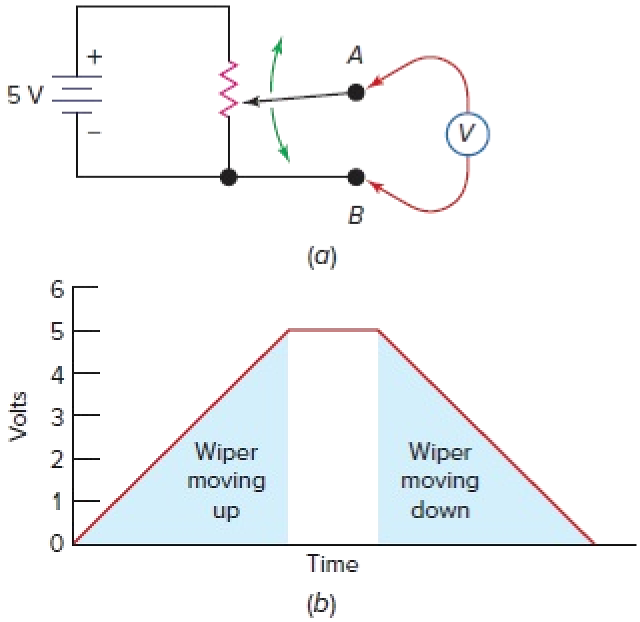

Fig. 1-1 (*a*) Analog output from a potentiometer. (*b*) Analog signal waveform.

Analog signal

A digital device operates with a digital signal. Figure 1-2(*a*) pictures a square-wave generator. The generator produces a square waveform that is displayed on the oscilloscope. The digital signal is only at +5 V *or* at 0 V, as diagrammed in Fig. 1-2(*b*). The voltage at point *A* moves from 0 to 5 V. The voltage then stays at +5 V for a time. At point *B* the voltage drops immediately from +5 to 0 V. The voltage then stays at 0 V for a time. Only two voltages are present in a digital electronic circuit. In the waveform diagram in Fig. 1-2(*b*) these voltages are labeled *HIGH* and *LOW*. The HIGH voltage is +5 V; the LOW voltage is 0 V. Later we shall call the HIGH voltage (+5 V) a logical 1 and the LOW voltage (0 V) a logical 0. Circuits that handle only HIGH and LOW signals are called *digital circuits*.

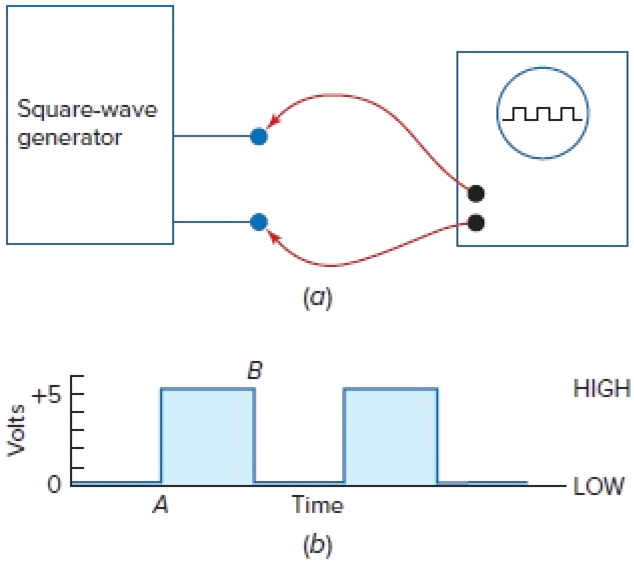

Fig. 1-2 (*a*) Digital signal displayed on scope. (*b*) Digital signal waveform.

HIGH and LOW signals

Digital circuits

The digital signal in Fig. 1-2(*b*) could also be generated by a simple on-off switch. A digital signal could also be generated by a transistor turning on and off. Digital electronic signals are usually generated and processed by integrated circuits (ICs).

Both analog and digital signals are represented in graph form in Figs. 1-1 and 1-2. A *signal* can be defined as useful information transmitted within, to, or from electronic circuits. Signals are commonly represented as a voltage varying with time, as they are in Figs. 1-1 and 1-2. However, a signal could be an electric current that either varies continuously (analog) or has an on-off (HIGH-LOW) characteristic (digital). Within most digital circuits, it is customary to represent signals in the voltage versus time format. When digital circuits are interfaced with nondigital devices such as lamps and motors, then the signal can be thought of as current versus time.

The standard *volt-ohm-millimeter* (VOM) shown in Fig. 1-3(*a*) is an example of an *analog* measuring device. As the voltage, resistance, or current being measured by the VOM increases, the needle *gradually and continuously moves* up the scale. A *digital multimeter* (DMM) is shown in Fig. 1-3(*b*). This is an example of a *digital* measuring device. As the current, resistance, or voltage being measured by the DMM increases, the display *jumps upward in small steps*. The DMM is an example of digital circuitry taking over tasks previously performed only by analog devices. This *trend toward digital circuitry* is growing. Currently, the modern technician's bench probably has both a VOM and a DMM.