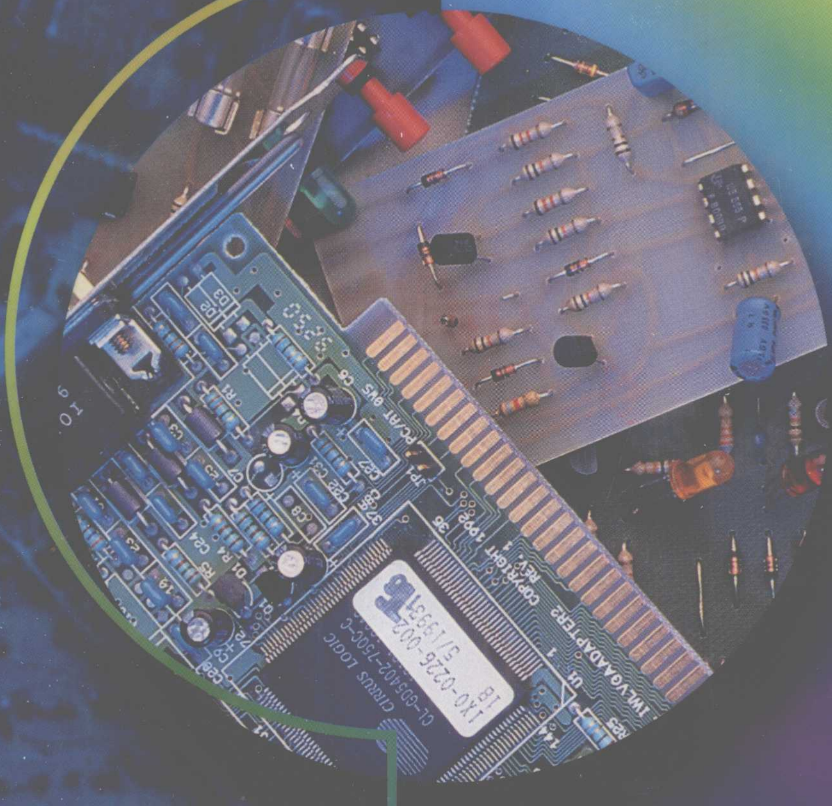
DIGITAL ELECTRONICS

Principles and Applications



Fifth Edition

Tokheim

Basic Skills in Electricity and Electronics

Editors' Foreword

The Glencoe *Basic Skills in Electricity and Electronics* series has been designed to provide entry-level competencies in a wide range of occupations in the electrical and electronic fields. The series consists of coordinated instructional materials designed especially for the career-oriented student. Each major subject area covered in the series is supported by a textbook, an experiments manual, and an instructor's productivity center. All the materials focus on the theory, practices, applications, and experiences necessary for those preparing to enter technical careers.

There are two fundamental considerations in the preparation of materials for such a series: the needs of the learner and needs of the employer. The materials in this series meet these needs in an expert fashion. The authors and editors have drawn upon their broad teaching and technical experiences to accurately interpret and meet the needs of the student. The needs of business and industry have been identified through personal interviews, industry publications, government occupational trend reports, and reports by industry associations.

The processes used to produce and refine the series have been ongoing. Technological change is rapid and the content has been revised to focus on current trends. Refinements in pedagogy have been defined and implemented based on classroom testing and feedback from students and instructors using the series. Every effort has been made to offer the best possible learning materials.

The widespread acceptance of the *Basic Skills in Electricity and Electronics* series and the positive responses from users confirm the basic soundness in content and design of these materials as well as their effectiveness as learning tools. Instructors will find the texts and manuals in each of the subject areas logically structured, well-paced, and developed around a framework of modern objectives. Students will find the materials to be readable, lucidly illustrated, and interesting. They will also find a generous amount of self-study and review materials and examples to help them determine their own progress.

Both the initial and on-going success of this series are due in large part to the wisdom and vision of Gordon Rockmaker who was a magical combination of editor, writer, teacher, electrical engineer and friend. Gordon has retired but he is still our friend. The publisher and editors welcome comments and suggestions from instructors and students using the materials in this series.

Charles A. Schuler,
Project Editor
and
Brian P. Mackin,
Editorial Director

Basic Skills in Electricity and Electronics

Charles A. Schuler, Project Editor

New Editions in This Series

Electricity: Principles and Applications, Fifth Edition, Richard J. Fowler
Electronics: Principles and Applications, Fifth Edition, Charles A. Schuler
Digital Electronics: Principles and Applications, Fifth Edition, Roger L. Tokheim

Other Series Titles Available:

Communication Electronics, Second Edition, Louis E. Frenzel
Microprocessors: Principles and Applications, Second Edition, Charles M. Gilmore
Industrial Electronics, Frank D. Petruzella
Mathematics for Electronics, Harry Forster, Jr.

Preface

Digital Electronics: Principles and Applications, Fifth Edition, is designed to be used as an introductory text for students who are new to the field of electronics. Prerequisites are general mathematics and basic DC circuits. Digital electronics can be studied before or concurrently with a course in basic electronics, since knowledge of active discrete components is not a prerequisite. Binary mathematics and Boolean concepts are introduced and explained in this book as needed.

Digital electronics is not a specialized field in electronics. Digital circuits were first used in computing devices, but they are now commonly found in a broad range of products. The advances in microelectronic design and manufacturing, computer technology, and information systems, have caused a rapid increase in the use of digital circuits.

For this edition, we sought the advice of instructors who have used the work for many years and instructors who have used the text for only a short period of time. They provided precise recommendations and consistent responses to questionnaires. Their collective information and suggestions are included in this new edition. The text interior was redesigned to use color more effectively, while retaining the popular marginal color strip. Students can quickly find their chapter-ending assignments with the red strip. Highlighted key terms now appear on each page across from their point of discussion in the text. Color strips are also used as a quick thumb reference to find the numerous illustrative examples within a chapter. The text design uses a consistent color-coding of circuit components. This edition also contains informative "Did You Know," "Job Tips," and "About Electronics" sidebars, which should spark interesting in-class discussions.

The fifth edition of *Digital Electronics: Principles and Applications* includes numerous changes and improvements that are a direct result of the reviewers' recommendations and the feedback from instructors of digital electronics. De Morgan's Theorems are now introduced in Chapter 4. Chapter 5 now contains coverage of optoisolators and stepper motors. Several subtle changes in the first chapter include information on the DT-1000 trainer display boards and questions related to using electronic simulation software. The chapter also discusses the use of simulation software. Additional objectives and coverage strengthens the coverage of Chapter 5, including interfacing circuits featuring an optoisolator and the operation of stepper motor driver circuits. Several of the changes in Chapter 6 relate to the Gray code commonly associated with *optical shaft encoding*. Instructors and students should both enjoy the new section in Chapter 8 on Counting Real World Events. Additional coverage of the *logic probe, DMM/Logic Probe, IC tester,* the *Portable IC Tester,* and the *Digital Real Time*™ *Oscilloscope* strengthens this chapter. Coverage of CPUs is improved in Chapter 10, along with coverage of the *arithmetic-logic unit (ALU).* A noteworthy addition to Chapter 11 is updated coverage of memories. Chapter 12 includes important new sections, including Section 12-18 on Programmable Logic Controllers (PLCs), and 12-19 on microcontrollers, along with several interesting examples. This edition retains the popular analysis techniques that help to develop the student's ability to troubleshoot. It also retains the electronic game circuits demonstrating the function of digital subsystems. In response to reviewer requests and recommendations received from the questionnaires, the Experiments Manual now contains nine experiments that can be performed using computer simulation software, such as Electronics Workbench®.

The material in this text is based on carefully selected and formulated performance objectives. Surveys, classroom testing, and feedback from students, teachers, and industry representatives were used in developing these objectives. The systems-subsystems approach is fundamental to digital electronics because of the extensive use of medium-, large-, and very large-scale integrated circuits. Small-scale integrated circuits are used when students learn the fundamentals. Most of the circuits in the text can be wired for classroom demonstration using off-the-shelf TTL or CMOS ICs. A companion volume, *Experiments Manual for Digital Electronics: Principles and Applications,* Fifth Edition, is closely correlated with this textbook. Digital design problems, troubleshooting problems, and chapter tests are also available in the companion experiments manual.

Appreciation should be given to the many instructors, students, and industry representatives who contributed to this book. I would like to give special thinks to family members—Marshall, Rachael, Dan, and Carrie for their work on this textbook.

Acknowledgements

The author, project editor, and publisher would like to thank the instructors listed below who provided general and detailed comments, and those who responded to the survey that was sent out while the book was being revised. Their comments and suggestions provided the valuable input necessary to make a good book even better.

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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 electrical flow: It is only *ten one-thousandths* of an ampere. An ordinary flashlight uses 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). This amount of current is too small to be noticed.

High voltage, on 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.

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

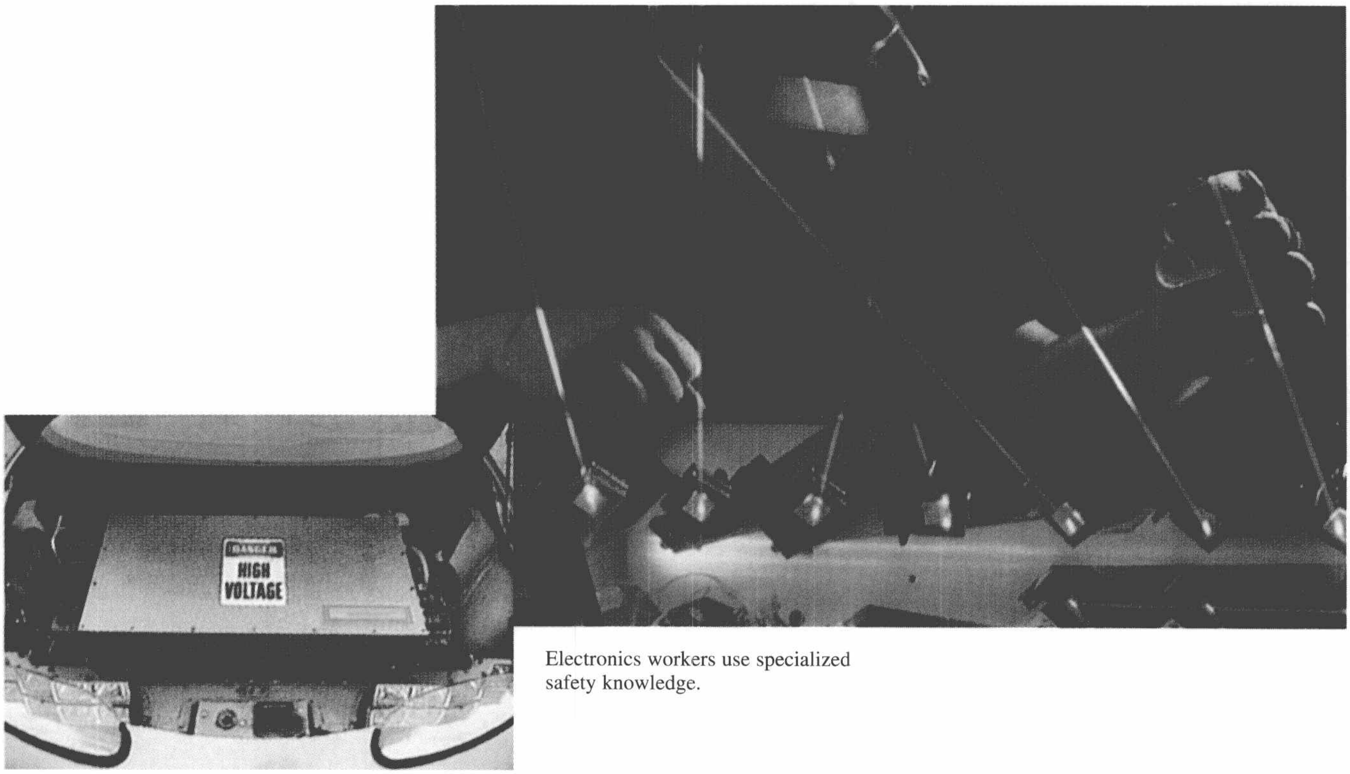
Safe practices will protect you and your fellow workers. Study the following rules. Discuss them with others, and ask your instructor about any you do not understand.

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 adaptors that defeat the equipment ground.
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 halogenated-type extinguishers are usually preferred. Foam-type extin-

guishers 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.

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

Chapter Objectives

This chapter will help you to:

1. *Identify* several characteristics of digital circuits as opposed to linear (analog) circuits.
2. *Classify* devices as using digital, analog, or a combination of technologies.
3. *Differentiate* between digital and analog signals and *identify* the HIGH and LOW portions of the digital waveform.
4. *List* three types of multivibrators and *describe* the general purpose of each type of circuit.
5. *Analyze* simple logic-level indicator circuits.
6. *Cite* several reasons for using digital circuits.
7. *Write* several limitations of digital circuits.

This chapter introduces you to digital electronics. Digital electronics is the world of the calculator, the computer, the integrated circuit, and the binary numbers 0 and 1. This is an exciting field within electronics because the uses for digital circuits are expanding so rapidly. One small integrated circuit can perform the task of thousands of transistors, diodes, and resistors. You see digital circuits in operation every day. At stores the cash registers read out digital displays. The tiny pocket calculators verge on becoming personal computers. All sizes of computers perform complicated tasks with fantastic speed and accuracy. Factory machines are controlled by digital circuits. Digital clocks and watches flash the time. Most automobiles use microprocessors to control engine functions. Technicians use digital voltmeters and frequency counters.

All persons working in electronics must now understand digital electronic circuits. The inexpensive integrated circuit has made the subject of digital electronics easy to study. You will use many integrated circuits to construct digital circuits.

Calculators

Integrated circuit

Digital clocks

Microprocessors

Personal computers

1-1 What Is a Digital Circuit?

In your experience with electricity and electronics you have probably used analog circuits. The circuit in Fig. 1-1(*a*) on the next page 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.

Analog signal

A digital device operates with a digital signal. Figure 1-2(*a*) on the next page 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 diagramed 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

Digital circuits

Logical 0s and 1s

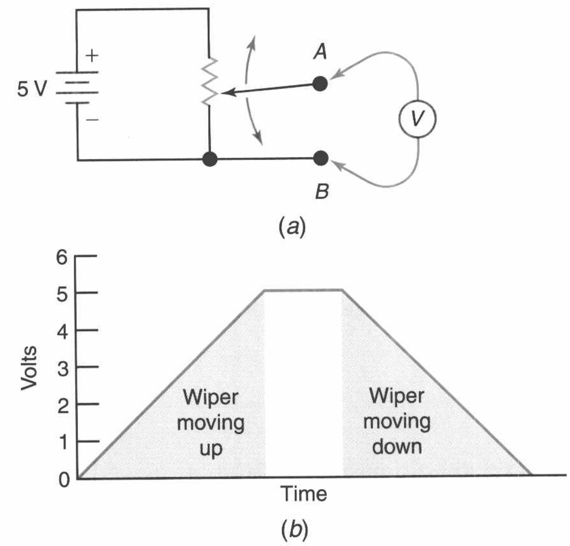


Fig. 1-1 (*a*) Analog output from a potentiometer. (*b*) Analog signal waveform.

Signal

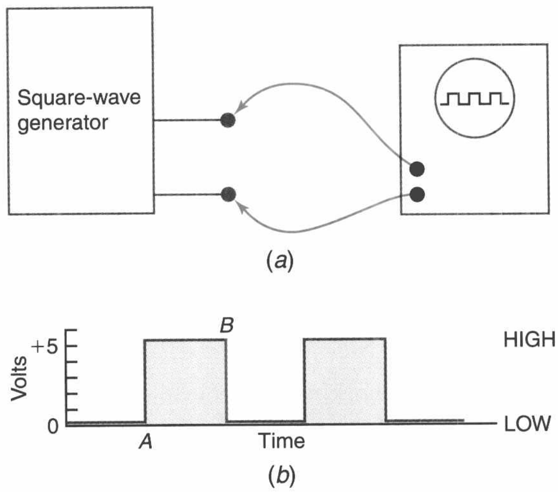


Fig. 1-2 (*a*) Digital signal displayed on scope. (*b*) Digital signal waveform.

Volt-ohm-millimeter

Digital multimeter

HIGH and LOW signals

Trend toward digital circuitry

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.* We mentioned that digital electronics is the world of logical 0s and 1s. The voltages in Fig. 1-2(*b*) are rather typical of the voltages you will be working with in digital electronics.

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. In recent years digital electronic signals usually have been 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 electronics 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 electrical current that either varies continuously (analog) or has an on-off 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 an analog VOM and a digital DMM.

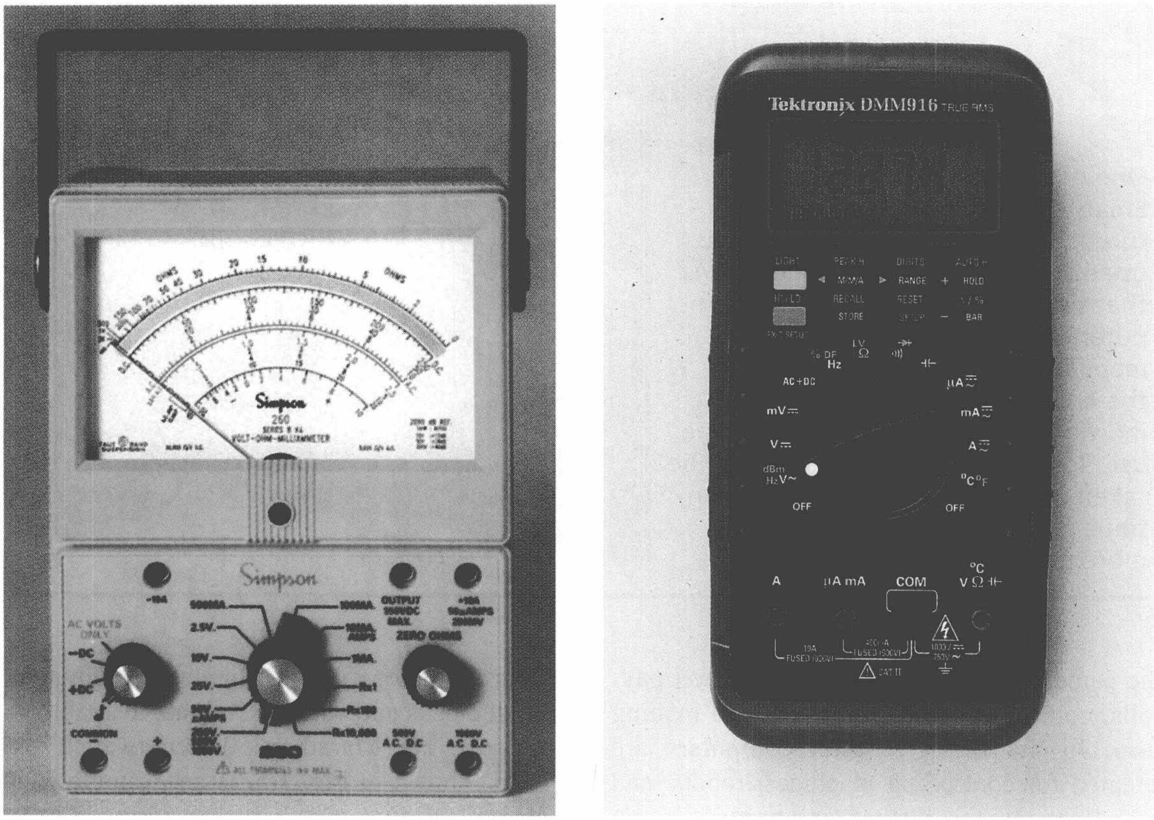
About Electronics

A Changing Field. Electronics is among the most exciting areas of technical study. New developments are reported weekly. Interestingly, most developments are based on the fundamentals learned in the first classes in electricity, analog and digital circuits, computer technology and robotics, and communications.

TEST

Supply the missing word in each statement.

1. Refer to Fig. 1-2. The +5-V level of the ________ (analog, digital) signal could



(*a*) (*b*)

Fig. 1-3 (*a*) Analog meter. (*Courtesy of Simpson Electric Company.*) (*b*) Digital multimeter (DMM). (*Courtesy of Tektronix, Inc.*)

also be called a logical 1 or a _________ (HIGH, LOW).

2. A(n) _________ device is one that has a signal which varies continuously in step with the input.
3. Refer to Fig. 1-4. The *input* to the electronic block is classified as a(n) _________ (analog, digital) signal.
4. Refer to Fig. 1-4. The *output* from the electronic block is classified as a(n) _________ (analog, digital) signal.
5. An analog circuit is one that processes analog signals while a digital circuit processes _________ signals.

1-2 Where Are Digital Circuits Used?

Microcomputer

Digital electronics is a fast-growing field, as witnessed by the widespread use of microcomputers. Microcomputers are only a few decades old; yet hundreds of millions of them are used in homes, schools, businesses, and governments. Microcomputers are extremely adaptable. At home a computer might be used for playing video games, managing a household budget, or controlling lights and appliances. At school students use the same computer to aid them in learning spelling, math, and writing. The staff uses the same computers for word processing, testing, and grading. In business

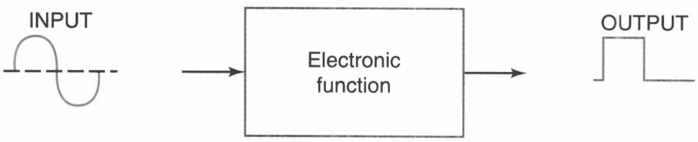
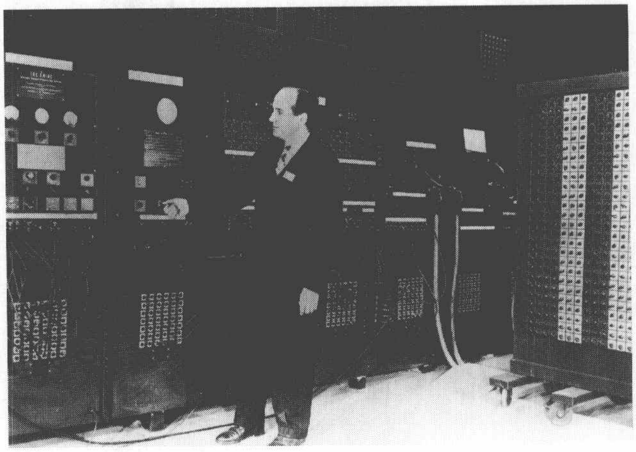


Fig. 1-4 Block diagram of electronic circuit shaping a sine wave into a square wave.

Did You Know?

The History of the Computer. One of the first computers was the Eniac, developed in the 1940s (pictured). The 1970s marked expanded use of the computer in businesses. At that time, expensive mainframe computers occupied special rooms in many offices. The 1980s ushered in the era of personal computers and individuals purchased them for home use. Today, personal computers can be taken anywhere as these devices continue to become both smaller and more powerful.



the same microcomputer might process payrolls, control inventory, and generate mailing lists. In the factories microcomputers are adapted for controlling machines, robots, and processes. In the military computers guide bombs and missiles, aim guns, and coordinate communications.

Microprocessors

Semiconductor memories

Microcomputers are designed around complex ICs called *microprocessors.* In addition, many IC semiconductor memories make up the microcomputer. Microcomputers with microprocessors, interface chips, and semiconductor memories have started the personal computer (PC) revolution. Small computers that used to cost tens of thousands of dollars now cost only hundreds. Digital circuits housed in ICs are used in both large and small computers.

Calculator

A handheld calculator is another example of a digital electronic device used by nearly everyone. Calculators range from the inexpensive models to the sophisticated versions used by engineers and scientists.

Peripheral devices

Only a few decades ago, even simple calculators would have cost hundreds of dollars. The more sophisticated programmable calculators can sometimes be connected to *peripheral devices* such as optical wands and printers. Programmable calculators verge on becoming very small computers. Scientists, engineers, and technicians have made great advances in producing digital ICs. As a result of these advances, the field of digital electronics has mushroomed.

Digital timepiece

The digital timepiece is a triumph of electronic technology. Very accurate multifunction digital clocks and wristwatches are available at low cost. The Marathon 50 "wristwatch" by Timex, shown in Fig. 1-5, is an example of a specialty digital watch that features a programmable electronic pedometer and a unique pulse calculation mode. It also includes a chronograph, countdown timer, light, and day and date indicator, and is water-resistant.

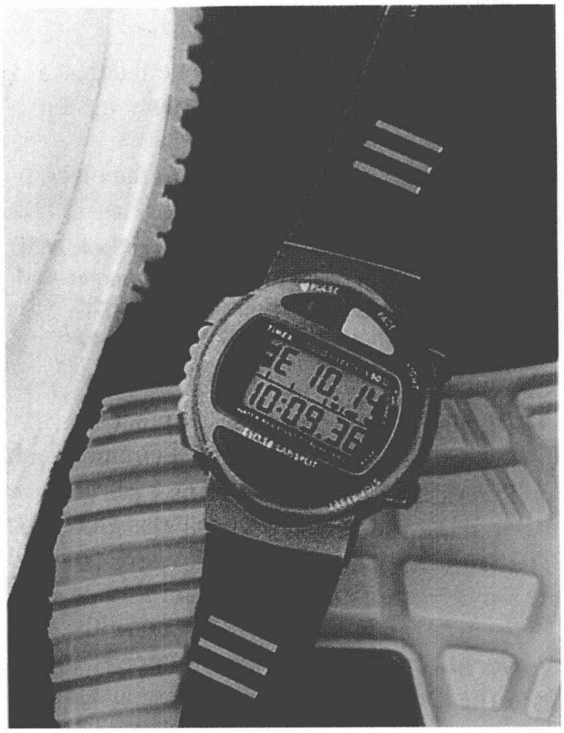
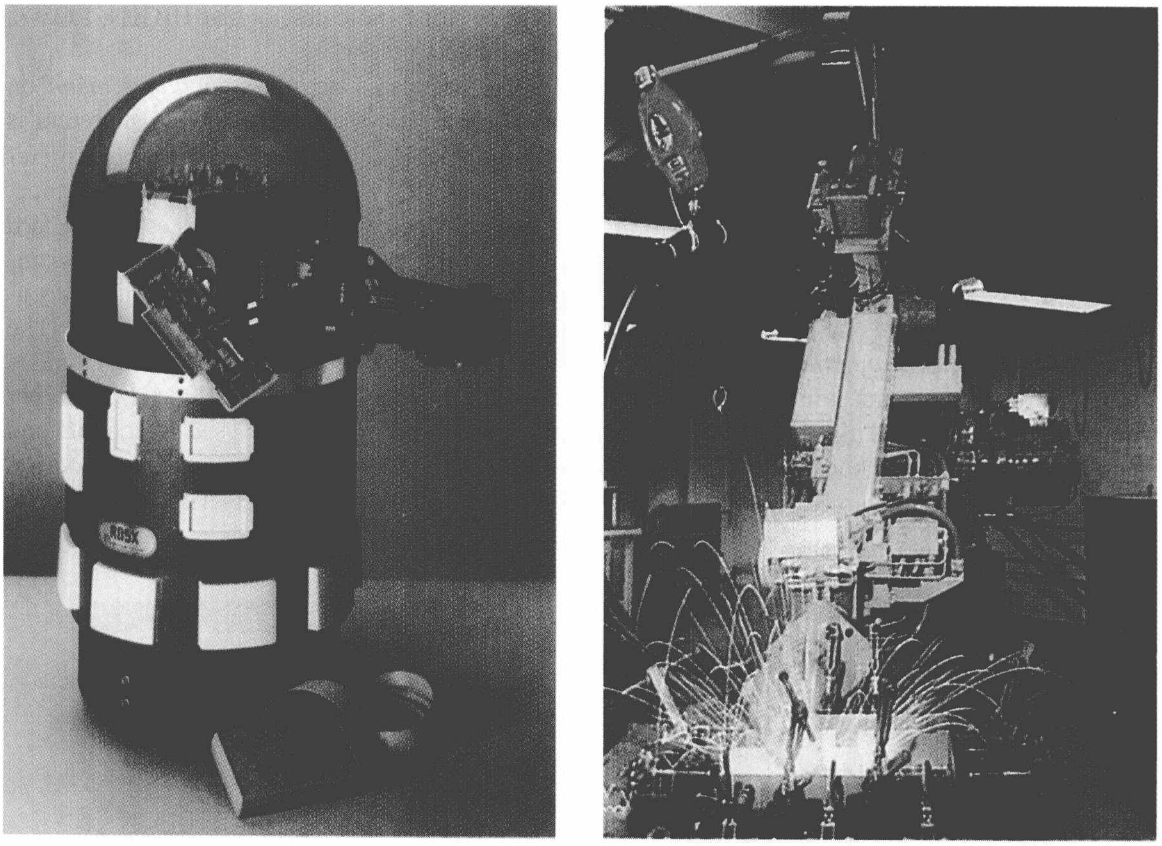


Fig. 1-5 A specialty wristwatch for runners. (*Courtesy of Timex Corporation.*)



(*a*) (*b*)

Fig. 1-6 (*a*) RB5X educational robots are used in many schools. (*Courtesy of General Robotics Corporation.*) (*b*) Industrial robot arms are used to perform repetitive and hazardous tasks. (*Courtesy of Doug Martin.*)

Battery-operated wristwatches commonly use low-power liquid-crystal displays (LCDs).

Robots and other computer-controlled machines add to the mystique of electronic technology. Robots have captured the imagination of inventors, science fiction writers, and movie producers. A *robot* may be defined as a machine that can perform humanlike actions and functions. A computer serves as the control center for modern robots. The robot's computer can be reprogrammed to permit the machine to perform a different sequence of operations. The study of the science and technology of the robot is called *robotics.*

Robots are commonly classified as to their use. *Hobby robots* are used in education, advertising, and entertainment. *Industrial robots* usually take the form of arms and are used in manufacturing and materials handling. One popular educational robot is pictured in Fig. 1-6(*a*). The RB5X robot by General Robotics Corporation is controlled by a built-in microprocessor system (computer) which may be programmed using Tiny BASIC, factory-programmed PROMs, RCL (a "conversational robot control language"), or machine code. The RB5X is a mobile robot with tactile and sonar sensors. The RB5X robot is commonly equipped with a voice synthesis system and arm. The RB5X robot has been used in upper elementary through middle school science and technology programs to introduce students to concepts such as computer-controlled movement, voice generation, and programming. Older students may use the RB5X robot to study applied digital electronics, interfacing, programming, servo mechanisms, sensor/vision systems technology, and artificial intelligence.

Manufacturing robot arms are widely used in hazardous operations where fumes, radiation, sparks, repetitive motions, or high temperatures may be harmful to a human operator. One industrial robot is pictured in Fig. 1-6(*b*) performing welding operations.

Electronically synthesized voice

Robotics

Hobby robots

Industrial robots

DMM

The technician's bench has a new look. Digital multimeters read out resistance, voltage, and current values. The high-quality DMM pictured in Fig. 1-3(*b*) is extremely accurate and loaded with features. Besides measuring ac and dc voltage, ac and dc current, and resistance, it will measure capacitance, frequency, and temperature. The inexpensive DMM/logic probe pictured in Fig. 1-7(*a*) is a compact unit you might find in a student's toolkit. This unit is especially useful in digital circuits because it has a built-in *logic probe,* which is an easy-to-use test instrument that indicates logical HIGHs, LOWs, and detects pulses.

JOB TIP

More technicians are fired for lack of people skills than for lack of technical skills.

Logic probe

Digital capacitance meter

Frequency counters

Function generator

There is also a *digital capacitance meter* on most electronic workbenches. One such unit is pictured in Fig. 1-7(*b*). This handheld meter measures a wide range of capacitance. *Frequency counters* are also pieces of standard test equipment found in most school and industry labs. The digital test instrument accurately senses and displays the frequency. The high-quality unit pictured in Fig. 1-7(*c*) has a frequency range of 1 Hz to 100 MHz. Another popular digital instrument used in schools and labs is the *function generator.* The function generator shown in Fig. 1-7(*d*) can generate

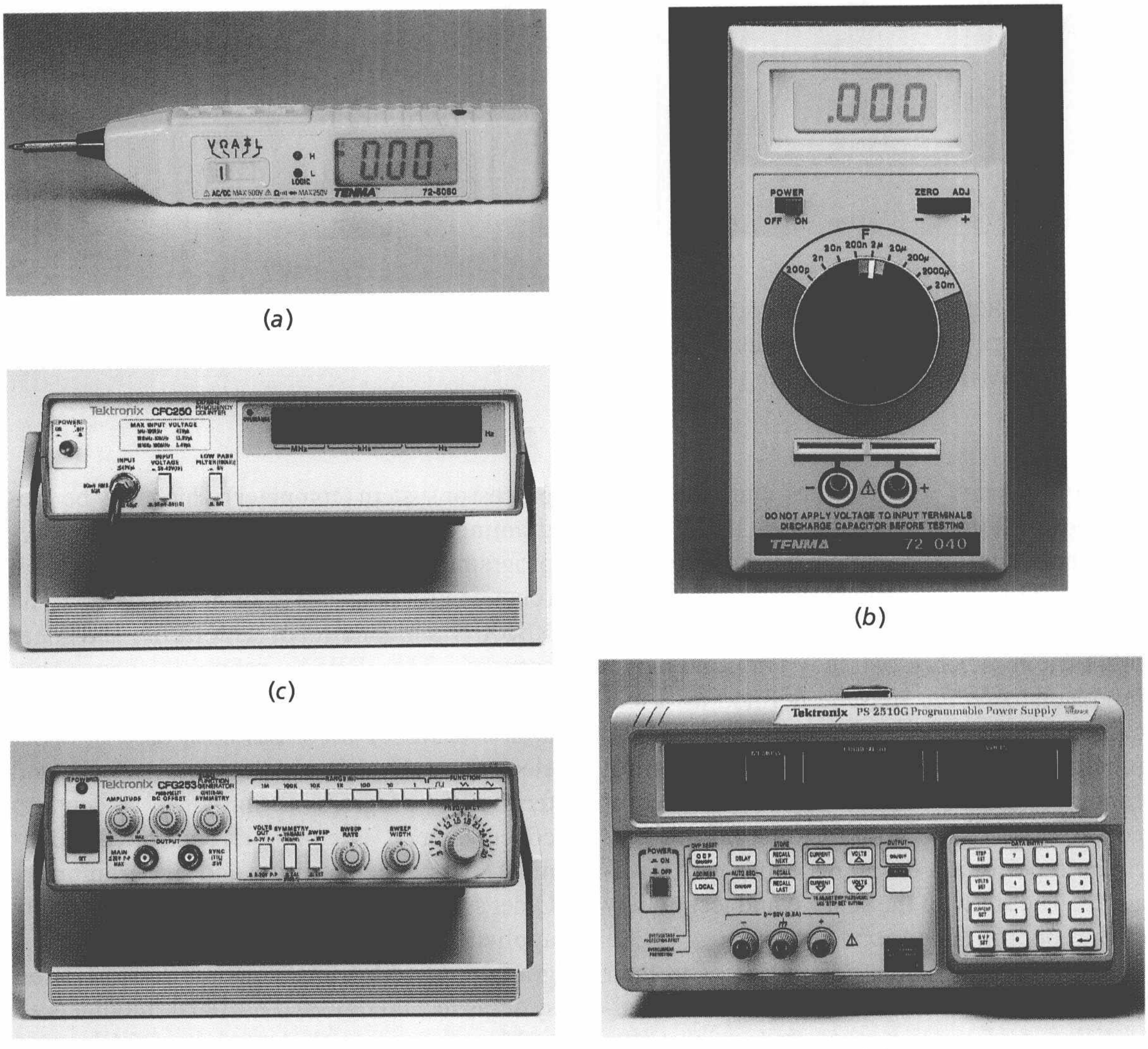


Fig. 1-7 (*a*) Combination DMM/logic probe. (*Courtesy of MCM Electronics.*) (*b*) Capacitance meter. (*Courtesy of MCM Electronics.*) (*c*) Frequency counter. (*Courtesy of Tektronix, Inc.*) (*d*) Function generator. (*Courtesy of Tektronix, Inc.*) (*e*) Programmable power supply. (*Courtesy of Tektronix, Inc.*)

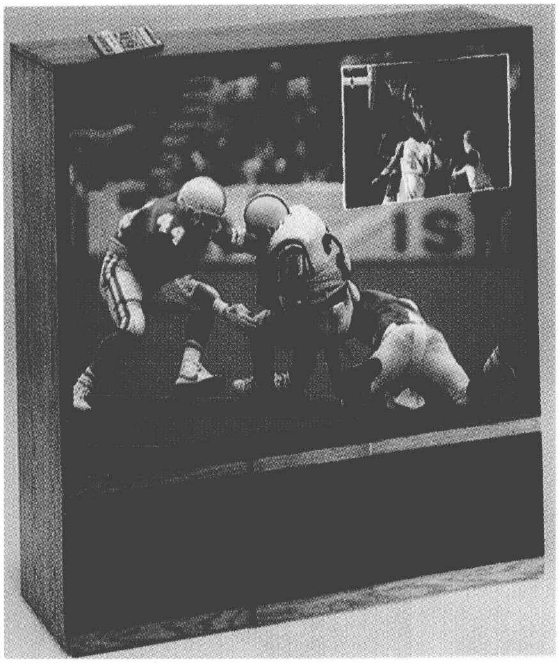


Fig. 1-8 A digital picture-in-picture television. *(Courtesy of Phillips Consumer Electronics Company.)*

square-, triangular-, or sine-wave signals from less than 1 Hz to 3 MHz. Finally, the modern workbench features a high-tech version of a power supply. A *programmable power supply* from Tektronix, Inc. is shown in Fig. 1-7(*e*). Many modern test instruments make extensive use of digital circuitry.

Electronic products for home entertainment (such as televisions and stereos) have traditionally been designed using analog circuits. This is changing, with some digital circuitry used in both television and sound systems. The picture-in-picture television illustrated in Fig. 1-8 is one example of the use of digital circuits in the storage and generation of the smaller picture. Most modern consumer products used for home entertainment contain both analog and digital circuitry.

One high-quality entertainment product is Korg's 01/WFD Music Workstation pictured in Fig. 1-9. The 01/WFD music synthesizer uses full digital processing and its 48-M ROM stores 255 multisounds and 119 drum sounds. Like a computer, the music workstation has a built-in 3.5-in disk drive for long-term storage and a large RAM section for internal user storage. To aid programming, a backlit dot-matrix LCD (60 × 240 dot) graces the front of the synthesizer.

Digital electronic circuits are at work in modern automobiles. There is a microprocessor in the "computer" of modern automobiles to control several ignition, fuel system, emissions, and transmission variables. Figure 1-10 gives an inside look at a powertrain control module by Delco Electronics Corporation. This powerful computer is featured in all Cadillac Northstar V8 engine-equipped vehicles. Notice the use of many large-scale ICs on the drivetrain control module PC board in Fig. 1-10.

Automotive electronics

From the driver's seat of some modern automobiles, a digital tachometer stares back at you from the instrument cluster. The glow of a digital display shows the time and tuning of your sound system. The same digital display identifies your selection on the compact disk player. A digital thermometer monitors the interior and exterior temperatures, while a digital compass points the way to your destination. Antilock braking and traction systems make driving less hazardous. Automobile manufacturers are spending large sums of money on research and development efforts in automotive electronics.

Programmable power supply

Many home appliances use electric motors. Federal regulations call on manufacturers to improve refrigerator, freezer, air conditioner, and

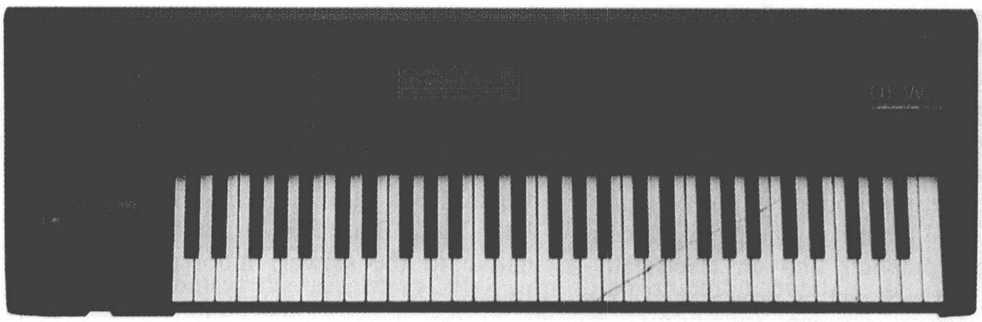


Fig. 1-9 Digital synthesizer with a floppy disk drive. *(Courtesy of Korg U.S.A., Inc.)*

Digital synthesizer

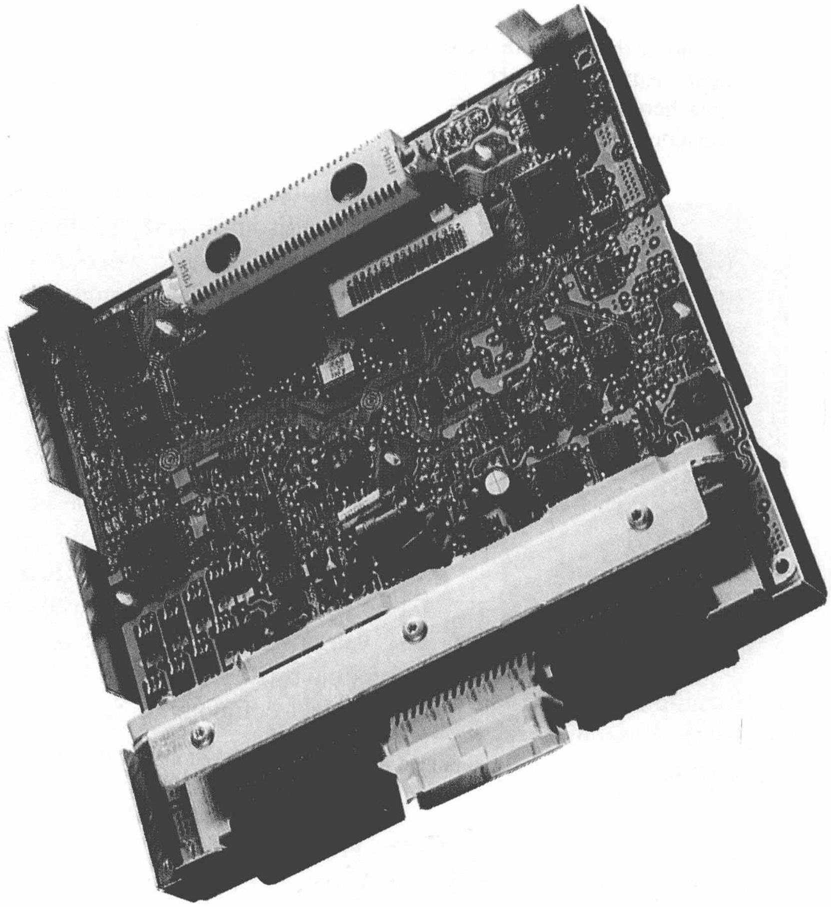


Fig. 1-10 A powertrain control module is used in all Cadillac Northstar V8 engine–equipped vehicles. (*Courtesy of Delco Electronics Corporation.*)

heating equipment efficiencies by up to 35 percent. To save energy, General Electric Company has developed the electrically commutated motor (ECM) shown in Fig. 1-11. The ECM variable-speed motor used for air conditioning, heating, and refrigeration equipment is about 20 percent more efficient than conventional induction motors. The printed circuit board pictured contains a power supply and much digital circuitry. The PC board contains a microcomputer and an electrically erasable PROM that can be programmed by a personal computer for different appliances. The ECM is a direct-current brushless permanent-magnet motor.

Applications of digital circuits

In your home there are other pieces of digital equipment. Appliances such as microwave ovens, washers, and dryers may have microprocessor-controlled or microcontroller-based digital circuitry. Your bathroom may house a digital scale, digital thermometer, or digital blood pressure monitor. Your home's heating and cooling may be controlled by one of the newer "intelligent" setback thermostats. Electronic and video games make extensive use of digital electronics. Even your telephone equipment may now have digital readouts and memory characteristics.

Digital cameras

Digital imaging has been simplified recently with the introduction of *digital cameras.* Instead of using traditional film, these cameras record images as electronic data. The Sony Digital Mavica® camera is pictured in Fig. 1-12. This digital camera is somewhat unique in that the storage medium is a floppy disk which can be removed from the camera and inserted into a computer for a simple transfer of data. Computers with a preinstalled Joint Photographic Experts Group (JPEG) viewer (such as Windows® 95 or Adobe Photoshop) can view the pictures directly on either their PC or Macintosh systems. Viewing software also comes with the camera. The 3.5-in. floppy

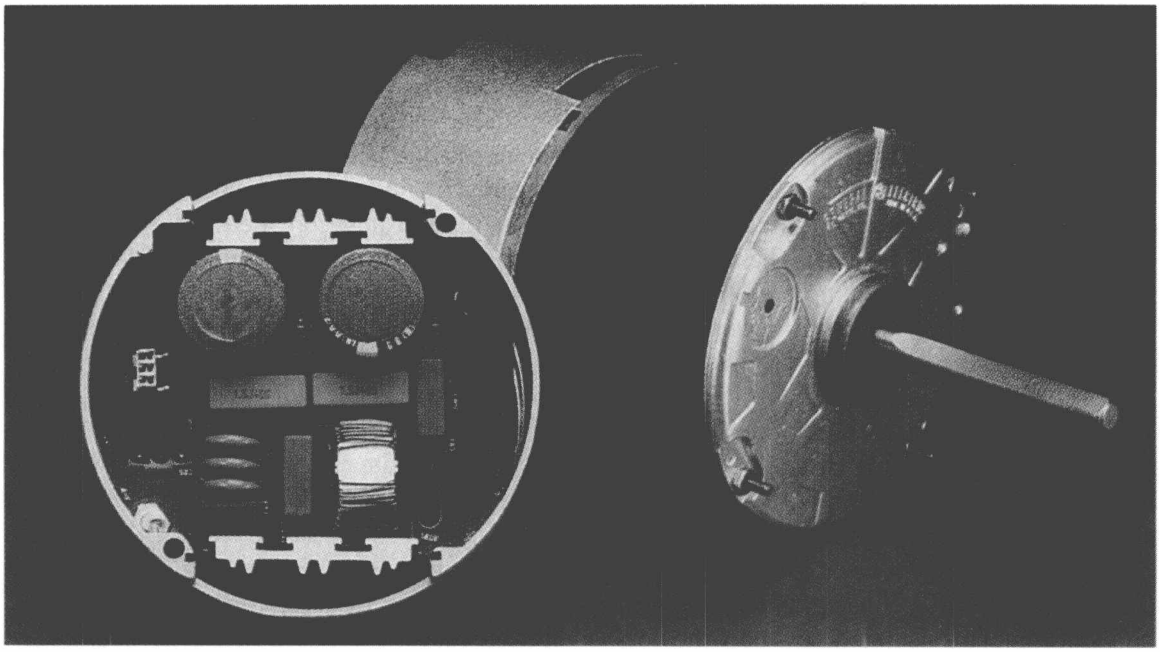


Fig. 1-11 ECM (electrically commutated motor) variable-speed motor. (*Courtesy of General Electric Company.*)

disk used by the Sony camera in Fig. 1-12 can store up to 40 images at 640 × 480 24-bit videographics array (VGA) resolution. Digital cameras do not yet have the resolution of film cameras, but for some quick digitizing of color photos these units work well.

In recent years, manufacturers have produced unique products using digital technology. Some of these include portable electronic dictionaries and thesauruses, foreign language translators, handheld spelling checkers, electronic data organizer/schedulers, electronic Rolodex directories and telephone dialers, and specialized calculators. One shirt-pocket size product is the Digital Book System pictured in Fig. 1-13. This unit accepts two integrated circuit ROM cards at once allowing simultaneous and interactive access to both books. Two ROM cards are shown next to the compact Digital Book System unit in Fig. 1-13. Franklin's Digital Book System is a handheld alternative to the slower, more expensive CD-ROM.

One exotic robot in the news recently is the Mars Rover Sojourner. The six-wheeled semi-autonomous "rover" was landed on the planet Mars in 1997 as part of the Pathfinder mission.

Fig. 1-12 Mavica® digital camera with floppy disk storage. (*Courtesy of Sony Electronics, Inc.*)

Fig. 1-13 Digital Book System. (*Courtesy of Franklin Electronic Publishing.*)