GROB
BASIC ELECTRONICS

FIFTH EDITION

Basic Electronics

Fifth Edition

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Preface

This basic text is for beginning students without any experience in electricity and electronics. The first chapter is on elementary electricity; the last chapters cover transistors, integrated circuits, and digital electronics. Between these two points, the topics progress through Ohm's law, series and parallel dc circuits, networks, meters, magnetism, ac circuits with inductance and capacitance, and the subject of resonance. These fundamentals form the basis for the study of advanced applications, including communications electronics in general, and radio and television in particular. The chapter on digital electronics serves as an introduction to microprocessors and computers.

For each subject, the basic principles are explained first, followed by typical applications. Where appropriate, troubleshooting techniques are covered. This practical approach has proved effective in helping students to learn electronics in a way that is interesting and useful. While the technology has advanced dramatically over the years, the method of presentation used so successfully in the classroom has remained intact with only fine tuning taking place from edition to edition.

Mathematics is held to a minimum. Some numerical problems require powers of 10 because of the metric units. Trigonometric functions are used for ac circuits, where the phase angle is important. Also, Chap. 25 explains the details of how to apply complex numbers to ac circuits.

The order of topics follows a typical one-year course in electricity and electronics fundamentals. Typically such courses include dc and ac circuits and circuit theorems. However, the material on Kirchhoff's laws and other circuit theorems may be used for a separate course on network analysis, possibly combined with the details of *RC* and *L/R* time constants.

In the fifth edition, network analysis has been expanded to include applications of Kirchhoff's laws and network theorems to ac circuits. Chapter 12 on batteries includes state-of-the-art coverage of alkaline, silver-oxide, and lithium batteries. The chapter on resistors and color coding appears early in the book to relate more closely to laboratory work at the start of the course.

Finally, the last four chapters in the fifth edition emphasize transistors, integrated circuits, operational amplifiers, and digital electronics for computers.

The SI standard of V and v for voltage is used throughout the book, eliminating the use of E and e. Also, the SI unit of the siemens is used for conductance. For magnetic units, the SI system is emphasized, with conversion factors for cgs units. However, certain non-SI magnetic units are still widely used in industry, and these are referred to, as appropriate, in the text.

Organization The text is divided into 32 chapters for step-by-step development of the topics. Each chapter is designed to develop a key concept and build upon that concept. For example, individual chapters on Ohm's law, series circuits, and parallel circuits build up to more advanced chapters on series-parallel circuits, voltage dividers, current dividers, and networks.

The chapters on magnetism and electromagnetic induction lead into the development of sine-wave alternating voltage and current. There are separate chapters on inductance and its ac reactance before these fundamentals are combined for inductive circuits. The same sequential development is used for capacitive circuits. Then, these principles of L and C are combined with resistance for ac circuits. The chapters on resonance and filters describe these applications for sine-wave ac circuits.

The important details for *RC* and *L/R* time constants are reserved for Chap. 23. Here, the effects on dc transients and nonsinusoidal waveforms in capacitive and inductive circuits can be compared.

The four chapters on electronic devices, transistor amplifiers, digital electronics, and integrated circuits provide an introduction to electronic devices and circuits, including rectifiers, oscillators, operational amplifiers, and digital logic.

Practical approach Each chapter concludes with discussions of common troubles in components and the circuits they effect. For instance, the effects of an open circuit and a short circuit are explained in the first few chapters on dc circuits. Typical troubles in resistors, coils, capacitors, and transistors are explained in their respective chapters. Methods of testing for an open or short circuit are included.

The choke coil is explained as an application of inductive reactance, while the action of coupling and bypass capacitors is described in detail as an application of capacitive reactance.

Programmed questions An important feature is the inclusion of practice problems at the end of each main section. The purpose of these questions is to have students check their understanding of each section after reading the material. The purpose is not to see how many answers are right or wrong but rather to provide immediate reinforcement of the section just completed. Answers are given at the end of the chapter.

Learning aids The entire book is written with the student in mind. Numerous subheads, brief but substantive paragraphs, and readable sentences encourage students to study the text and figures. Illustrative examples with step-by-step solutions and a highlighted format clarify the calculations and the theory behind them. The two-color design is inviting but not merely cosmetic; it aids student comprehension.

The practice problems and answers for each main section serve the purpose of applying principles of programmed learning. This self-testing is in short units and can be reinforced immediately with correct answers.

Each chapter starts with an introduction that states the objective, followed by a list of important terms and a list of sections. This format enables the student to obtain an overall view of the material in each chapter.

At the end of each chapter a short summary lists the main points covered in the chapter. The short answer questions for self-examination are based on the summary. Also, summaries for groups of chapters are given as a review, with additional self-examination questions. This organized structure of ideas in the listing of sections, important terms, summaries, and self-testing with review motivates the student to study and learn.

There are many tables in the text for comparisons and summaries. The tables provide a concise listing of important points and help to compare similar or opposite characteristics. Examples of such tables are the comparisons between series and parallel circuits, inductive and capacitive reactance, and dc and ac circuits.

Each review summary has a short list of reference books for the topics in those chapters. A more complete bibliography on pages 714 to 716 lists books on electricity and electronics, transistors and integrated circuits, digital electronics and computers, and mathematics. The listing also includes manuals for transistors and integrated circuits, trade publications, and sources of other training materials.

Answers to all self-examination questions and to odd-numbered problems are given at the end of the book.

Glossaries A listing of technical abbreviations is given at the end of Chaps. 31 and 32. The expanding fields of digital electronics and integrated circuits have their own terminology, especially alphabetical abbreviations such as MOSFET, LSI, and TTL. It is helpful to have these summarized for convenient reference. Furthermore, a comprehensive glossary of technical terms in alphabetical order is included on pages 706 to 713.

Credits The photographs of components and equipment have been provided by many manufacturers, as noted in the legend accompanying the photograph. The fifth edition continues the original material developed in previous editions with the help of my colleagues Harry G. Rice and Philip Stein.

Finally, it is a pleasure to thank my wife, Ruth, for her help in preparation of the manuscript.

Bernard Grob

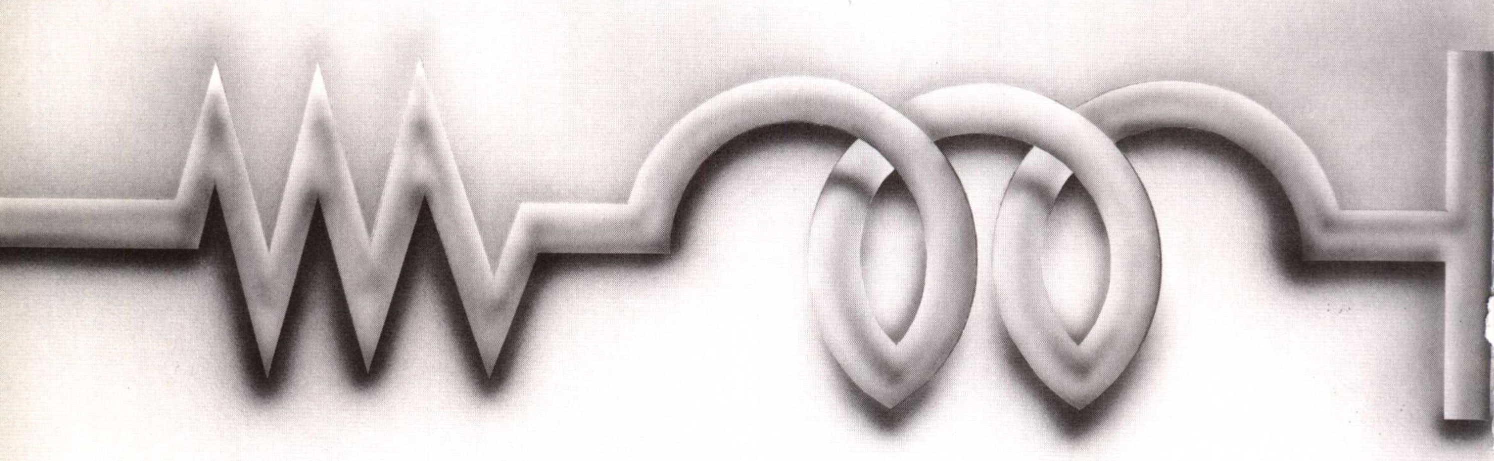
Contents

Basic Electronics

Survey of Electronics

Electronics, radio, and television are practical applications of the general principles of electricity. The same electric current produced by a battery for a flashlight can also be used in many different ways. Some examples are running a motor and producing heat and light for electric power applications, while electronic calculators and computers illustrate more advanced applications in digital electronics. In addition, radio and television are considered as communications electronics. They all are based on the fundamental laws of electricity and magnetism. Magnetic effects are always associated with an electric current.

The name *electronics* comes from the electron, which is a very small, invisible quantity of electricity present in all materials. In terms of its many uses, electronics can be defined to include all applications involving the control of electricity in a vacuum, such as vacuum tubes, in gas or vapor, and in the solid semiconductor materials used for transistors and integrated circuits. Typical semiconductor devices are shown in Fig. S-1. The main factor in their operation is control of individual



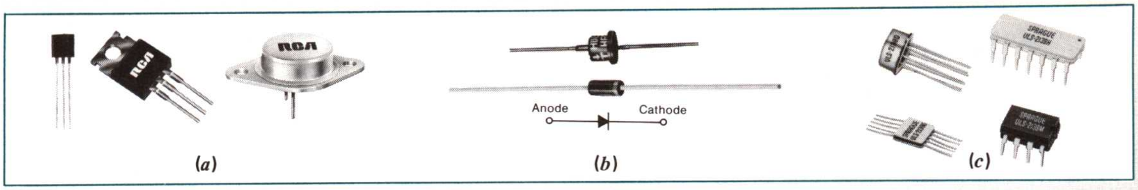


Fig. S-1 Semiconductor devices. (*a*) Transistor amplifiers. (*b*) Diode rectifiers, with schematic symbol. (*c*) Integrated circuit (IC) packages.

electrons for the desired effect. In a transistor, as an example, the input can control a larger output current, to provide amplification. The integrated circuit (IC) contains many transistors on a small semiconductor chip. Integrated-circuit chips are used for the small personal computer in Fig. S-2.

Fig. S-2 Personal computer. (*Texas Instruments*)

More details are explained in the following sections:

S-1 Development of Electronics
S-2 Wireless Broadcasting
S-3 Radio Broadcast Services
S-4 Applications of Electronics
S-5 Electronic Components
S-6 Electronic Circuits

S-1 Development of Electronics

History shows that electronics started in the pioneer days of radio communications. Television developed from radio. Furthermore, radio itself is based on earlier experiments in electricity and magnetism. The start of wireless transmission for radio communications can be taken from the work of Heinrich Hertz, a German physicist. In 1887, he was the first to demonstrate the effect of electromagnetic radiation through space. The distance of transmission was only a few feet. However, the experiment demonstrated that radio waves could travel from one place to another without the need for any connecting wires between the transmitting and receiving equipment.

Hertz proved that radio waves, although invisible, travel with the same velocity as light waves. In fact, radio waves and light waves are two examples of electromagnetic radiation. This form of energy combines the effects of electricity and magnetism. An electromagnetic wave transmits electric energy through space.

The work of Hertz followed earlier experiments on electricity and magnetism. In 1820, a Danish physicist, H. C. Oersted, showed that an electric current produces magnetic effects. Then, in 1831, a British physicist, Michael Faraday, discovered that a magnet in motion can generate electricity. The motion provides the requirement of a change in the magnetic field. In 1864, the British physicist James Clark Maxwell, on the basis of earlier work in electricity and magnetism, predicted the electromagnetic waves demonstrated later by Hertz.

The importance of this work can be judged by the fact that basic units are named after these scientists. The maxwell (Mx) and the oersted (Oe) are units of magnetism. The hertz (Hz) unit is equal to one cycle per second, which is the measure for the frequency of any alternating voltage or current. The farad (F) is the unit of capacitance, indicating how much electric charge can be stored in a capacitor.

In 1895, Guglielmo Marconi used a long wire as an antenna to develop a practical radio system for long distances. The antenna is needed for efficient radiation. He succeeded in producing wireless communication across the Atlantic Ocean in 1901.

The rapid advances after that are due largely to the introduction and progress of the vacuum tube as an amplifier for electric signals. Dr. Lee DeForest, with his audion tube, invented in 1906, was a leader in this field. As the design of vacuum tubes advanced, radio broadcasting progressed rapidly. Regularly scheduled programs were broadcast in 1920 by station KDKA in the standard amplitude modulation (AM) radio band. The commercial frequency modulation (FM) radio broadcast service was started in 1939. Stereo broadcasting in this band began in 1961.

Commercial television broadcasting was started officially in 1941, but its popular use did not begin until 1945. Our present color television system was adopted in 1953.

Since the invention of transistors in 1948 at Bell Telephone Laboratories, solid-state devices have replaced tubes for most uses in electronics, radio, and television. The transistor is an application of controlled electron flow in solid semiconductor materials such as silicon (Si) and germanium (Ge). Transistors and tubes have similar uses for the control of electron flow and amplification of signals. The transistor is much smaller, however, and more efficient, as it does not have the heater used in tubes.

Solid-state electronic devices include transistors, diodes, and integrated circuits. A diode is not an amplifier but is used as a one-way conductor to convert alternating current to direct current. Solid-state devices have made new applications practicable because of their small size and the economy of IC packages. One example is the rapid growth of digital electronics for electronic calculators, personal computers, and many other uses.

S-2 Wireless Broadcasting

Broadcasting means to send out in all directions. A radio broadcasting system is illustrated in Fig. S-3. The transmitter sends out electromagnetic radio waves radiated from its antenna. Receivers can pick up the transmitted radio signal by means of a receiving antenna or aerial. The receiver reproduces the desired signal transmitted by the broadcast station. There are many radio signals in space from different transmitters, but the receiver can be tuned to the frequency of the station we want.

In Fig. S-3, the electromagnetic wave shown is a radio-frequency (RF) carrier signal with amplitude modulation (AM). The amplitude or strength of the RF carrier varies in step with variations in the desired voice or music information, which is the audio signal. This technique of modulating a carrier wave is necessary

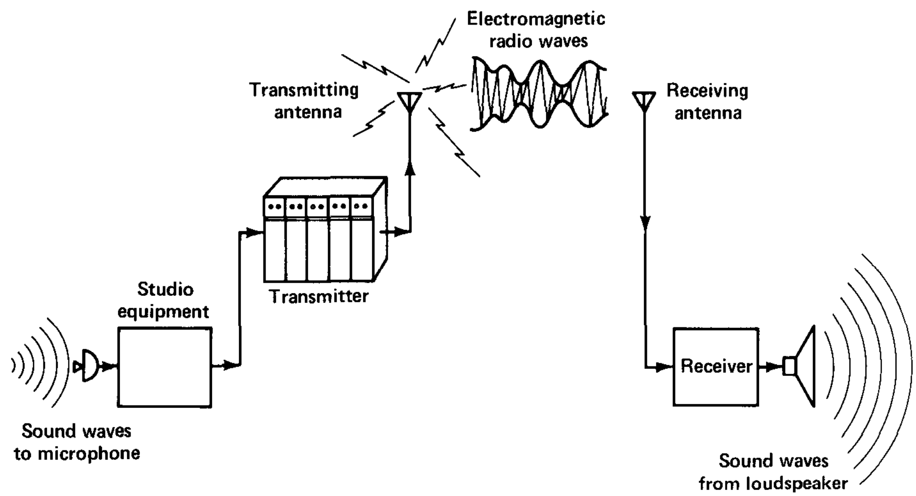


Fig. S-3 Radio broadcasting between transmitter and receiver. An amplitude-modulated (AM) carrier wave is shown here.

because the audio signal itself cannot be used for wireless transmission. The variations are too slow for effective radiation from an antenna. A higher-frequency carrier wave is chosen for the best radio transmission. Its modulation provides the desired signal information.

In the method of frequency modulation (FM), the modulating signal varies the frequency of the RF carrier wave. Either AM or FM can be used for any type of modulating signal.

Frequency is an important characteristic of any varying voltage or current, to specify how fast the amplitudes change. A complete set of changes is one cycle. The number of cycles repeated in a second is the frequency. The unit for frequency is the hertz (Hz), equal to one cycle per second (cps). As an example, the 60-cycle ac power line has a frequency of 60 Hz.

Radio frequencies are generally considered to be about 30,000 Hz and above. Radio-frequency carrier frequencies for wireless transmission are usually much higher. They are usually specified in kilohertz (kHz), equal to 1000 Hz, and megahertz (MHz), where 1 MHz = 1,000,000 Hz.

S-3 Radio Broadcast Services

Radio is an abbreviated form of radiotelegraph and radiotelephone. The word *radio* means radiation for wireless transmission. At first, communication was by radiotelegraph, using short dots and longer dashes in the Morse code. Now radiotelephone is used more for voice communications and for broadcasting voice and music programs for entertainment. This application can be considered as communications electronics, which includes television. Practically all radio and television receivers are now solid-state, with transistors and integrated circuits instead of vacuum-tube amplifiers. See Fig. S-4 for a comparison of the old and the new in radio.

The transmission distance for wireless communication can be less than a mile or as much as 5000 miles, depending on the type of service. There are many different uses, such as radio broadcasting of voice and music, television broadcasting, amateur radio, and citizen's band (CB) radio. In addition, radio communication is used for specific services, such as police radio. Finally, radio navigation for ships and planes is another important application.

All radio services in the United States are regulated by the Federal Communications Commission (FCC). The FCC assigns the RF carrier frequencies for transmission and monitors use of the airwaves. A few of the most important radio applications are described here briefly, but a more complete list, including FCC frequency allocations from 30 kHz to 300,000 MHz, is given in App. B.

Standard AM Radio Broadcast Band This service is the original system of broadcasting for what we generally call radio. Amplitude modulation is used

(a)

(b)

Fig. S-4 (*a*) Old radio. (*b*) New radio. Width is 16 in. (*Tandy*)

in transmission of the assigned RF carrier wave. Stations are assigned every 10 kHz in the band of 540 to 1600 kHz. The last digit is usually omitted from these numbers on the tuning dial for the carrier frequencies of different stations.

FM Radio Broadcast Band This band is 88 to 108 MHz, with stations assigned every 200 kHz or 0.2 MHz. The system of frequency modulation reduces static and interference. For this reason, the FM band is used for broadcasting high-fidelity audio signals.

Television Broadcasting Television is just another application of wireless radio communications, but with picture information in addition to the sound signal. Two separate carrier waves are transmitted by the station in its assigned channel. One carrier is an AM picture signal, modulated by video signal with the picture information. The other carrier is an FM sound signal modulated by the audio.

A television channel is 6 MHz wide to include both the picture and sound signals for each broadcast station. Channel 2, for instance, is 54 to 60 MHz.

Amateur Radio This field is one of the largest noncommercial radio services. Amateur radio operators, or "hams," usually build and operate their own transmitters and receivers to call one another in one of the assigned bands. A popular band is 7 to 7.3 MHz. Their main organization is the American Radio Relay League (ARRL), Newington, Connecticut.

Citizen's Band (CB) Radio Forty 10-kHz channels from 26.965 to 27.405 MHz are available for public use of two-way radio. These CB channels are for class D service, with maximum power output of 4 watts (W). The CB transceiver includes a transmitter and a receiver. No operator's license is required for these personal radio services, often used in cars and boats.

S-4 Applications of Electronics

In addition to its use in radio and television, electronics is used in almost all industries for control functions, automation, and computing. There are so many applications that the broad field of electronics must be considered in smaller areas. Three logical groupings of electronics applications are defined here. Also included is a brief description of some important divisions with some typical job titles for working in the electronics business.

1. *Communications electronics.* This field includes AM radio, FM radio with stereo, and television with color. The equipment is divided between transmitters and receivers. Also, transmitters can be divided between radio-frequency equipment to produce the carrier wave radiated from the antenna and

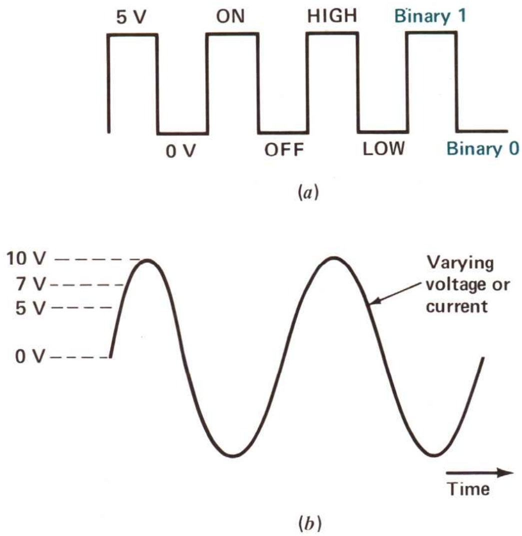


Fig. S-5 (*a*) Pulse waveform that is either HIGH or LOW for digital circuits. (*b*) Analog waveform with continuous variations.

the audio and video equipment in the studio that supplies the modulating signal with the desired information.

High-fidelity audio equipment can be considered with radio receivers. The receiver itself has audio amplifiers to drive the loudspeakers that reproduce the sound.

Satellite communications is also a transmit-receive system using electromagnetic radio waves. The satellite just happens to be orbiting around the earth at a height of above 22,000 miles in order to have a tremendous field of view. Actually, the satellite is a relay station for transmitter and receiver earth stations.

2. *Electric power*. These applications are in the generation and distribution of 60-Hz ac power, as the source of energy for electrical equipment. Included are lighting, heating, motors, and generators.
3. *Digital electronics*. We see the digits 0 to 9 on an electronic calculator or digital watch, but digital electronics has a much broader meaning. The circuits for digital applications operate with pulses of voltage or current, as shown in Fig. S-5*a*. A pulse waveform is either completely ON or OFF because of the sudden changes in amplitude. In-between values have no function. Note that the ON and OFF states can also be labeled HIGH and LOW, or 1 and 0 in *binary notation,* which uses only two digits. Effectively, the digital pulses correspond to the action of switching circuits that are either on or off.

Voltage or current variations with a continuous set of values form an *analog waveform,* as shown in Fig. S-5*b*. The 60-Hz power line and audio and video signals are common examples. In Fig. S-5*b*, note that values between 0 and 10 V are marked to indicate that all the in-between values are an essential part of the waveform.

Actually, all the possible variations in types of electronic circuits can be divided into just two types—digital circuits that recognize pulses when they are HIGH or LOW, and analog circuits that use all values in the waveform. The applications of digital electronics, including calculators (Fig. S-6), computers, data proc-

(*a*) (*b*)

Fig. S-6 Two examples of programmable electronic calculators. Width is about 6 in. (*a*) Scientific type with exponents, logarithms, and trigonometric functions for sine (SIN), cosine (COS), and tangent (TAN) of angles. (*b*) Type for digital electronics and computer science. Functions included are for decimal (DEC), hexadecimal (HEX), octal (OCT), or binary (BIN) numbers. (*Hewlett-Packard*)