Principles of Electric Circuits

Sixth Edition

FLOYD

Sixth Edition

PRINCIPLES OF ELECTRIC CIRCUITS

THOMAS L. FLOYD

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PREFACE

Principles of Electric Circuits, Sixth Edition, provides comprehensive, practical coverage of basic electrical concepts and circuits. Material is presented in a readable style complemented by numerous examples and illustrations. As in previous editions, the text includes strong coverage of troubleshooting and applications. This edition has been thoroughly reviewed and a tremendous effort has been made to ensure that the coverage is accurate and up-to-date.

New Software and Internet-Related Features

- Electronics Workbench® (EWB) tutorials for most chapters are now available on the Internet at www.prenhall.com/floyd
- PSpice tutorials for each chapter and a selection of PSpice circuits are now available on the Internet at www.prenhall.com/floyd. (PSpice student demonstration software can be downloaded from www.orcad.com).

The CD-ROM packaged with the text contains the following three items:

1. Approximately 100 EWB circuits for the textbook's Troubleshooting and Analysis Problems. EWB software version 5.X or higher is required to view these circuits.
2. Limited demonstration version of EWB version 5.X software. This allows the reader access to 15 of the circuits on the CD-ROM.
3. A full student version of EWB version 5.X. This is available for purchase by contacting Interactive Image Technologies.

Users should direct all technical questions about the CD-ROM to Interactive Image Technologies at (800) 263-5552 or www.interactiv.com.

Other New Features

- Troubleshooting and Analysis Problems at the end of most chapters coordinate with EWB circuits on the CD-ROM that comes with the textbook. Answers are in the Instructor's Resource Manual.
- Revised organization of the chapters on reactive circuits (Chapters 16, 17, and 18) that facilitates two popular approaches to the subject matter
- Safety notes in some chapters
- Historical Notes at the opening of many chapters
- Expanded use of calculator solutions
- Identification of the most difficult end-of-chapter problems

Other Features

- Functional full-color format
- TECHnology Theory Into Practice (Tech TIP) sections in most chapters
- Chapter Overview and Objectives at the opening of each chapter
- Introduction and Objectives at the beginning of each section in a chapter
- Many worked examples, each with a related problem
- Reviews at the end of each chapter section

- Chapter summaries
- List of chapter formulas
- Chapter glossaries (comprehensive glossary at the end of the book.)
- Chapter self-tests
- Sectionalized chapter problem sets
- Conventional current direction is used. (An alternate version of this text uses electron-flow direction.)
- Ancillary package that includes
  - Lab Manual: *Experiments in Basic Circuits: Theory and Application,* by Dave Buchla. Solutions manual available.
  - Lab Manual: *Experiments in Electric Circuits,* by Brian Stanley. Solutions manual available.
  - PowerPoint slides
  - Test Item File (printed testbank)
  - Prentice Hall Test Manager (electronic testbank)
  - Instructor's Resource Manual
  - Bergwall Videos

Illustration of Chapter Features

Chapter Opener Each chapter begins with a two-page opener as shown in Figure A. A typical chapter opener contains a section list, a reference to the Electronics Workbench (EWB) and PSpice tutorials on the website at www.prenhall.com/floyd, a chapter overview, chapter objectives, and associated art related to the TECHnology Theory Into Practice (Tech TIP) section and, in some chapters, one or two Historical Notes related to the chapter.

EWB and PSpice Tutorials The website tutorials correspond to chapters in the textbook, and a tutorial is referenced at the beginning of most chapters. If your course covers EWB or PSpice, you can study the tutorial for a given chapter just as if it were another section in the text. Of course, the other textbook material is not affected if these tutorials are not used; they are strictly optional.

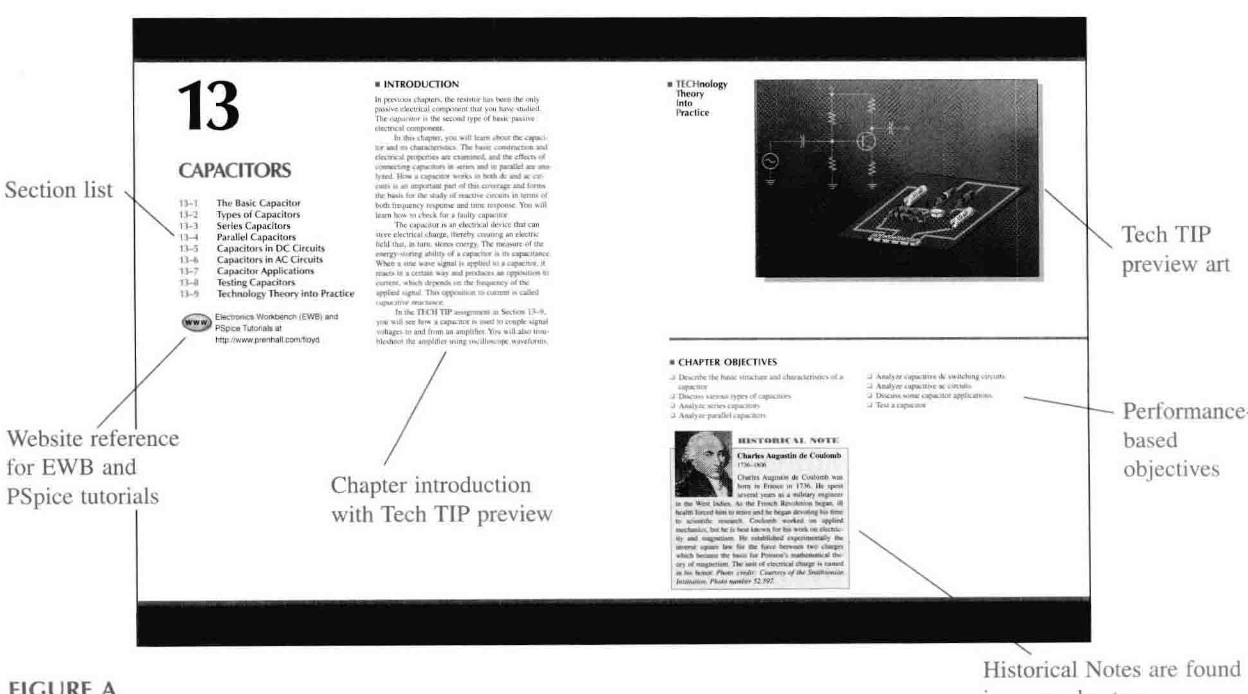
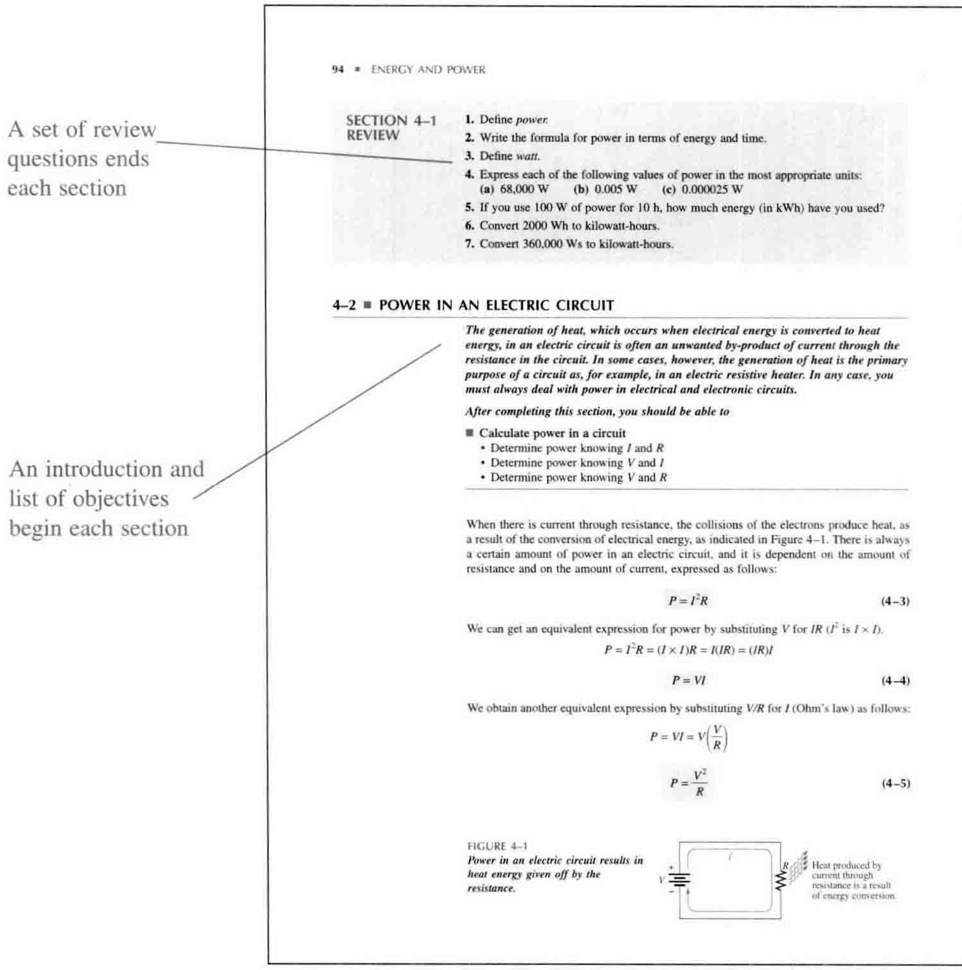


FIGURE A
Chapter opener.



94 ■ ENERGY AND POWER

SECTION 4–1 REVIEW

1. Define *power.*
2. Write the formula for power in terms of energy and time.
3. Define *watt.*
4. Express each of the following values of power in the most appropriate units: **(a)** 68,000 W **(b)** 0.005 W **(c)** 0.000025 W
5. If you use 100 W of power for 10 h, how much energy (in kWh) have you used?
6. Convert 2000 Wh to kilowatt-hours.
7. Convert 360,000 Ws to kilowatt-hours.

4–2 ■ POWER IN AN ELECTRIC CIRCUIT

The generation of heat, which occurs when electrical energy is converted to heat energy, in an electric circuit is often an unwanted by-product of current through the resistance in the circuit. In some cases, however, the generation of heat is the primary purpose of a circuit as, for example, in an electric resistive heater. In any case, you must always deal with power in electrical and electronic circuits.

After completing this section, you should be able to

- **Calculate power in a circuit**
  - Determine power knowing I and R
  - Determine power knowing V and I
  - Determine power knowing V and R

When there is current through resistance, the collisions of the electrons produce heat, as a result of the conversion of electrical energy, as indicated in Figure 4–1. There is always a certain amount of power in an electric circuit, and it is dependent on the amount of resistance and on the amount of current, expressed as follows:

$$P = I^2R \qquad (4\text{–}3)$$

We can get an equivalent expression for power by substituting V for IR (I^2 is $I \times I$).

$$P = I^2R = (I \times I)R = I(IR) = (IR)I$$

$$P = VI \qquad (4\text{–}4)$$

We obtain another equivalent expression by substituting V/R for I (Ohm's law) as follows:

$$P = VI = V\left(\frac{V}{R}\right)$$

$$P = \frac{V^2}{R} \qquad (4\text{–}5)$$

FIGURE 4–1
Power in an electric circuit results in heat energy given off by the resistance.

Heat produced by current through resistance is a result of energy conversion.

FIGURE B
Section opener and section review.

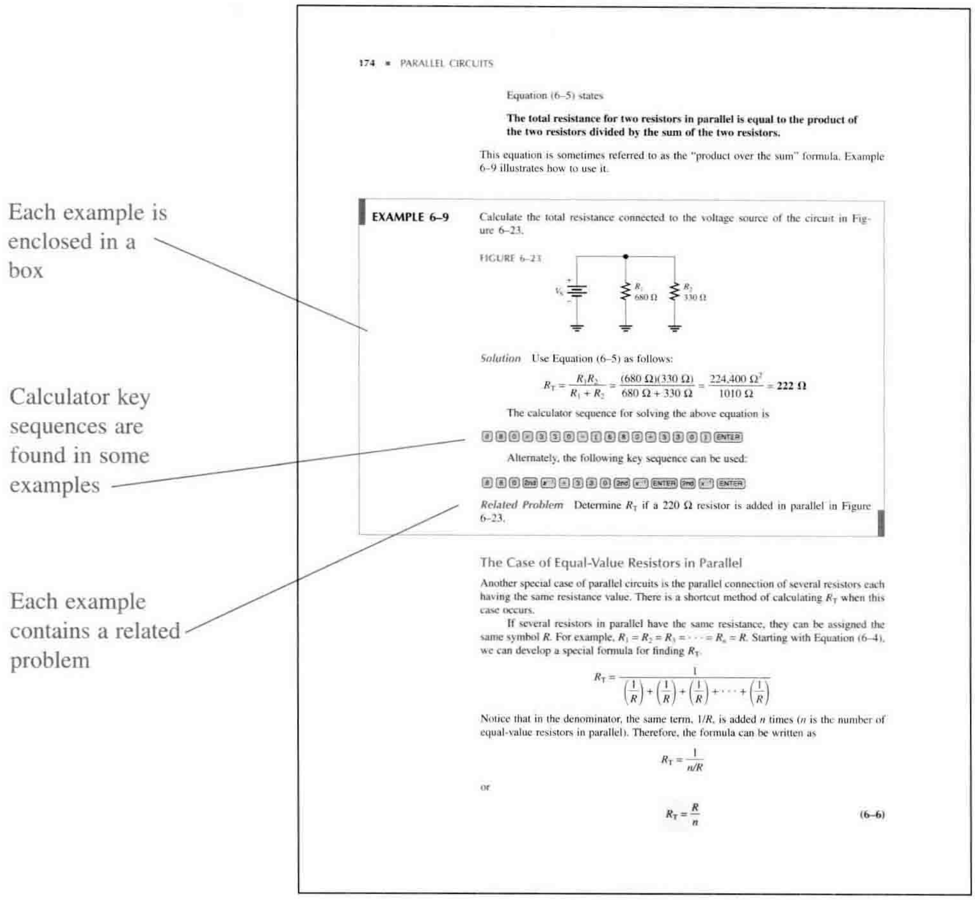
Section Opener Each section in a chapter begins with a brief introduction that provides the essence of the section and a list of section objectives. A typical section opener is shown in Figure B.

Section Review Each section ends with a review consisting of questions and/or exercises that focus on the main concepts covered in the section. Answers to these section reviews are at the end of the chapter. A typical section review is also shown in Figure B.

Worked Examples and Related Problems Numerous examples help to illustrate and clarify basic concepts or demonstrate specific procedures. Each example concludes with a related problem that reinforces or expands on the topic covered in the example. Some of the related problems require a repetition of the calculations in the example using different values or conditions. Others focus on a more limited part of the example or encourage further thought. Answers to the related problems are found at the end of the chapter. A typical worked example and the related problem are shown in Figure C.

Troubleshooting Sections Many chapters include troubleshooting sections emphasizing troubleshooting techniques and the use of test instruments as they apply to situations related to chapter topics.

FIGURE C
An example and related problem.



174 ■ PARALLEL CIRCUITS

Equation (6–5) states

The total resistance for two resistors in parallel is equal to the product of the two resistors divided by the sum of the two resistors.

This equation is sometimes referred to as the "product over the sum" formula. Example 6–9 illustrates how to use it.

EXAMPLE 6–9 Calculate the total resistance connected to the voltage source of the circuit in Figure 6–23.

FIGURE 6–23

Solution Use Equation (6–5) as follows:

$$R_T = \frac{R_1R_2}{R_1 + R_2} = \frac{(680\ \Omega)(330\ \Omega)}{680\ \Omega + 330\ \Omega} = \frac{224{,}400\ \Omega^2}{1010\ \Omega} = \mathbf{222\ \Omega}$$

The calculator sequence for solving the above equation is

Alternately, the following key sequence can be used:

Related Problem Determine R_T if a 220 Ω resistor is added in parallel in Figure 6–23.

The Case of Equal-Value Resistors in Parallel

Another special case of parallel circuits is the parallel connection of several resistors each having the same resistance value. There is a shortcut method of calculating R_T when this case occurs.

If several resistors in parallel have the same resistance, they can be assigned the same symbol R. For example, $R_1 = R_2 = R_3 = \cdots = R_n = R$. Starting with Equation (6–4), we can develop a special formula for finding R_T.

$$R_T = \frac{1}{\left(\frac{1}{R}\right) + \left(\frac{1}{R}\right) + \left(\frac{1}{R}\right) + \cdots + \left(\frac{1}{R}\right)}$$

Notice that in the denominator, the same term, $1/R$, is added n times (n is the number of equal-value resistors in parallel). Therefore, the formula can be written as

$$R_T = \frac{1}{n/R}$$

or

$$R_T = \frac{R}{n} \qquad \textbf{(6–6)}$$

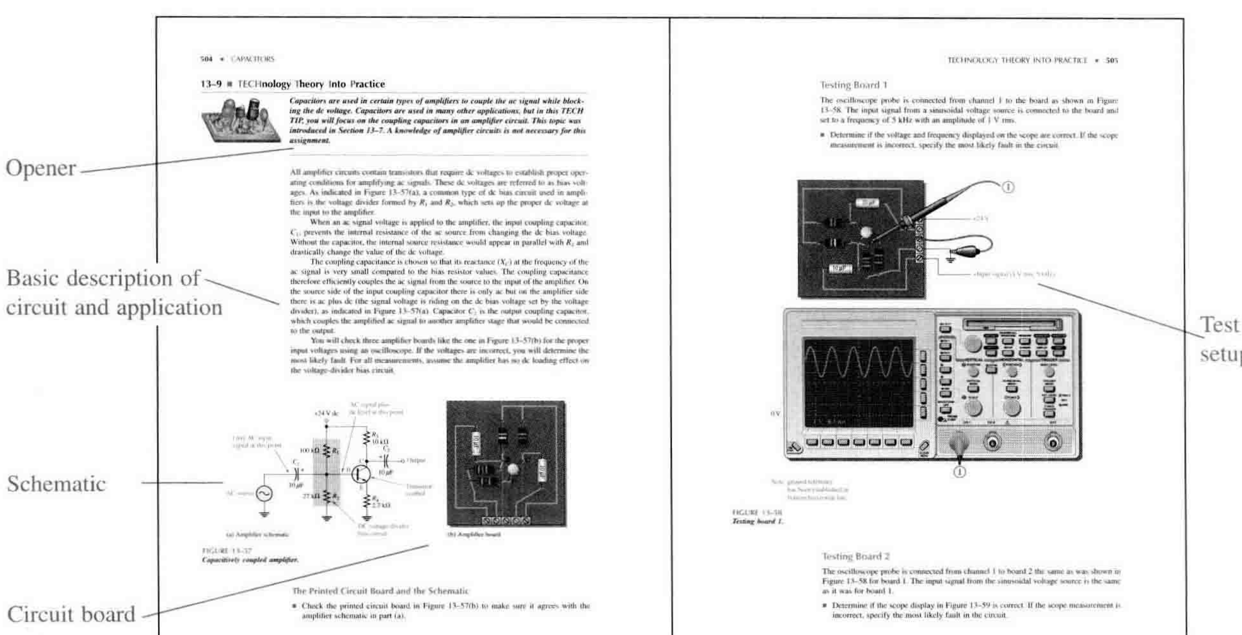


FIGURE D
Representative pages from a typical TECHnology Theory Into Practice (Tech TIP) section.

TECHnology Theory Into Practice (Tech TIP) The last section of each chapter (except Chapters 1 and 22) presents a practical application of certain material presented in the chapter. Each Tech TIP includes a series of activities, many of which involve comparing circuit board layouts with schematics, analyzing circuits, using measurements to determine circuit operation, and in some cases, developing simple test procedures. Results and answers to Tech TIPs are found in the Instructor's Resource Manual. A typical Tech TIP section is illustrated in Figure D.

Chapter End Matter Each chapter ends with a summary, glossary, formula list, multiple-choice self-test, and extensive sectionalized problem set including EWB Troubleshooting and Analysis problems. The most difficult problems are indicated by an asterisk. Also, answers to section reviews, related problems, and self-tests are at the end of each chapter. Terms that appear **boldface** in the text are defined in the end-of-chapter glossaries.

Book End Matter Appendices at the end of the book consist of a table of standard resistor values, a brief coverage of batteries, derivations of selected text equations, and coverage of capacitor color coding. Following the appendices are answers to selected odd-numbered problems (solutions to all end-of-chapter problems are in the Instructor's Resource Manual), comprehensive glossary, and index.

Suggestions for Teaching with *Principles of Electric Circuits*

Selected Course Emphasis and Flexibility of the Text This textbook is designed primarily for use in a two-term course sequence in which dc topics (Chapters 1 through 10) are covered in the first term and ac topics (Chapters 11 through 22) are covered in the second term. A one-term course covering dc and ac topics is possible but would require very selective and abbreviated coverage of many topics.

If time limitations or course emphasis restricts the topics that can be covered, as is usually the case, there are several options for selective coverage. The following suggestions for light treatment or omission do not necessarily imply that a certain topic is less important than others but that, in the context of a specific program, the topic may not require the emphasis that the more fundamental topics do. Because course emphasis, level, and available time vary from one program to another, the omission or abbreviated treatment of selected topics must be made on an individual basis. Therefore, the following suggestions are intended only as a general guide.

1. Chapters that may be considered for omission or selective coverage:
   - Chapter 8, Circuit Theorems and Conversions
   - Chapter 9, Branch, Mesh, and Node Analysis
   - Chapter 10, Magnetism and Electromagnetism
   - Chapter 19, Basic Filters
   - Chapter 20, Circuit Theorems in AC Analysis
   - Chapter 21, Pulse Response of Reactive Circuits
   - Chapter 22, Polyphase Systems in Power Applications
2. The Tech Tip and troubleshooting sections can be omitted without affecting other material.
3. Other specific topics may be omitted or covered lightly on a section-by-section basis at the discretion of the instructor.

The order in which certain topics appear in the text can be altered at the instructor's discretion. For example, the topics of capacitors and inductors (Chapter 13 and 14) can be covered at the end of the dc course in the first term by delaying coverage of the ac topics in Sections 13–6, 13–7, 14–6, and 14–7 until the ac course in the second term. Another possibility is to cover Chapters 13 and 14 in the second term but cover Chapter 16 (*RC* Circuits) immediately after Chapter 13 (Capacitors) and cover Chapter 17 (*RL* Circuits) immediately after Chapter 14 (Inductors).

Tech TIPS These sections are useful for motivation and for introducing applications of basic concepts and components. Suggestions for using these sections are:

- As an integral part of the chapter to illustrate how the concepts and components can be applied in a practical situation. The activities can be assigned for homework.
- As extra credit assignments.
- As in-class activities to promote discussion and interaction and to help students understand why they need to know the material.

Coverage of Reactive Circuits Chapters 16, 17, and 18 have been designed to facilitate two approaches to teaching these topics on reactive circuits.

The first approach is to cover the topics on the basis of components. That is, first cover all of Chapter 16 (*RC* Circuits), then all of Chapter 17 (*RL* Circuits), and, finally, all of Chapter 18 (*RLC* Circuits and Resonance).

The second approach is to cover the topics on the basis of circuit type. That is, first cover all topics related to series reactive circuits, then all topics related to parallel reactive circuits, and finally, all topics related to series-parallel reactive circuits. To facilitate this second approach, each of the chapters have been divided into the following parts: *Part 1: Series Reactive Circuits, Part 2: Parallel Reactive Circuits, Part 3: Series-Parallel Reactive Circuits,* and *Part 4: Special Topics.* So, for series reactive circuits, cover Part 1 of all three chapters in sequence. For parallel reactive circuits, cover Part 2 of all three chapters in sequence. For series-parallel reactive circuits, cover Part 3 of all three chapters in sequence. Finally, cover Part 4 of all three chapters.

A Brief History of Electronics

It is always good to have a sense of the history of your career field. So, before you begin your study of electric circuits, let's briefly look at the beginnings of electronics and some of the important developments that have led to the electronics technology that we have today. The names of many of the early pioneers in electricity and electromagnetics still live on in terms of familiar units and quantities. Names such as Ohm, Ampere, Volta, Farad, Henry, Coulomb, Oersted, and Hertz are some of the better known examples. More widely known names such as Franklin and Edison are also very significant in the history of electricity and electronics because of their tremendous contributions. Brief biographies of many of these appear in Historical Notes at the beginning of the appropriate chapters.

The Beginning of Electronics The early experiments in electronics involved electric currents in glass vacuum tubes. One of the first to conduct such experiments was a German named Heinrich Geissler (1814–1879). Geissler removed most of the air from a glass tube and found that the tube glowed when there was an electric current through it. Around 1878, British scientist Sir William Crookes (1832–1919) experimented with tubes similar to those of Geissler. In his experiments, Crookes found that the current in the vacuum tubes seemed to consist of particles.

Thomas Edison (1847–1931), experimenting with the carbon-filament light bulb he had invented, made another important finding. He inserted a small metal plate in the bulb. When the plate was positively charged, there was a current from the filament to the plate. This device was the first thermionic diode. Edison patented it but never used it.

The electron was discovered in the 1890s. The French physicist Jean Baptiste Perrin (1870–1942) demonstrated that the current in a vacuum tube consisted of the movement of negatively charged particles in a given direction. Some of the properties of these particles were measured by Sir Joseph Thompson (1856–1940), a British physicist, in experiments he performed between 1895 and 1897. These negatively charged particles later became known as electrons. The charge on the electron was accurately measured by an American physicist, Robert A. Millikan (1868–1953), in 1909. As a result of these discoveries, electrons could be controlled, and the electronic age was ushered in.

Putting the Electron to Work In 1904 a British scientist, John A. Fleming, constructed a vacuum tube that allowed electric current in only one direction. The tube was used to detect electromagnetic waves. Called the Fleming valve, it was the forerunner of the more recent vacuum diode tubes. Major progress in electronics, however, awaited the development of a device that could boost, or amplify, a weak electromagnetic wave or radio signal. This device was the audion, patented in 1907 by Lee deForest, an American. It was a triode vacuum tube capable of amplifying small electrical ac signals.

Two other Americans, Harold Arnold and Irving Langmuir, made great improvements in the triode vacuum tube between 1912 and 1914. About the same time, deForest and Edwin Armstrong, an electrical engineer, used the triode tube in an oscillator circuit. In 1914, the triode was incorporated in the telephone system and made the transcontinental telephone network possible. In 1916 Walter Schottky, a German, invented the tetrode tube. The tetrode, along with the pentode (invented in 1926 by Dutch engineer Tellegen), greatly improved the triode. The first television picture tube, called the kinescope, was developed in the 1920s by Vladimir Zworykin, an American researcher.

During World War II, several types of microwave tubes were developed that made possible modern microwave radar and other communications systems. In 1939, the magnetron was invented in Britain by Henry Boot and John Randall. In that same year, the klystron microwave tube was developed by two Americans, Russell Varian and his brother Sigurd Varian. The traveling-wave tube (TWT) was invented in 1943 by Rudolf Komphner, an Austrian-American.

Solid-State Electronics The crystal detectors used in early radios were the forerunners of modern solid-state devices. However, the era of solid-state electronics began with the invention of the transistor in 1947 at Bell Labs. The inventors were Walter Brattain, John Bardeen, and William Shockley.

In the early 1960s, the integrated circuit (IC) was developed. It incorporated many transistors and other components on a single small chip of semiconductor material. Integrated circuit technology has been continuously developed and improved, allowing increasingly more complex circuits to be built on smaller chips.

Around 1965, the first integrated general-purpose operational amplifier was introduced. This low-cost, highly versatile device incorporated nine transistors and twelve resistors in a small package. It proved to have many advantages over comparable discrete component circuits in terms of reliability and performance. Since this introduction, the IC operational amplifier has become a basic building block for a wide variety of linear systems.

Applications

Electricity and electronics are very broad and diverse fields and almost anything you can think of somehow uses electricity or electronics. The following are some of the major application areas.

Computers As everyone knows, computers are used just about everywhere and their applications are almost unlimited. For example, computers are used in business for record keeping, accounting, payroll, inventory control, market analysis, and statistics. In industry, computers are used for controlling and monitoring manufacturing processes. Information, communications, navigation, medical, military, law enforcement, and domestic applications are some of the other broad areas where computers are found.

Communications Electronic communications involves a wide variety of specialized fields that include telephone systems, satellites, radio, television, data communications, and radar, to name a few.

Automation Electronic systems are used extensively in the control of manufacturing processes. For example, the robotic systems used in the assembly of automobiles are electronically controlled. A few other applications are the control of ingredient mixes in food processing, the operation of machine tools, distribution of power, and printing.

Transportation Electronics is an integral part of most types of transportation equipment and systems. One example is the electronics found in most modern automobiles for entertainment, brake controls, ignition controls, engine monitoring, and communications. The airline industry would be completely shut down without electronics for navigation, communication, and scheduling purposes. Also, trucks, trains, and boats depend on electronics for much of their operation.

Medicine Electronic systems are used in the medical field for many things. For example, the monitoring of patient functions such as heart rate, blood pressure, temperature, and respiration is accomplished electronically. Diagnostic tools such as the CAT scan, EKG, X-ray, and ultrasound are all electronic-based systems.

Consumer Electronics Products used directly by the consumer constitute a large segment of the electronics market. There are systems for entertainment and information such as radios, televisions, VCRs, computers, sound systems, and electronic games. There are systems for communications such as cellular phones, pagers, recorders, intercoms, CB radio, short-wave radio, and computers. Also, many products that do work in the home such as washing machines, dryers, refrigerators, ranges, and security systems have electronic controls.

Acknowledgments

Many very capable people have been involved with this Sixth Edition of *Principles of Electric Circuits.* It has been completely reviewed and checked for both content and accuracy. Those at Prentice Hall who have been instrumental in moving this project through its many phases include Rex Davidson, Katie Bradford, and Scott Sambucci. They deserve much credit.

My appreciation, once again, to Lois Porter who has done another wonderful job of editing the manuscript. Also, thanks to Jane Lopez for the great job on the graphics art used in the text. Chuck Garbinski has been my accuracy checker on this project and I commend him for his outstanding work. In addition, Chuck created the EWB circuit files for the Electronics Workbench features that are new to this edition. Last but certainly not least, thanks to my colleague Dave Buchla for his consultations on many topics and his thorough review of the manuscript. As always, we depend on expert input from many users and nonusers of *Principles of Electric Circuits.* My thanks to the following reviewers who made many valuable suggestions and provided much constructive criticism.

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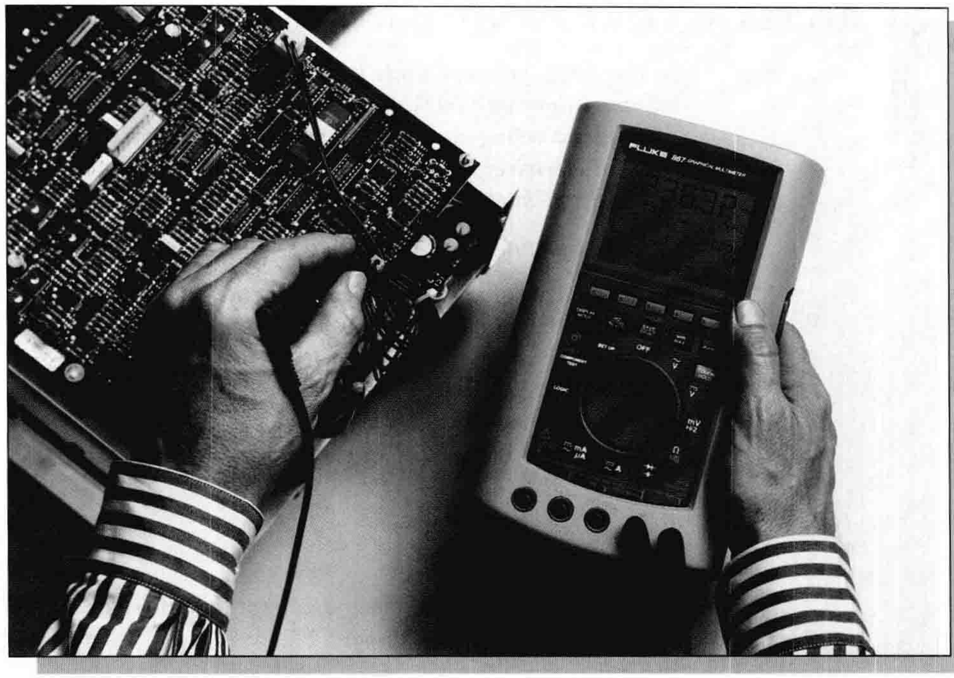
CONTENTS

■ **TECHnology Theory Into Practice**



Fluke 867 graphical multimeter (courtesy of John Fluke Manufacturing Co.)

■ CHAPTER OBJECTIVES

- ❑ Recognize some common components and measuring instruments
- ❑ List the electrical and magnetic quantities and their units
- ❑ Use scientific notation (powers of ten) to express quantities
- ❑ Use metric prefixes to express large and small numbers
- ❑ Convert from one metric unit to another

1–1 ■ ELECTRICAL COMPONENTS AND MEASURING INSTRUMENTS

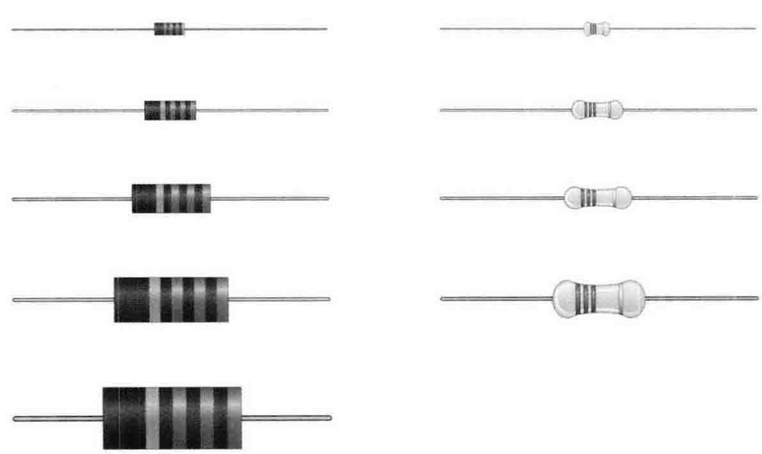
In this book, you will study many types of electrical components and several instruments. A thorough background in dc and ac fundamentals provides the foundation for understanding complex electronic devices and circuits. A preview of the basic types of electrical and electronic components and instruments that you will be studying in detail later in this and in other courses is provided in this section.

After completing this section, you should be able to

- **Recognize some common components and measuring instruments**
  - State the purpose of a resistor
  - State the purpose of a capacitor
  - State the purpose of an inductor
  - State the purpose of a transformer
  - List some basic types of electronic test and measuring instruments

Resistors

Resistors resist, or limit, electric current in a circuit. Several common types of resistors are shown in Figure 1–1 through Figure 1–4.



(a) Carbon-composition (b) Metal film

FIGURE 1–1
Two common types of individual fixed resistors with axial leads.

(a) Metal film chip resistor (b) Chip resistor array (c) Resistor network (simm) (d) Resistor network (surface mount)

FIGURE 1–2
Chip resistor and resistor networks.