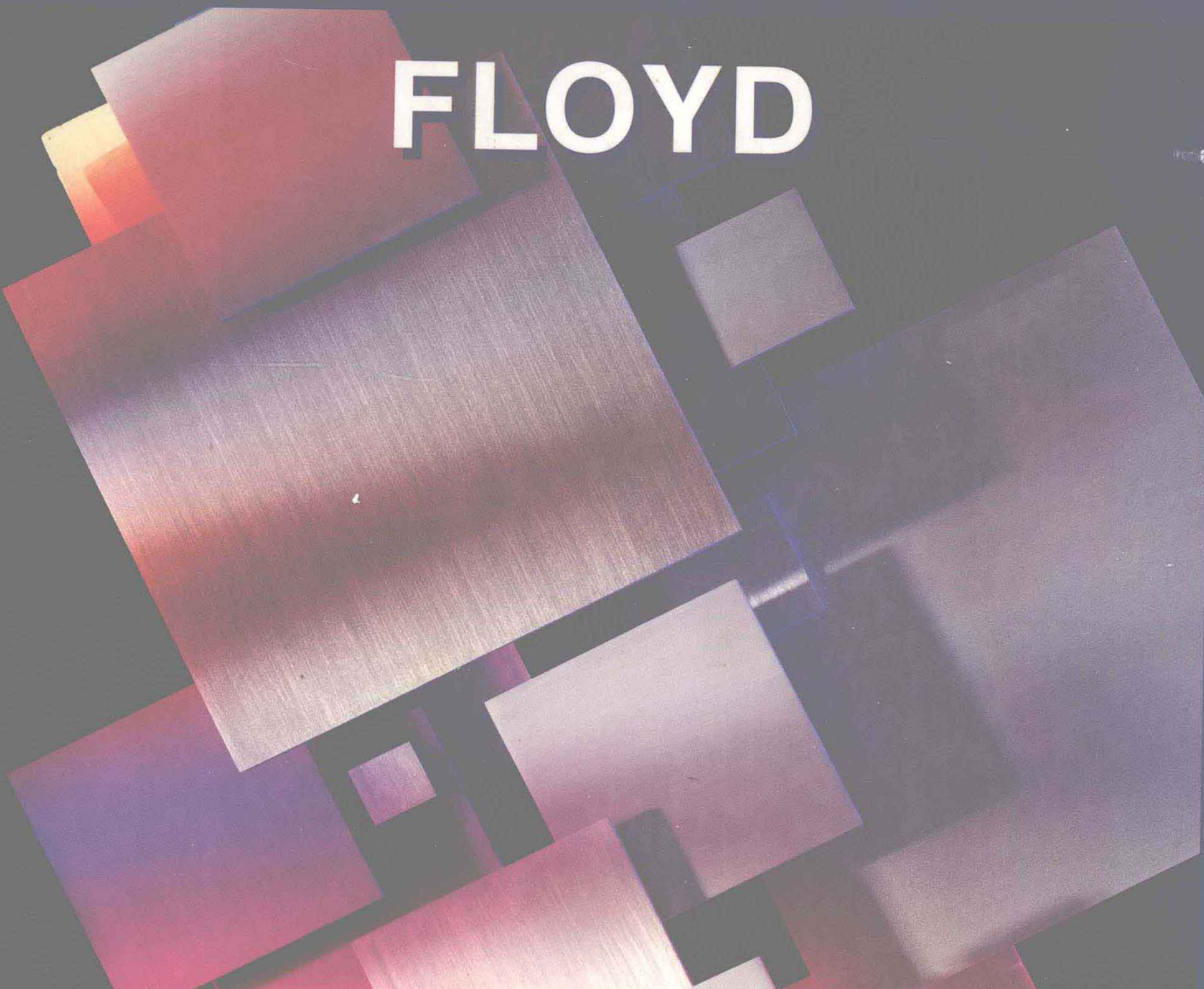
Electronic Devices

Electron-Flow Version

Third Edition



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Third Edition

ELECTRONIC DEVICES
Electron-Flow Version

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Prentice Hall
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ELECTRONIC DEVICES
Electron-Flow Version

TO SHEILA AND TAYLOR, WITH LOVE.

PREFACE

This Third Edition of *Electronic Devices: Electron-Flow Version* provides a thorough, comprehensive, and practical coverage of electronic devices, circuits, and applications in a clear and well-illustrated format. The extensive troubleshooting coverage, the system applications, and the use of data sheets provide an important link between theory and the real world. The content is separated into two basic topic areas. Chapters 1 through 11 cover discrete devices and circuits, and Chapters 12 through 18 deal primarily with linear integrated circuits.

This edition retains the content and organization of the previous edition. However, there are many small changes throughout that improve the clarity or expand the presentation of certain topics. Also, new to this edition are the Electronics Workbench (EWB) and PSpice exercises with available circuits disks. These are included in selected examples and troubleshooting sections.

Overview

Discrete Devices and Circuits Basic semiconductor theory, *pn* junctions, and the diode are introduced in Chapter 1. Diode rectifiers and other general-purpose diode applications are covered in Chapter 2. Special-purpose diodes including the zener, varactor, and optical devices are introduced in Chapter 3. Bipolar junction transistors (BJTs), small-signal BJT amplifiers, and power amplifiers are covered in Chapters 4 through 7. Chapters 8 and 9 discuss field-effect transistors (FETs) and FET amplifiers. Frequency responses of both BJT and FET amplifiers are covered in Chapter 10. Thyristors and other devices are introduced in Chapter 11.

Linear Integrated Circuits (ICs) Operational amplifiers (op-amps) are introduced in Chapter 12, and their frequency response and stability characteristics are covered in Chapter 13. Basic op-amp circuit configurations are studied in Chapters 14 and 15. Active filters is the topic in Chapter 16, followed by a discussion of oscillators (both discrete and IC) in Chapter 17. Finally, Chapter 18 provides a coverage of discrete and IC voltage regulators.

Features

The most significant features (not necessarily in order of importance) are as follows:

- EWB and PSpice exercises with available circuits disks
- Extensive treatment of both discrete and integrated circuits
- Full-color format
- Extensive use of examples
- Related exercise in each numbered example
- Extensive use of color illustrations

- ☐ Clear writing style
- ☐ Standard component values
- ☐ Two-page chapter openers with system application preview
- ☐ Section openers with performance-based section objectives
- ☐ Section review questions
- ☐ Answers to section reviews and related exercises at end of chapters
- ☐ Mathematics kept to a minimum
- ☐ Illustrated summaries at key locations in several chapters
- ☐ System application section in all chapters except Chapter 1
- ☐ Unique circuit board color graphics in all system applications
- ☐ Extensive troubleshooting coverage
- ☐ Data sheets used throughout text
- ☐ End-of-chapter summaries
- ☐ End-of-chapter glossaries
- ☐ End-of-chapter multiple-choice self-tests
- ☐ End-of-chapter key formula lists
- ☐ Basic end-of-chapter problems
- ☐ Data sheet end-of-chapter problems
- ☐ Troubleshooting end-of-chapter problems
- ☐ Advanced end-of-chapter problems
- ☐ Comprehensive glossary at end of book

The comprehensive ancillary package for this edition includes the following:

- ☐ *Instructor's Resource Manual* with Test Item File and Transparency Masters (ISBN: 0-13-080025-2)
- ☐ *Laboratory Exercises for Electronic Devices* by Dave Buchla (ISBN: 0-13-080026-0)
- ☐ *Laboratory Solutions Manual* by Dave Buchla (ISBN: 0-13-080024-4)
- ☐ *Experiments in Electronic Devices* by Howard Berlin (ISBN: 0-13-080023-6)
- ☐ *Laboratory Solutions Manual* by Howard Berlin (ISBN: 0-13-080022-8)
- ☐ PH Custom Test (WIN) (ISBN: 0-13-080021-X)
- ☐ PowerPoint Transparencies (ISBN: 0-13-080019-8)
- ☐ PSpice® Circuit Files created by Chuck Garbinski (ISBN: 0-13-080032-5)
- ☐ Electronics Workbench® Circuit Files created by Gary Snyder included on the CD-ROM in the back of this book. The CD-ROM also contains a complete time-locked version of Electronics Workbench® and tutorial.
- ☐ Bergwall Video Library available to adopters (contact Prentice-Hall representative for details)

Chapter Pedagogy

Chapter Opener Each chapter begins with a two-page spread as shown in Figure P–1. The left page provides the chapter title, a section listing, chapter objectives, and a brief introduction. The right page presents a brief description of the system application along with a block diagram.

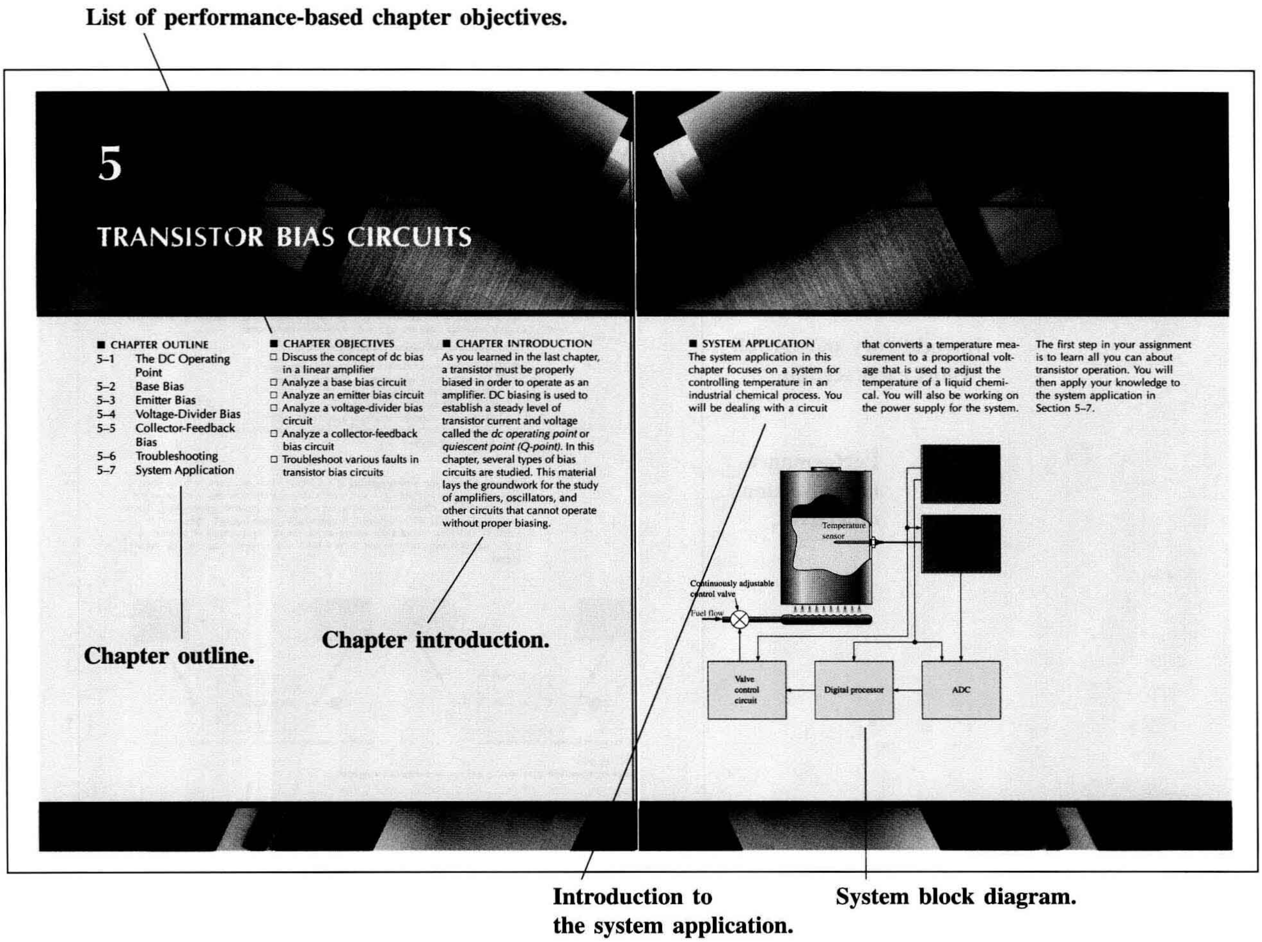
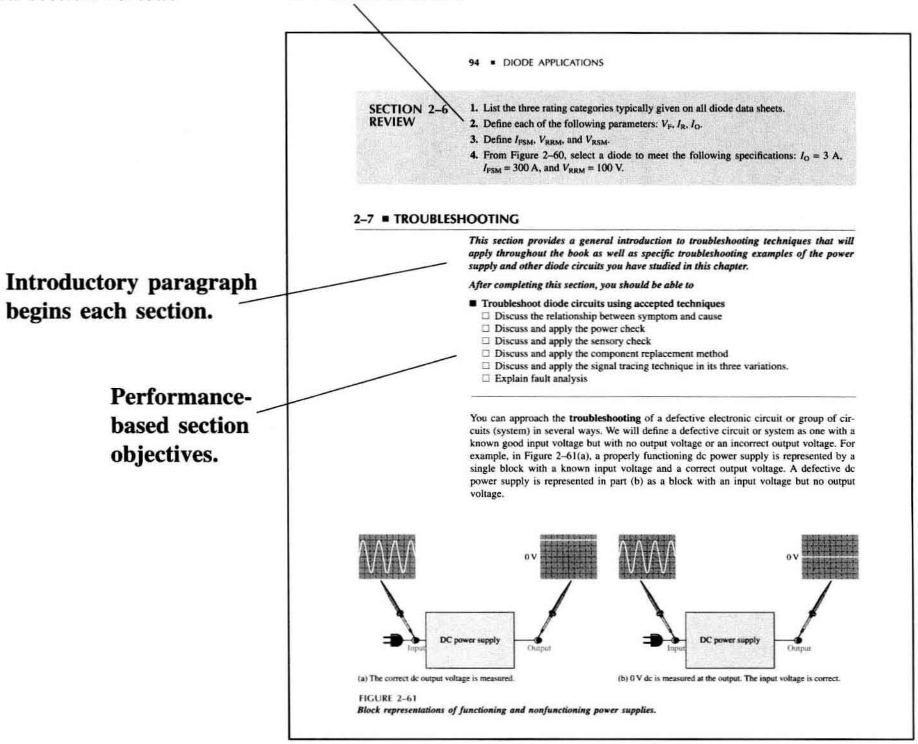


FIGURE P–1
A typical chapter opener.

Section Opener and Section Review Each section within a chapter begins with an introduction that provides a general section overview followed by a list of performance-based objectives. Each section ends with a set of review questions or problems that focus on the main concepts that were covered. Answers to the reviews are given at the end of the chapter. Figure P–2 illustrates these features.

Examples and Related Exercises Worked out examples are used extensively to illustrate and clarify topics. At the end of each example and within the example box is a related exercise, which reinforces or expands on the example. Some related exercises require the student to repeat the procedure illustrated in the example with a different set of values or conditions. Others focus on a more limited part of the example or encourage further thought beyond the procedure shown in the example. Figure P–3 illustrates a typical example with a related exercise and an EWB/PSpice exercise. Answers to related exercises can be found at the end of the chapter.

FIGURE P–2
A typical section opener and section review.



94 ■ DIODE APPLICATIONS

SECTION 2–6 REVIEW

1. List the three rating categories typically given on all diode data sheets.
2. Define each of the following parameters: V_F, I_R, I_O.
3. Define I_{FSM}, V_{RRM}, and V_{RSM}.
4. From Figure 2–60, select a diode to meet the following specifications: $I_O = 3$ A, $I_{FSM} = 300$ A, and $V_{RRM} = 100$ V.

2–7 ■ TROUBLESHOOTING

This section provides a general introduction to troubleshooting techniques that will apply throughout the book as well as specific troubleshooting examples of the power supply and other diode circuits you have studied in this chapter.

After completing this section, you should be able to

- **Troubleshoot diode circuits using accepted techniques**
  - ☐ Discuss the relationship between symptom and cause
  - ☐ Discuss and apply the power check
  - ☐ Discuss and apply the sensory check
  - ☐ Discuss and apply the component replacement method
  - ☐ Discuss and apply the signal tracing technique in its three variations.
  - ☐ Explain fault analysis

You can approach the **troubleshooting** of a defective electronic circuit or group of circuits (system) in several ways. We will define a defective circuit or system as one with a known good input voltage but with no output voltage or an incorrect output voltage. For example, in Figure 2–61(a), a properly functioning dc power supply is represented by a single block with a known input voltage and a correct output voltage. A defective dc power supply is represented in part (b) as a block with an input voltage but no output voltage.

(a) The correct dc output voltage is measured.

(b) 0 V dc is measured at the output. The input voltage is correct.

FIGURE 2–61
Block representations of functioning and nonfunctioning power supplies.

Illustrated Summaries Topics are summarized at appropriate points in certain chapters by an illustrated summary that pulls together important concepts, symbols, circuits, and formulas that are significant in the development of the topic. A typical illustrated summary is shown in Figure P–4.

System Application The last section of each chapter (except Chapter 1) presents a system application of devices and circuits covered in the chapter. A series of activities with a practical slant are provided to give the student a simulated "on-the-job" experience. These activities include relating a schematic to a graphical representation of a printed circuit board, analysis of a circuit, development of test procedures, setting up a test bench, troubleshooting circuit boards and writing a final report. A typical system application section is illustrated in Figure P–5. Results of system application activities are available in the Instructor's Resource Manual.

Chapter End Matter A chapter summary, a glossary, a list of key formulas, and a multiple-choice self-test follow the text of the chapter. Terms that appear boldface in the text are defined in the glossary.

All chapters have a sectionalized set of basic problems with answers to the odd-numbered ones provided at the end of the book. Additionally, many chapters include a set of data sheet problems, a set of troubleshooting problems, and/or a set of advanced problems.

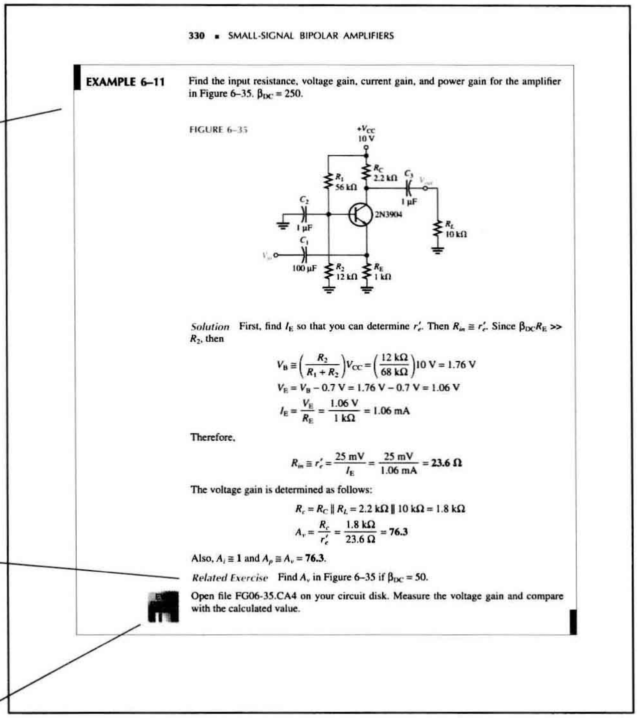
Answers to section reviews and related exercises are the last items in each chapter.

FIGURE P–3
A typical example with a related exercise and an EWB/PSpice exercise.

Each example is enclosed in a box.

Each example contains a related exercise relevant to the example.

Selected examples include an EWB/PSpice exercise coordinated to available circuits disks.



330 ■ SMALL-SIGNAL BIPOLAR AMPLIFIERS

EXAMPLE 6–11 Find the input resistance, voltage gain, current gain, and power gain for the amplifier in Figure 6–35. $\beta_{DC} = 250$.

FIGURE 6–35

Solution First, find I_E so that you can determine r'_e. Then $R_{in} \cong r'_e$. Since $\beta_{DC}R_E >> R_2$, then

$$V_B \cong \left(\frac{R_2}{R_1 + R_2}\right)V_{CC} = \left(\frac{12\text{ k}\Omega}{68\text{ k}\Omega}\right)10\text{ V} = 1.76\text{ V}$$

$$V_E = V_B - 0.7\text{ V} = 1.76\text{ V} - 0.7\text{ V} = 1.06\text{ V}$$

$$I_E = \frac{V_E}{R_E} = \frac{1.06\text{ V}}{1\text{ k}\Omega} = 1.06\text{ mA}$$

Therefore,

$$R_{in} \cong r'_e = \frac{25\text{ mV}}{I_E} = \frac{25\text{ mV}}{1.06\text{ mA}} = \mathbf{23.6\ \Omega}$$

The voltage gain is determined as follows:

$$R_c = R_C \parallel R_L = 2.2\text{ k}\Omega \parallel 10\text{ k}\Omega = 1.8\text{ k}\Omega$$

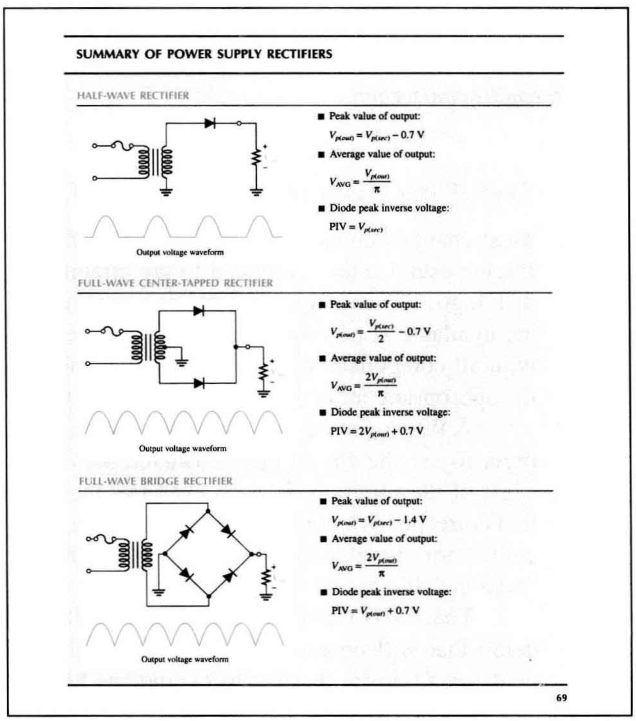
$$A_v = \frac{R_c}{r'_e} = \frac{1.8\text{ k}\Omega}{23.6\ \Omega} = \mathbf{76.3}$$

Also, $A_i \cong$ **1** and $A_p \cong A_v =$ **76.3**.

Related Exercise Find A_v in Figure 6–35 if $\beta_{DC} = 50$.

Open file FG06-35.CA4 on your circuit disk. Measure the voltage gain and compare with the calculated value.

FIGURE P–4
A typical illustrated summary.



SUMMARY OF POWER SUPPLY RECTIFIERS

HALF-WAVE RECTIFIER

- Peak value of output: $V_{p(out)} = V_{p(sec)} - 0.7\text{ V}$
- Average value of output: $V_{AVG} = \frac{V_{p(out)}}{\pi}$
- Diode peak inverse voltage: $\text{PIV} = V_{p(sec)}$

Output voltage waveform

FULL-WAVE CENTER-TAPPED RECTIFIER

- Peak value of output: $V_{p(out)} = \frac{V_{p(sec)}}{2} - 0.7\text{ V}$
- Average value of output: $V_{AVG} = \frac{2V_{p(out)}}{\pi}$
- Diode peak inverse voltage: $\text{PIV} = 2V_{p(out)} + 0.7\text{ V}$

Output voltage waveform

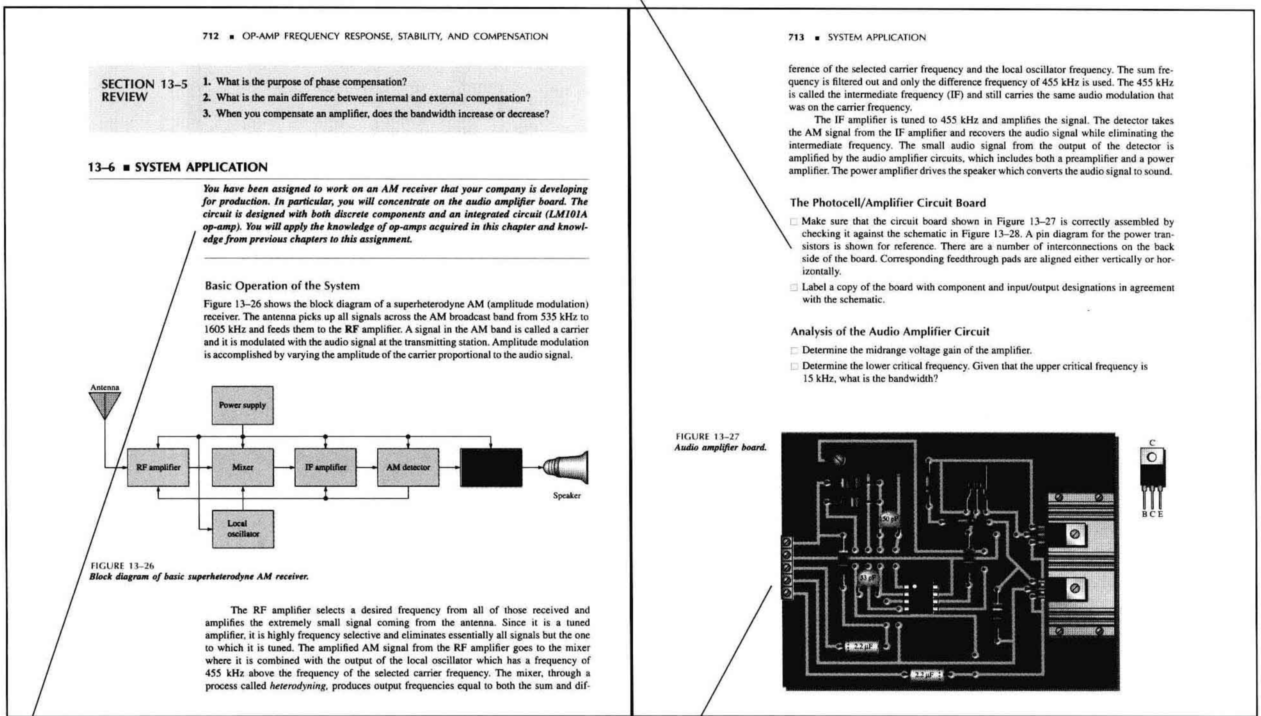
FULL-WAVE BRIDGE RECTIFIER

- Peak value of output: $V_{p(out)} = V_{p(sec)} - 1.4\text{ V}$
- Average value of output: $V_{AVG} = \frac{2V_{p(out)}}{\pi}$
- Diode peak inverse voltage: $\text{PIV} = V_{p(out)} + 0.7\text{ V}$

Output voltage waveform

69

A series of activities is provided, which simulate "on-the-job" experiences.


712 ■ OP-AMP FREQUENCY RESPONSE, STABILITY, AND COMPENSATION

SECTION 13–5 REVIEW

1. What is the purpose of phase compensation?
2. What is the main difference between internal and external compensation?
3. When you compensate an amplifier, does the bandwidth increase or decrease?

13–6 ■ SYSTEM APPLICATION

You have been assigned to work on an AM receiver that your company is developing for production. In particular, you will concentrate on the audio amplifier board. The circuit is designed with both discrete components and an integrated circuit (LM101A op-amp). You will apply the knowledge of op-amps acquired in this chapter and knowledge from previous chapters to this assignment.

Basic Operation of the System

Figure 13–26 shows the block diagram of a superheterodyne AM (amplitude modulation) receiver. The antenna picks up all signals across the AM broadcast band from 535 kHz to 1605 kHz and feeds them to the **RF** amplifier. A signal in the AM band is called a carrier and it is modulated with the audio signal at the transmitting station. Amplitude modulation is accomplished by varying the amplitude of the carrier proportional to the audio signal.

FIGURE 13–26
Block diagram of basic superheterodyne AM receiver.

The RF amplifier selects a desired frequency from all of those received and amplifies the extremely small signal coming from the antenna. Since it is a tuned amplifier, it is highly frequency selective and eliminates essentially all signals but the one to which it is tuned. The amplified AM signal from the RF amplifier goes to the mixer where it is combined with the output of the local oscillator which has a frequency of 455 kHz above the frequency of the selected carrier frequency. The mixer, through a process called *heterodyning*, produces output frequencies equal to both the sum and dif-

713 ■ SYSTEM APPLICATION

ference of the selected carrier frequency and the local oscillator frequency. The sum frequency is filtered out and only the difference frequency of 455 kHz is used. The 455 kHz is called the intermediate frequency (IF) and still carries the same audio modulation that was on the carrier frequency.

The IF amplifier is tuned to 455 kHz and amplifies the signal. The detector takes the AM signal from the IF amplifier and recovers the audio signal while eliminating the intermediate frequency. The small audio signal from the output of the detector is amplified by the audio amplifier circuits, which includes both a preamplifier and a power amplifier. The power amplifier drives the speaker which converts the audio signal to sound.

The Photocell/Amplifier Circuit Board

- ☐ Make sure that the circuit board shown in Figure 13–27 is correctly assembled by checking it against the schematic in Figure 13–28. A pin diagram for the power transistors is shown for reference. There are a number of interconnections on the back side of the board. Corresponding feedthrough pads are aligned either vertically or horizontally.
- ☐ Label a copy of the board with component and input/output designations in agreement with the schematic.

Analysis of the Audio Amplifier Circuit

- ☐ Determine the midrange voltage gain of the amplifier.
- ☐ Determine the lower critical frequency. Given that the upper critical frequency is 15 kHz, what is the bandwidth?

FIGURE 13–27
Audio amplifier board.

An overall introduction to the system application is provided before a particular PC board circuit is focused on.

Most system applications include realistic PC board graphics.

FIGURE P–5
Portion of a typical system application section.

EWB/PSpice Exercises and Circuits Disks

Most chapters contain selected examples that include an Electronics Workbench (EWB)/PSpice exercise that is related to the circuit in the example and is indicated by a special disk logo. The example circuits are simulated in both EWB and PSpice files on disks that are available at no cost. Each circuit on the disk appears essentially as it does in the text with all component values included. For most circuits, the student is required to connect the appropriate input source and determine the proper measurements to take.

A Windows® 95 version of Electronics Workbench or PSpice software is required in order to use the circuit files; however, the circuits will also work with Windows 3.x versions of the program. In each exercise, the simulated circuit is referenced by a filename that corresponds to the figure number in the text. Student files on the circuits disks can be copied for distribution to the students. The instructor/student should first refer to the "read me" file on the disk for information on using the disk.

The EWB CD-ROM included with this text also contains a fully functional EWB demo that will operate 15 circuits from throughout the text. In addition, the CD-ROM contains a tutorial that instructs students how to operate EWB and how to simulate circuits. The CD-ROM also includes a locked version of Electronics Workbench® Student

Version 5.0 that can be unlocked by calling Interactive Image Technologies. Instructions for unlocking the software are included on the CD-ROM.

In most cases, the measured results obtained from the simulations will differ somewhat from the theoretically calculated results in the text example. Also, you may observe some minor differences between the results obtained with EWB and those obtained with PSpice should you elect to use both simulation programs in your course. Any minor differences are due mainly to device modelling, loading effects, simulation times, and sampling methods.

In addition to the example exercises, most troubleshooting sections contain EWB/PSpice troubleshooting exercises in which a variety of faults are introduced in a simulated circuit and the student must troubleshoot the circuit to find the fault in each case.

Because the computer simulation features are optional, a basic knowledge of EWB or PSpice is assumed and no instruction is given in this text. There are, however, brief tutorials for both EWB and PSpice in the Instructor's Resource Manual that accompanies this edition of *Electronic Devices: Electron-Flow Version*. These tutorials may be copied for student use. Generally, the user's guides that are included in the software packages are also very helpful. In addition, several textbooks on PSpice are available.

Suggestions for Use

Electronic Devices: Electron-Flow Version, Third Edition, can be used in a variety of scheduling and program requirements.

Two-Term Course Chapters 1 through 11 can be covered in the first term. Depending on individual situations, selective coverage may be necessary. For example, Chapter 11 may be omitted if the topic of thyristors is covered in a later industrial electronics course. Chapters 12 through 18 can be covered in the second term. Again, selective coverage may be necessary.

One-Term Course By omitting certain topics and/or by maintaining a rigorous schedule, this text can be used in one-term courses which cover only discrete devices and circuits or only linear integrated circuits. Also, a significant reduction in the coverage of discrete devices in Chapters 1 through 11 and a limited coverage of integrated circuits (only op-amps, for example) will allow use in a one-term course.

To the Student

Knowledge and skills are not obtained without effort. Hard work is required to properly prepare yourself for any career, and electronics is no exception. Much reading, thinking, problem solving, and laboratory experience are required to make the most effective use of this book. Don't expect every concept or procedure to become immediately clear. Some topics may take several readings, working through many problems, and some help from your instructor before you really understand them.

Go through each example step-by-step and then do the related exercise. Work through each section review and check your answers at the end of the chapter. If you don't understand an example or if you can't answer a review question, go back into the section until you can and only then move on to the next section.

The multiple-choice self-tests at the end of each chapter are a good way to check your overall comprehension and retention of the material covered in a chapter. You should do the self-test before working the end-of-chapter problems and check your answers at the end of the book.

The problems at the end of each chapter provide exercises with varying degrees of difficulty that reinforce the theory. Many chapters offer a set of advanced problems for those of you who want additional challenge. By working through a problem you acquire a level of insight and understanding that reading or classroom lectures alone do not provide. Generally you cannot fully understand a concept or procedure by simply watching or listening to someone else. In the final analysis, only hard work and critical thinking will produce the results you expect and deserve.

A Brief History

Before you begin your study of electronic devices and circuits, let's briefly look back at the beginnings of electronics and some of the important developments that have led to the electronics technology that we have today. It is always good to have a sense of the history of your career field. 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.

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 consists of the movement of negatively charged particles in a given direction. Some of the properties of these particles were measured by Sir Joseph Thomson (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 A vacuum tube that allowed electrical current in only one direction was constructed in 1904 by British scientist John A. Fleming. 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.

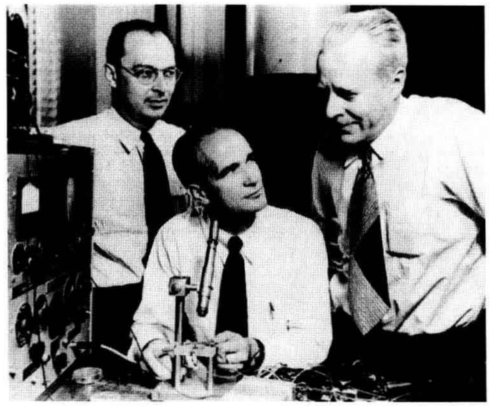


FIGURE P–6
Nobel Prize winners Drs. John Bardeen, William Shockley, and Walter Brattain, shown left to right, with apparatus used in their first investigations that led to the invention of the transistor. The trio received the 1956 Nobel Physics award for their invention of the transistor, which was announced by Bell Laboratories in 1948. (Courtesy of Bell Laboratories)

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. The tetrode tube was invented in 1916 by Walter Schottky, a German. 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 Sworykin, 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 the 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, shown in Figure P–6.

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.

Acknowledgments

This Third Edition of *Electronic Devices: Electron-Flow Version* is the result of the efforts and talents of many people. I want to express my appreciation to Carol Robison, Linda Ludewig, Rex Davidson, and Pat Tonneman of Prentice-Hall. Also, I am grateful to Lois Porter for another wonderfully thorough job in editing the manuscript, and to Dave Buchla for his ideas and suggestions. Finally, many thanks to Gary Snyder and Chuck Garbinski, who developed the circuit disks for the EWB and PSpice exercises and the related matter that appears in the Instructor's Resource Manual.

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Keep up the good work. Your efforts are greatly appreciated

Tom Floyd

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