Introductory Electronic Devices and Circuits

4th Edition

Robert T. Paynter

FOURTH EDITION

INTRODUCTORY ELECTRONIC DEVICES AND CIRCUITS

Robert T. Paynter

St. Louis Community College

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▪ *This book is dedicated to the folks who stayed the course:*

Wayne Newcomb (a.k.a. Big Bad Bob Wayne)
John Gerber & the rest of the gang in River Falls
Craig and Linda Kessler
Ron and Tori Welling
Bill Muckler
Bob Colbert
Mike Powers
My parents, Bill and Mary Paynter
Fred and Shirley Matthews

and most of all

Susan Matthews Paynter

Preface: To the Instructor

The fourth edition of *Introductory Electronic Devices and Circuits* is, for me, a return to writing. As you probably know, I was unable to work on the third edition of the text. The authors of that edition (John Clemons, Fred Evangelisti, Fred Kerr, and Charles Klingensmith) did an admirable job under the circumstances, but now it is time for my book to come home. Even so, you may find traces of their work in this edition (credit for which is hereby given).

From the start, my goal has been to produce a text that students can really *use* in their studies. To this end, many of the learning aids developed throughout the previous editions have been retained in this edition:

Examples of the learning aids are shown on the following pages.

① **Chapter outlines** provide a handy overview of the chapter organization.

② **Performance-based objectives** enable the students to measure their progress by telling them what they are expected to be able to *do* as a result of their studies.

③ **Objective identifiers** in the margins cross-reference the objectives with the chapter material. This helps the students to quickly locate the material that will enable them to fulfill a given objective.

④ **Margin notes** include a running glossary of new terms, notes that highlight the differences between theory and practice, and reminders of principles covered in earlier chapters.

⑤ **In-chapter practice problems** are included in the examples to provide the students with an immediate opportunity to apply the principles being demonstrated.

⑥ **Summary illustrations** provide a convenient summary of circuit operating principles and applications. Many provide comparisons between a variety of related circuits.

The following have also been retained from previous editions:

- **Section Review** questions at the end of each section.
- An **Equation Summary** and **Key Term List** at the end of each chapter, along with **Answers to the Example Practice Problems.**
- An extensive set of practice problems at the end of most chapters. In addition to standard practice problems, the problem sets include:

  Troubleshooting Practice Problems

  "The Brain Drain" (Challengers)

  Suggested Computer Applications Problems

(1)

OUTLINE

8.1 Amplifier Properties
8.2 BJT Amplifier Configurations
8.3 Amplifier Classifications
8.4 Decibels

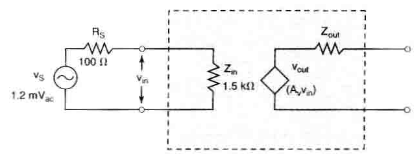
(2)

OBJECTIVES

After studying the material in this chapter, you should be able to:

1. List the three fundamental ac properties of amplifiers.
2. Discuss the concept of gain.
3. Draw and discuss the general model of a voltage amplifier.
4. Discuss the effects that amplifier input and output impedance have on the effective voltage gain of the circuit.
5. Describe the ideal voltage amplifier.
6. List, compare, and contrast the three BJT amplifier configurations.
7. Determine the configuration of any BJT amplifier.
8. Discuss the concept of amplifier efficiency.
9. List, compare, and contrast the various classes of amplifier operation.
10. Convert any power or voltage gain value to and from dB form.

FIGURE 8.5



When we add a signal source and a load to the amplifier model in Figure 8.4a, we obtain the circuit shown in Figure 8.4b. The input circuit consists of v_S, R_S, and Z_{in} (the amplifier input impedance). The output circuit consists of v_{out}, Z_{out} (the amplifier output impedance), and R_L. As you can see, the circuits are nearly identical (in terms of their components).

(3)

Amplifier Input Impedance (Z_{in})

OBJECTIVE 4 ►

(4) **Input impedance** The load that an amplifier places on its source.

When an amplifier is connected to a signal source, the source sees the amplifier as a load. The input impedance (Z_{in}) of the amplifier is the value of this load. For example, the value of Z_{in} for the amplifier in Figure 8.5 is shown to be 1.5 kΩ. In this case, the amplifier acts as a 1.5 kΩ load that is in series with the source resistance (R_S).

If we assume that the input impedance of the amplifier in Figure 8.5 is purely resistive, the signal voltage at the amplifier input is found as

$$v_{in} = v_S \frac{Z_{in}}{R_s + Z_{in}} \tag{8.5}$$

Since R_S and Z_{in} form a voltage divider, the input voltage to the amplifier must be lower than the rated value of the source. This point is illustrated in the following example.

EXAMPLE 8.3

Calculate the value of v_{in} for the circuit in Figure 8.5.

Solution: Using the values shown in the figure, the value of v_{in} is found as

$$v_{in} = v_S \frac{Z_{in}}{R_S + Z_{in}}$$

$$= (1.2\ \text{mV}_{ac})\frac{1.5\ \text{k}\Omega}{1.6\ \text{k}\Omega}$$

$$= 1.125\ \text{mV}_{ac}$$

(5)

PRACTICE PROBLEM 8.3

Amplifier like the one in Figure 8.5 has the following values: v_S = 800 μV$_{ac}$, R_S = 70 Ω, and Z_{in} = 750 Ω. Calculate the value of v_{in} for the circuit.

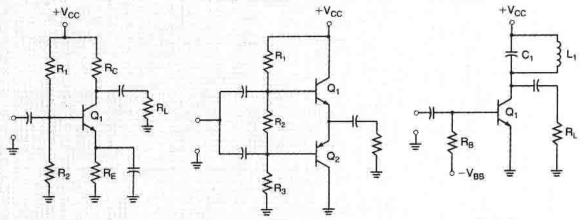
The Effect of R_S and Z_{in} on Amplifier Output Voltage

Example 8.3 demonstrated the effect that R_S and Z_{in} can have on the input to an amplifier. As the following example demonstrates, the reduction of the source voltage can cause a noticeable reduction in the circuit's output voltage.

290 CHAPTER 8 / INTRODUCTION TO AMPLIFIERS

SUMMARY ILLUSTRATION

Amplifier classes



6

Circuit:	Class A	Class B	Class C
Conduction:	Transistor conducts during 360° of ac input.	Each transistor conducts for 180° of the ac input.	Transistor conducts for less than 180° of the ac input.
Maximum theoretical efficiency:	25%	78.5%	99%
Distortion:	Little or none. Subject to nonlinear distortion.	Little or none. Crossover distortion is most common.	Mild to severe.

FIGURE 8.25 Amplifier classes.

Section Review

1. How does an amplifier increase the power level of an ac input signal?
2. What is the *efficiency* rating of an amplifier?
3. What would the efficiency rating be for an ideal amplifier? Why can't this rating be achieved in practice?
4. What is *distortion*? Why is it undesirable?
5. What are the typical characteristics of a *class A* amplifier?
6. In terms of biasing, how is class A operation achieved? Explain your answer.
7. Why are class A amplifiers typically used as small-signal amplifiers?
8. What are the typical characteristics of a *class B* amplifier?
9. What is a *class AB* amplifier? Why is it used?
10. What are the typical characteristics of a *class C* amplifier?
11. How is the output of a class C amplifier produced?
12. What factor limits the use of the class C amplifier?

SECTION 8.3 / AMPLIFIER CLASSIFICATIONS 307

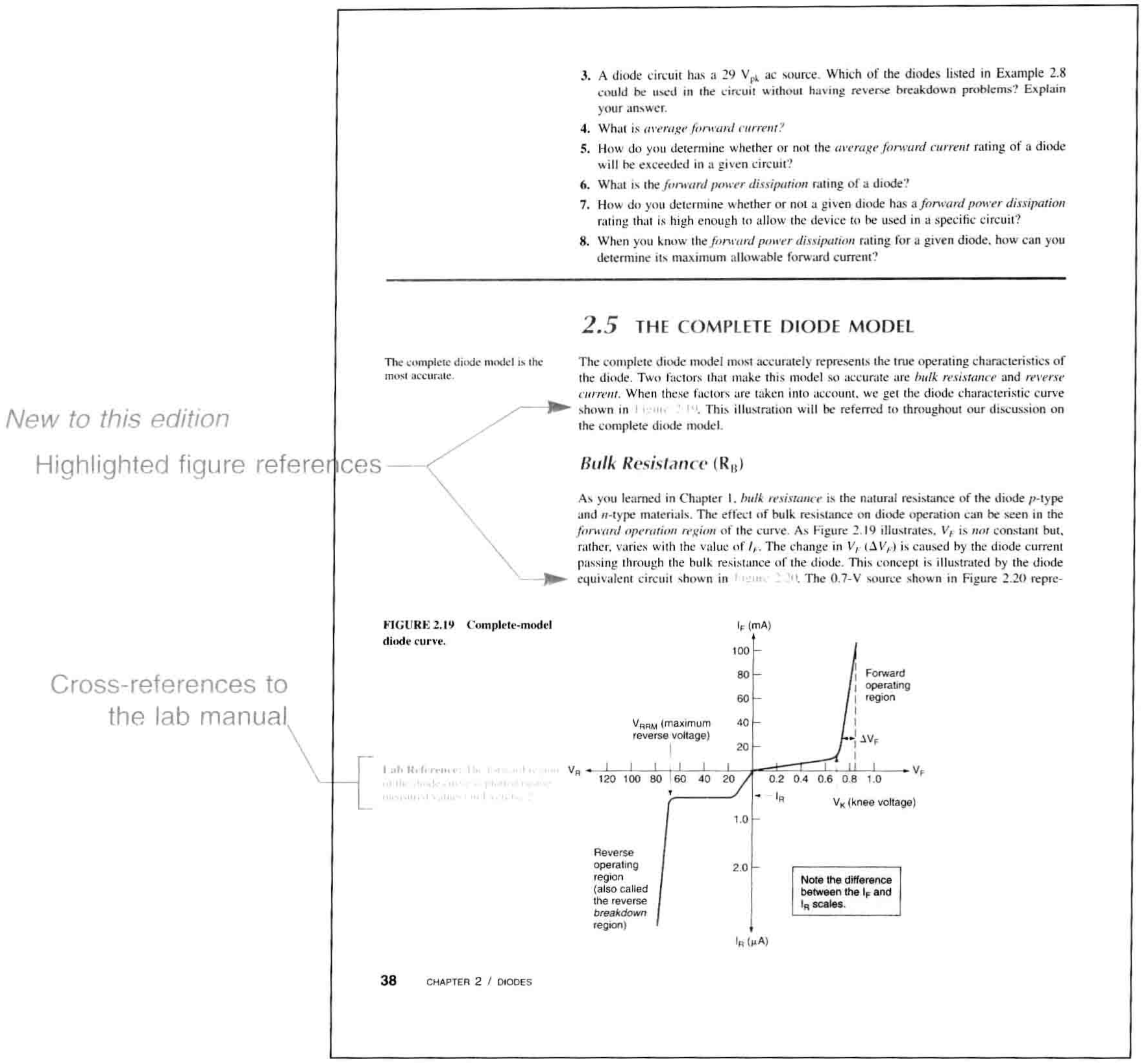
NEW TO THIS EDITION

The fourth edition of *Introductory Electronic Devices and Circuits* incorporates many changes I had planned to make in the third edition. Some of these changes include providing the students with some new learning aids, new coverage of several topics, and improved coverage of many others. Here are some of the cornerstones of the fourth edition:

Highlighted Figure References

From the start, one of my goals has been to provide students with the easiest possible access to any information they may need. For example, the objective identifiers were developed to help students quickly locate the information that is relevant to a given objective. In this edition, the easy access to information has been taken one step further.

I have found that many students spend quite a bit of time searching the text for information about a given figure. In this edition, it will be easier for students to locate this information. This has been accomplished by highlighting *the first reference in the text* to each figure. Your students can spend more time reading about a given figure because they will need less time to locate the discussion. The only exceptions are those figures that are contained in the examples and practice problems (since it is obvious where they are covered).



3. A diode circuit has a 29 V_{pk} ac source. Which of the diodes listed in Example 2.8 could be used in the circuit without having reverse breakdown problems? Explain your answer.
4. What is *average forward current?*
5. How do you determine whether or not the *average forward current* rating of a diode will be exceeded in a given circuit?
6. What is the *forward power dissipation* rating of a diode?
7. How do you determine whether or not a given diode has a *forward power dissipation* rating that is high enough to allow the device to be used in a specific circuit?
8. When you know the *forward power dissipation* rating for a given diode, how can you determine its maximum allowable forward current?

2.5 THE COMPLETE DIODE MODEL

The complete diode model is the most accurate.

The complete diode model most accurately represents the true operating characteristics of the diode. Two factors that make this model so accurate are *bulk resistance* and *reverse current*. When these factors are taken into account, we get the diode characteristic curve shown in Figure 2.19. This illustration will be referred to throughout our discussion on the complete diode model.

Bulk Resistance (R_B)

As you learned in Chapter 1, *bulk resistance* is the natural resistance of the diode *p*-type and *n*-type materials. The effect of bulk resistance on diode operation can be seen in the *forward operation region* of the curve. As Figure 2.19 illustrates, V_F is *not* constant but, rather, varies with the value of I_F. The change in V_F (ΔV_F) is caused by the diode current passing through the bulk resistance of the diode. This concept is illustrated by the diode equivalent circuit shown in Figure 2.20. The 0.7-V source shown in Figure 2.20 repre-

FIGURE 2.19 Complete-model diode curve.

38 CHAPTER 2 / DIODES

Highlighted Lab References

Lab manuals have always contained references to the text. Now, you have a text that contains references to the lab manual. When a given circuit or procedure is covered in the lab manual, a *margin note* identifies the related lab exercise. This will help you to plan your lab schedule so that it more closely follows your progress through the text.

Improved Use of Color

The functional use of color is enhanced in this edition to help your students distinguish between the parts that make up the various circuits and graphs. Color is also used to help your students distinguish the various learning aids and margin notes.

Changes in Content

The approach to many topics has been improved or completely modified. Here are some of the changes you will see:

Chapter 2. Several of the sections have been repositioned to provide a more logical flow of material.

Chapter 8. This chapter has been completely rewritten to provide a more complete and realistic *overview* of amplifier operation. Your students are introduced to

- the overall purpose served by amplifiers
- the characteristics of the ideal amplifier
- the differences between ideal and practical amplifiers
- amplifier configurations and classes
- decibels

As it is now written, it is easier for your students to apply the information provided to amplifiers other than those containing BJTs.

Chapter 9. Current gain is now approached as a *circuit characteristic* rather than one of the transistor only. Your students are shown how amplifier input circuits and loads affect current gain. The result is a more realistic approach to the entire subject of gain.

Chapter 15. *Negative feedback* is approached more as an op-amp topic (rather than a discrete circuit topic). To reflect the change in approach, the material has been moved to this chapter.

Chapter 16. The section on *Other Op-Amp Circuits* has returned to complete this chapter on op-amp circuits. The coverage of *instrumentation amplifiers* has also been expanded and improved.

Chapter 20. This chapter more closely resembles its original form. The discussions of thyristor spec sheets and ratings that were omitted from the third edition have returned.

Chapter 21. The section on *Switching Voltage Regulators* has been expanded and improved. It now contains in-depth coverage of

- the operating principles of switching regulators
- the advantages and disadvantages of using switching and linear voltage regulators
- the various switching regulator configurations
- practical IC switching regulators

I sincerely believe these changes will help you to provide your students with a more thorough understanding of electronic devices and circuits.

ACKNOWLEDGMENTS

I am genuinely grateful to Prentice Hall for giving me the opportunity to develop this fourth edition of *Introductory Electronic Devices and Circuits*. It is, I believe, the best work that the reviewers, editors, and I have produced to date.

A project of this size could not have been completed without help from a variety of capable and concerned individuals. First and foremost, I would like to acknowledge the efforts of **Toby Boydell**, Seva Electronics (formerly of Conestoga College, Ontario). Toby has played a major role in this edition. He has provided quality input at every phase of development. He also provided the *solutions manual* for this edition and the answers found in Appendix G of the text. I would also like to thank the following professionals for the quality input they provided in their reviews of the text: Frank Brattain, Ivy Tech

State College; Gary Cardinale, DeVry Institute of Technology–Woodbridge; Robert Diffenderfer, DeVry Institute of Technology–Kansas City; Dr. Victor Gerez, Montana State University; Bob Griffin, Tarrant County Junior College; Dr. J. Jan Jellema, Eastern Michigan University; Dean Johnson, Northwest Technical College–Moorehead; Daniel Landiss, St. Louis Community College at Forest Park; Don Lovelace, Ashville-Buncombe Technical Community College; Leon Nicely, ITT Technical Institute–Ft. Lauderdale; and Malcolm Skipper, Midlands Technical College.

I would like to thank the staff at Prentice Hall for their "behind-the-scenes" work on this edition. These people deserve special recognition:

Carol Robison, my developmental editor, for making writing enjoyable again. She implemented the highest standards of quality control, while still managing to laugh at the worst of my jokes.

Marianne L'Abbate, my copy editor, for the most thorough and accurate editing I've ever seen.

Louise Sette, my production editor, for putting up with my delays and keeping things on track (despite my best efforts to derail them).

and

Dave Garza, Editor-in-Chief, for keeping the faith.

Finally, a special thanks goes out to my family and friends (especially Dick Arnoldy, Rich Reeves, and Bob Eversole) for their constant support, and to Susan for helping to put it all together . . . again.

Bob Paynter

To the Student

"WHY AM I LEARNING THIS?"

Have you ever found yourself asking this question? If you have, then take a moment to read further.

I believe that any subject is easier to learn when you know *why* you are learning it. For this reason, we're going to take a moment to discuss several things:

1. What *electronic devices* are
2. Why the study of electronic devices is important
3. How this area of study relates to the other areas of electronics
4. How you can get the most out of your study of electronic devices

One of the components that you have already studied is the *resistor.* In your basic dc electronics course, you were taught just about everything there is to know about resistors. Why? Because resistors are used in virtually every type of electronic circuit and/or system. If you take a moment to flip through the book, you'll see that there are very few circuits that do not contain at least one resistor.

A thorough understanding of resistors is necessary if you are going to be successful in understanding the area of electronic devices. *Each area of electronics is learned because it contributes to understanding the next.* If you want to understand electronic devices, you must first understand basic dc electronics. And, if you want to understand the areas of electronics that are studied after devices, you must come to understand the material in this book. Just as the knowledge of resistors is fundamental to this course, so the knowledge of devices is fundamental to the courses that will follow. This is *why* you are studying devices at this point in your education.

What *are* electronic devices? They are components with *dynamic* resistance characteristics. That is, they are components whose resistance is determined by the voltage applied to them or by the current drawn through them. Thus, some are *current-controlled resistances* while others are *voltage-controlled resistances.*

Electronic devices are somewhat complex components that are used in virtually every type of electronic system. They are used extensively in *communications systems* (such as televisions, radios, and VCRs), *digital systems* (such as PCs and calculators), and *industrial systems* (such as robotic and process control systems).

As you can see, the study of electronic devices is critical if your knowledge is to advance beyond the point where it is now. The next question is:

"WHAT CAN I DO TO GET THE MOST OUT OF THIS COURSE?"

There are several steps that you can take to ensure that you will be successful in learning this area of electronics. The first is to realize that *learning electronics requires active participation on your part.* If you are going to learn electronics, you must take an active role in your education. It's like learning how to ride a bicycle. If you want to learn how to ride a bike, you have to hop on and take a few spills. You can't learn how to ride a bike just by "reading the book." The same can be said about learning electronics. You must become actively involved in the learning process.

How do you get involved in the learning process? Here are some habits worth developing:

1. *Attend class on a regular basis.*
2. *Take part in classroom problem solving sessions.* This means getting out your calculator and solving the problems along with the class.
3. *Do all the assigned homework.* Circuit analysis is a skill. As with any skill you gain competency only through practice.
4. *Take part in classroom discussions.* More often than not, classroom discussion can serve to clarify points that may be confusing otherwise.
5. *Become an active participant in the textbook discussions.*

Being an *active participant* in the textbook discussions means that you must do more than simply "read the book." When you are studying new material, there are several things that you need to do:

1. *Learn the terminology.* You are taught new terms because you need to know what they mean and how and when to use them. When you come across a new term in the text, take time to commit the new term to memory. How do you know when a new term is being introduced? Throughout this text, new terms are identified in the margins. When you see a new term and its definition in the margin, stop and learn the term before going on to the next section.
2. *Use your calculator to work through the examples.* When you come across an example, get your calculator out and try the example for yourself. When you do this, you develop the skill necessary to solve the problems on your own.
3. *Solve the example practice problems.* Most of the examples in this book are followed by a practice problem that is identical in nature to the example. When you see these problems, try them. Then you can check your solutions by looking up the answers at the end of the chapter.
4. *Use the chapter objectives to measure your learning.* Each chapter begins with an extensive list of performance-based objectives. *These objectives tell you what you should be able to do as a result of learning the material.*

This book contains *objective identifiers* that are located in the margins of the text. For example, if you look at page 83, you'll see "objective 2" printed in the margin. This identifier tells you that this is the point where you are taught the skill mentioned in objective 2 (see the objective list on page 75). These objective identifiers can be used to help you with your studies. If you don't know how to perform the action called for in a specific objective, just flip through the chapter until you see the appropriate identifier. At that point in the chapter, you will find the information you need.

ONE FINAL NOTE

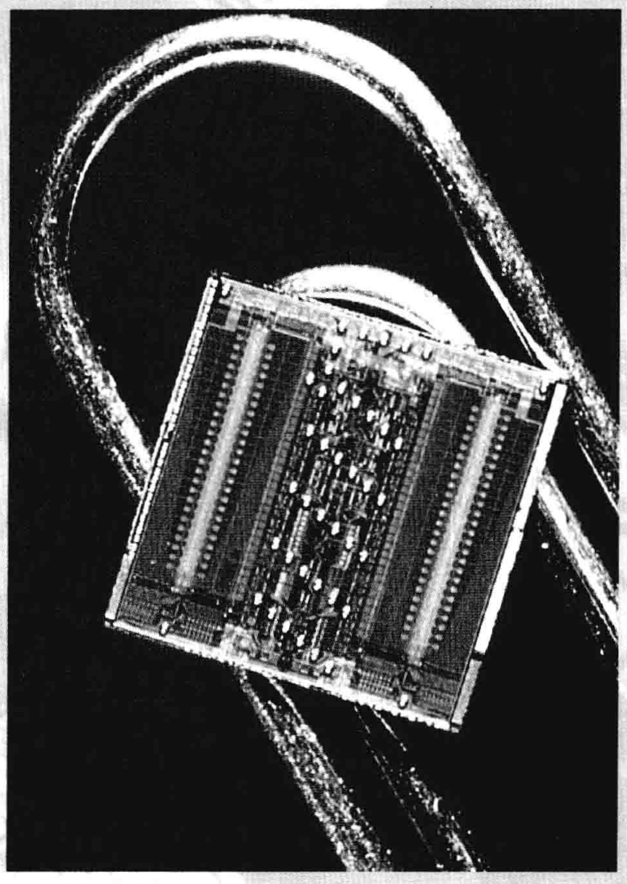
There is a lot of work involved in being an active learner. However, the extra effort will pay off in the end. Your understanding of electronic devices will be better as a result of your efforts, and it will also make learning the remaining areas of electronics much easier. I wish you the best of success.

Bob Paynter

Introductory Electronic Devices and Circuits

1

FUNDAMENTAL SOLID-STATE PRINCIPLES



The circuit shown, if constructed with vacuum tubes, would have been approximately 365 cubic meters in size.

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