COMPONENT PHOTOS

Photos of actual electronic devices bring students closer to the device being studied.

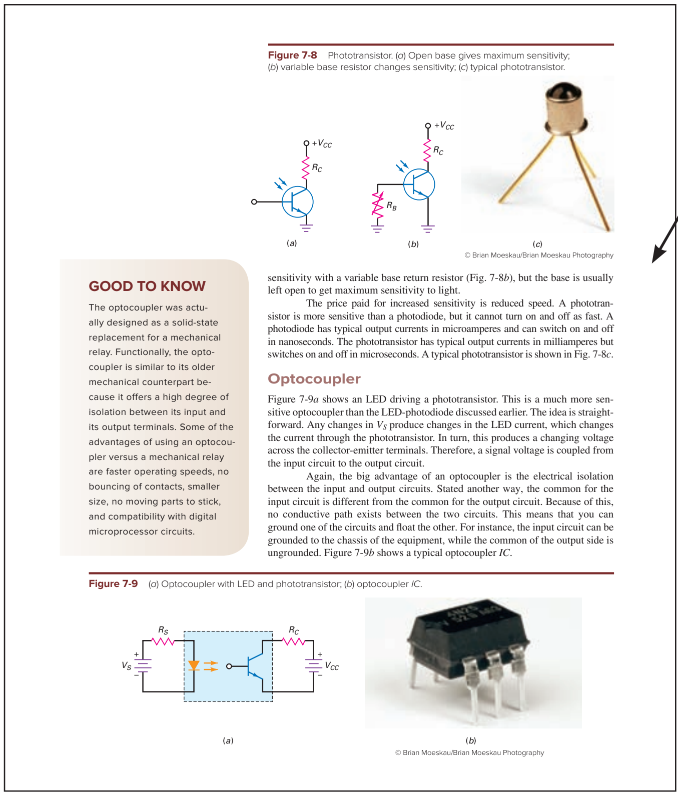

Figure 7-8 Phototransistor. (*a*) Open base gives maximum sensitivity; (*b*) variable base resistor changes sensitivity; (*c*) typical phototransistor.

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GOOD TO KNOW

The optocoupler was actually designed as a solid-state replacement for a mechanical relay. Functionally, the optocoupler is similar to its older mechanical counterpart because it offers a high degree of isolation between its input and its output terminals. Some of the advantages of using an optocoupler versus a mechanical relay are faster operating speeds, no bouncing of contacts, smaller size, no moving parts to stick, and compatibility with digital microprocessor circuits.

sensitivity with a variable base return resistor (Fig. 7-8*b*), but the base is usually left open to get maximum sensitivity to light.

The price paid for increased sensitivity is reduced speed. A phototransistor is more sensitive than a photodiode, but it cannot turn on and off as fast. A photodiode has typical output currents in microamperes and can switch on and off in nanoseconds. The phototransistor has typical output currents in milliamperes but switches on and off in microseconds. A typical phototransistor is shown in Fig. 7-8*c*.

Optocoupler

Figure 7-9*a* shows an LED driving a phototransistor. This is a much more sensitive optocoupler than the LED-photodiode discussed earlier. The idea is straightforward. Any changes in V_S produce changes in the LED current, which changes the current through the phototransistor. In turn, this produces a changing voltage across the collector-emitter terminals. Therefore, a signal voltage is coupled from the input circuit to the output circuit.

Again, the big advantage of an optocoupler is the electrical isolation between the input and output circuits. Stated another way, the common for the input circuit is different from the common for the output circuit. Because of this, no conductive path exists between the two circuits. This means that you can ground one of the circuits and float the other. For instance, the input circuit can be grounded to the chassis of the equipment, while the common of the output side is ungrounded. Figure 7-9*b* shows a typical optocoupler *IC*.

Figure 7-9 (*a*) Optocoupler with LED and phototransistor; (*b*) optocoupler *IC*.

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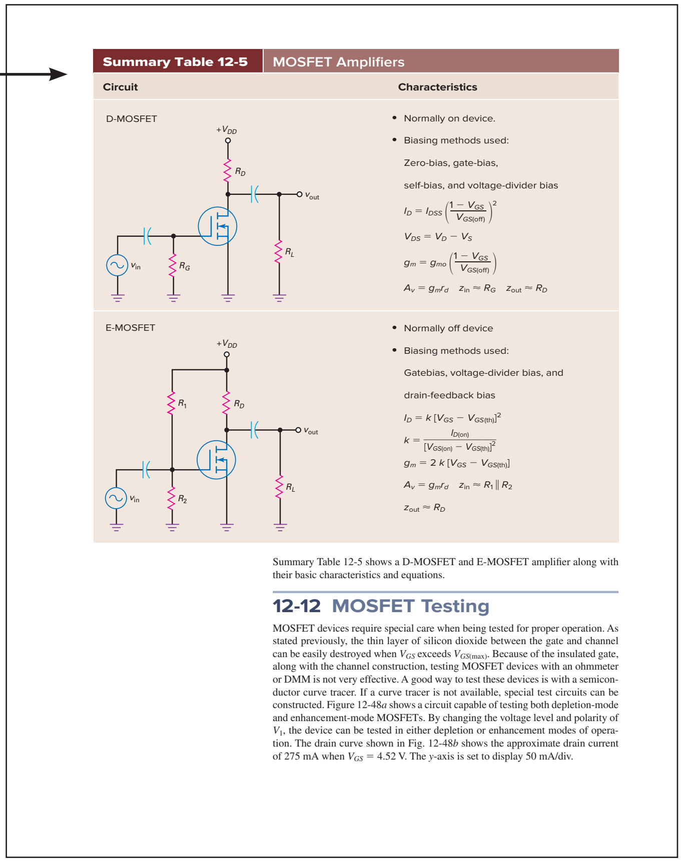
SUMMARY TABLES

Summary Tables have been included at important points within many chapters. Students use these tables as an excellent review of important topics and as a convenient information resource.



Summary Table 12-5 MOSFET Amplifiers

Circuit	Characteristics
D-MOSFET	• Normally on device. • Biasing methods used: Zero-bias, gate-bias, self-bias, and voltage-divider bias $I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_{GS(off)}}\right)^2$ $V_{DS} = V_D - V_S$ $g_m = g_{mo}\left(1 - \frac{V_{GS}}{V_{GS(off)}}\right)$ $A_v = g_m r_d \quad z_{in} \approx R_G \quad z_{out} \approx R_D$
E-MOSFET	• Normally off device • Biasing methods used: Gatebias, voltage-divider bias, and drain-feedback bias $I_D = k\,[V_{GS} - V_{GS(th)}]^2$ $k = \frac{I_{D(on)}}{[V_{GS(on)} - V_{GS(th)}]^2}$ $g_m = 2\,k\,[V_{GS} - V_{GS(th)}]$ $A_v = g_m r_d \quad z_{in} \approx R_1 \parallel R_2$ $z_{out} \approx R_D$

Summary Table 12-5 shows a D-MOSFET and E-MOSFET amplifier along with their basic characteristics and equations.

12-12 MOSFET Testing

MOSFET devices require special care when being tested for proper operation. As stated previously, the thin layer of silicon dioxide between the gate and channel can be easily destroyed when V_{GS} exceeds $V_{GS(max)}$. Because of the insulated gate, along with the channel construction, testing MOSFET devices with an ohmmeter or DMM is not very effective. A good way to test these devices is with a semiconductor curve tracer. If a curve tracer is not available, special test circuits can be constructed. Figure 12-48*a* shows a circuit capable of testing both depletion-mode and enhancement-mode MOSFETs. By changing the voltage level and polarity of V_1, the device can be tested in either depletion or enhancement modes of operation. The drain curve shown in Fig. 12-48*b* shows the approximate drain current of 275 mA when V_{GS} = 4.52 V. The *y*-axis is set to display 50 mA/div.

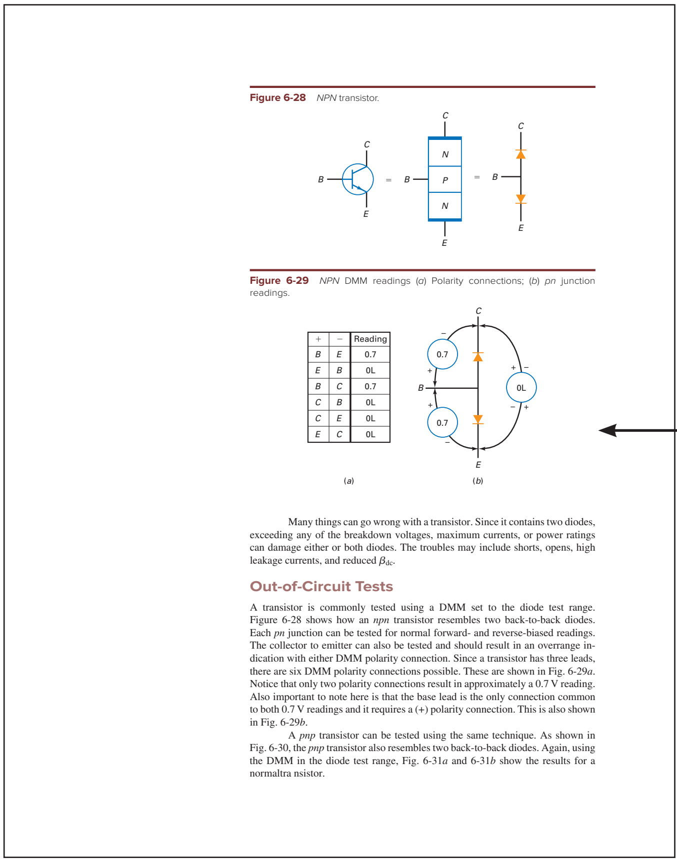


Figure 6-28 *NPN* transistor.

Figure 6-29 *NPN* DMM readings (*a*) Polarity connections; (*b*) *pn* junction readings.

+	−	Reading
B	E	0.7
E	B	0L
B	C	0.7
C	B	0L
C	E	0L
E	C	0L

Many things can go wrong with a transistor. Since it contains two diodes, exceeding any of the breakdown voltages, maximum currents, or power ratings can damage either or both diodes. The troubles may include shorts, opens, high leakage currents, and reduced β_{dc}.

Out-of-Circuit Tests

A transistor is commonly tested using a DMM set to the diode test range. Figure 6-28 shows how an *npn* transistor resembles two back-to-back diodes. Each *pn* junction can be tested for normal forward- and reverse-biased readings. The collector to emitter can also be tested and should result in an overrange indication with either DMM polarity connection. Since a transistor has three leads, there are six DMM polarity connections possible. These are shown in Fig. 6-29*a*. Notice that only two polarity connections result in approximately a 0.7 V reading. Also important to note here is that the base lead is the only connection common to both 0.7 V readings and it requires a (+) polarity connection. This is also shown in Fig. 6-29*b*.

A *pnp* transistor can be tested using the same technique. As shown in Fig. 6-30, the *pnp* transistor also resembles two back-to-back diodes. Again, using the DMM in the diode test range, Fig. 6-31*a* and 6-31*b* show the results for a normaltra nsistor.

COMPONENT TESTING

Students will find clear descriptions of how to test individual electronic components using common equipment such as digital multimeters (DMMs).

CHAPTER SUMMARIES

Students can use the summaries when reviewing for examinations, or just to make sure they haven't missed any key concepts. Important circuit derivations and definitions are listed to help solidify learning outcomes.

Summary

SEC. 1-1 THE THREE KINDS OF FORMULAS

A *definition* is a formula invented for a new concept. A *law* is a formula for a relation in nature. A *derivation* is a formula produced with mathematics.

SEC. 1-2 APPROXIMATIONS

Approximations are widely used in the electronics industry. The ideal approximation is useful for troubleshooting. The second approximation is useful for preliminary circuit calculations. Higher approximations are used with computers.

SEC. 1-3 VOLTAGE SOURCES

An ideal voltage source has no internal resistance. The second approximation of a voltage source has an internal resistance in series with the source. A stiff voltage source is defined as one whose internal resistance is less than 1⁄100 of the load resistance.

SEC. 1-4 CURRENT SOURCES

An ideal current source has an infinite internal resistance. The second approximation of a current source has a large internal resistance in parallel with the source. A *stiff current source* is defined as one whose internal resistance is more than 100 times the load resistance.

SEC. 1-5 THEVENIN'S THEOREM

The *Thevenin voltage* is defined as the voltage across an open load. The *Thevenin resistance* is defined as the resistance an ohmmeter would measure with an open load and all sources reduced to zero. Thevenin proved that a Thevenin equivalent circuit will produce the same load current as any other circuit with sources and linear resistances.

SEC. 1-6 NORTON'S THEOREM

The Norton resistance equals the Thevenin resistance. The Norton current equals the load current when the load is shorted. Norton proved that a Norton equivalent circuit produces the same load voltage as any other circuit with sources and linear resistances. Norton current equals Thevenin voltage divided by Thevenin resistance.

SEC. 1-7 TROUBLESHOOTING

The most common troubles are shorts, opens, and intermittent troubles. A short always has zero voltage across it; the current through a short must be calculated by examining the rest of the circuit. An open always has zero current through it; the voltage across an open must be calculated by examining the rest of the circuit. An intermittent trouble is an on-again, off-again trouble that requires patient and logical troubleshooting to isolate it.

TROUBLESHOOTING TABLES

Troubleshooting Tables allow students to easily see what the circuit point measurement value will be for each respective fault. Used in conjunction with Multisim, students can build their troubleshooting skills.

Troubleshooting

Use Fig. 7-42 for the remaining problems.

7-49 Find Trouble 1.

7-50 Find Trouble 2.

7-51 Find Troubles 3 and 4.

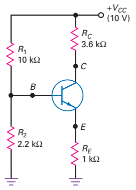
7-52 Find Troubles 5 and 6.

7-53 Find Troubles 7 and 8.

7-54 Find Troubles 9 and 10.

7-55 Find Troubles 11 and 12.

Figure 7-42



MEASUREMENTS

Trouble	V_B (V)	V_E (V)	V_C (V)	R_2 (Ω)
OK	1.8	1.1	6	OK
*T*1	10	9.3	9.4	OK
*T*2	0.7	0	0.1	OK
*T*3	1.8	1.1	10	OK
*T*4	2.1	2.1	2.1	OK
*T*5	0	0	10	OK
*T*6	3.4	2.7	2.8	∞
*T*7	1.83	1.212	10	OK
*T*8	0	0	10	0
*T*9	1.1	0.4	0.5	OK
*T*10	1.1	0.4	10	OK
*T*11	0	0	0	OK
*T*12	1.83	0	10	OK

END OF CHAPTER PROBLEMS

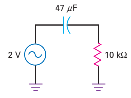
A wide variety of questions and problems are found at the end of each chapter. These include circuit analysis, troubleshooting, critical thinking, and job interview questions.

Problems

SEC. 8-1 BASE-BIASED AMPLIFIER

8-1 Multisim In Fig. 8-31, what is the lowest frequency at which good coupling exists?

Figure 8-31



8-2 Multisim If the load resistance is changed to 1 kΩ in Fig. 8-31, what is the lowest frequency for good coupling?

8-8 If the lowest input frequency of Fig. 8-32 is 1 kHz, what *C* value is required for effective bypassing?

SEC. 8-3 SMALL-SIGNAL OPERATION

8-9 If we want small-signal operation in Fig. 8-33, what is the maximum allowable ac emitter current?

8-10 The emitter resistor in Fig. 8-33 is doubled. If we want small-signal operation in Fig. 8-33, what is the maximum allowable ac emitter current?

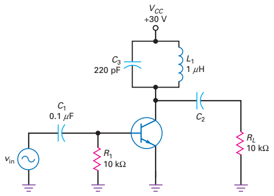
SEC. 8-4 AC BETA

8-11 If an ac base current of 100 μA produces an ac collector current of 15 mA, what is the ac beta?

8-12 If the ac beta is 200 and the ac base current is 12.5 μA, what is the ac collector current?

8-13 If the ac collector current is 4 mA and the ac beta is 100, what is the ac base current?

Figure 10-44



10-43 If the *Q* of the inductor is 125 in Fig. 10-44, what is the bandwidth of the amplifier?

10-44 What is the worst-case transistor power dissipation in Fig. 10-44 ($Q = 125$)?

SEC. 10-10 TRANSISTOR POWER RATING

10-45 A 2N3904 is used in Fig. 10-44. If the circuit has to operate over an ambient temperature range of 0 to 100°C, what is the maximum power rating of the transistor in the worst case?

10-46 A transistor has the derating curve shown in Fig. 10-34. What is the maximum power rating for an ambient temperature of 100°C?

10-47 The data sheet of a 2N3055 lists a power rating of 115 W for a case temperature of 25°C. If the derating factor is 0.657 W/°C, what is $P_{D(max)}$ when the case temperature is 90°C?

Critical Thinking

10-48 The output of an amplifier is a square-wave output even though the input is a sine wave. What is the explanation?

10-49 A power transistor like the one in Fig. 10-36 is used in an amplifier. Somebody tells you that since the case is grounded, you can safely touch the case. What do you think about this?

10-50 You are in a bookstore and you read the following in an electronics book: "Some power amplifiers can have an efficiency of 125 percent." Would you buy the book? Explain your answer.

10-51 Normally, the ac load line is more vertical than the dc load line. A couple of classmates say that they are willing to bet that they can draw a circuit whose ac load line is less vertical than the dc load line. Would you take the bet? Explain.

10-52 Draw the dc and ac load lines for Fig. 10-38.

Multisim Troubleshooting Problems

The Multisim troubleshooting files are found on the Instructor Resources section of *Connect for Electronic Principles*, in a folder named Multisim Troubleshooting Circuits (MTC). See page XVI for more details. For this chapter, the files are labeled MTC10-53 through MTC10-57 and are based on the circuit of Figure 10-43.

Open up and troubleshoot each of the respective files. Take measurements to determine if there is a fault and, if so, determine the circuit fault.

10-53 Open up and troubleshoot file MTC10-53.

10-54 Open up and troubleshoot file MTC10-54.

10-55 Open up and troubleshoot file MTC10-55.

10-56 Open up and troubleshoot file MTC10-56.

10-57 Open up and troubleshoot file MTC10-57.

Digital/Analog Trainer System

The following questions, 10-58 through 10-62, are directed toward the schematic diagram of the Digital/Analog Trainer System found on the Instructor Resources section of *Connect for Electronic Principles*. A full Instruction Manual for the Model XK-700 trainer can be found at www.elenco.com.

10-58 What type of circuit does the transistors Q_1 and Q_2 form?

10-59 What is the MPP output that could be measured at the junction of R_{46} and R_{47}?

10-60 What is the purpose of diodes D_{16} and D_{17}?

10-61 Using 0.7 V for the diode drops of D_{16} and D_{17}, what is the approximate quiescent collector current for Q_1 and Q_2?

10-62 Without any ac input signal to the power amp, what is the normal dc voltage level at the junction of R_{46} and R_{47}?

Job Interview Questions

1. Tell me about the three classes of amplifier operation. Illustrate the classes by drawing collector current waveforms.
2. Draw brief schematics showing the three types of coupling used between amplifier stages.
3. Draw a VDB amplifier. Then, draw its dc load line and ac load line. Assuming that the *Q* point is centered on the ac load lines, what is the ac saturation current? The ac cutoff voltage? The maximum peak-to-peak output?
4. Draw the circuit of a two-stage amplifier and tell me how to calculate the total current drain on the supply.
5. Draw a Class-C tuned amplifier. Tell me how to calculate the resonant frequency, and tell me what happens to the ac signal at the base. Explain how it is possible that the brief pulses of collector current produce a sine wave of voltage across the resonant tank circuit.
6. What is the most common application of a Class-C amplifier? Could this type of amplifier be used for an audio application? If not, why not?
7. Explain the purpose of heat sinks. Also, why do we put an insulating washer between the transistor and the heat sink?
8. What is meant by the duty cycle? How is it related to the power supplied by the source?
9. Define *Q*.
10. Which class of amplifier operation is most efficient? Why?
11. You have ordered a replacement transistor and heat sink. In the box with the heat sink is a package containing a white substance. What is it?
12. Comparing a Class-A amplifier to a Class-C amplifier, which has the greater fidelity? Why?
13. What type of amplifier is used when only a small range of frequencies is to be amplified?
14. What other types of amplifiers are you familiar with?

Self-Test Answers

1.	b	**13.**	b	**25.**	b
2.	b	**14.**	b	**26.**	c
3.	c	**15.**	b	**27.**	c
4.	a	**16.**	b	**28.**	a
5.	c	**17.**	c	**29.**	d
6.	d	**18.**	a	**30.**	d
7.	d	**19.**	a	**31.**	b
8.	b	**20.**	c	**32.**	c
9.	b	**21.**	b	**33.**	d
10.	d	**22.**	d	**34.**	c
11.	c	**23.**	a	**35.**	a
12.	d	**24.**	a		

Practice Problem Answers

10-1 $I_{CQ} = 100$ mA; $V_{CEQ} = 15$ V

10-2 $i_{c(sat)} = 350$ mA; $V_{CE(cutoff)} = 21$ V; MPP = 12 V

10-3 $Ap = 1122$

10-5 $R = 200\ \Omega$

10-6 $I_{CQ} = 331$ mA; $V_{CEQ} = 6.7$ V; $r_e = 8\ \Omega$

10-7 MPP = 5.3 V

10-8 $P_{D(max)} = 2.8$ W; $P_{out(max)} = 14$ W

10-9 Efficiency = 63%

10-10 Efficiency = 78%

10-11 $f_r = 4.76$ MHz; $v_{out} = 24\ V_{p\text{-}p}$

10-13 $P_D = 16.6$ mW

10-14 $P_{D(max)} = 425$ mW

Student Resources

In addition to the fully updated text, a number of student learning resources have been developed to aid readers in their understanding of electronic principles and applications.

- The online resources for this edition include **McGraw-Hill Connect®**, a web-based assignment and assessment platform that can help students to perform better in their coursework and to master important concepts. With Connect®, instructors can deliver assignments, quizzes, and tests easily online. Students can practice important skills at their own pace and on their own schedule. Ask your McGraw-Hill representative for more detail and check it out at www.mcgrawhillconnect.com.
- **McGraw-Hill LearnSmart®** is an adaptive learning system designed to help students learn faster, study more efficiently, and retain more knowledge for greater success. Through a series of adaptive questions, Learnsmart® pinpoints concepts the student does not understand and maps out a personalized study plan for success. It also lets instructors see exactly what students have accomplished, and it features a built-in assessment tool for graded assignments. Ask your McGraw-Hill representative for more information, and visit www.mhlearnsmart.com for a demonstration.
- Fueled by LearnSmart—the most widely used and intelligent adaptive learning resource—**SmartBook®** is the first and only adaptive reading experience available today.

  Distinguishing what a student knows from what they don't, and honing in on concepts they are most likely to forget, SmartBook personalizes content for each student in a continuously adapting reading experience. Reading is no longer a passive and linear experience, but an engaging and dynamic one where students are more likely to master and retain important concepts, coming to class better prepared. Valuable reports provide instructors insight as to how students are progressing through textbook content, and are useful for shaping in-class time or assessment.

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  This revolutionary technology is available only from McGraw-Hill Education and for hundreds of course areas as part of the LearnSmart Advantage series.
- **The Experiments Manual** for Electronic Principles correlated to the textbook, provides a full array of hands-on labs; Multisim "pre-lab" routines are included for those wanting to integrate computer simulation. Instructors can provide access to these files, which are housed in Connect.

Instructor Resources

- **Instructor's Manual** provides solutions and teaching suggestions for the text and Experiments Manual.
- **PowerPoint** slides for all chapters in the text, and **Electronic Test-banks** with additional review questions for each chapter can be found on the Instructor Resources section on Connect.
- **Experiments Manual,** for Electronic Principles, correlated to the textbook, with lab follow-up information included on the Instructor Resources section on Connect.

Directions for accessing the Instructor Resources through Connect

To access the Instructor Resources through Connect, you must first contact your McGraw-Hill Learning Technology Representative to obtain a password. If you do not know your McGraw-Hill representative, please go to www.mhhe.com/rep, to find your representative.

Once you have your password, please go to connect.mheducation.com, and login. Click on the course for which you are using *Electronic Principles*. If you have not added a course, click "Add Course," and select "Engineering Technology" from the drop-down menu. Select *Electronic Principles*, 8e and click "Next."

Once you have added the course, Click on the "Library" link, and then click "Instructor Resources."

Acknowledgments

The production of *Electronic Principles*, eighth edition, involves the combined effort of a team of professionals.

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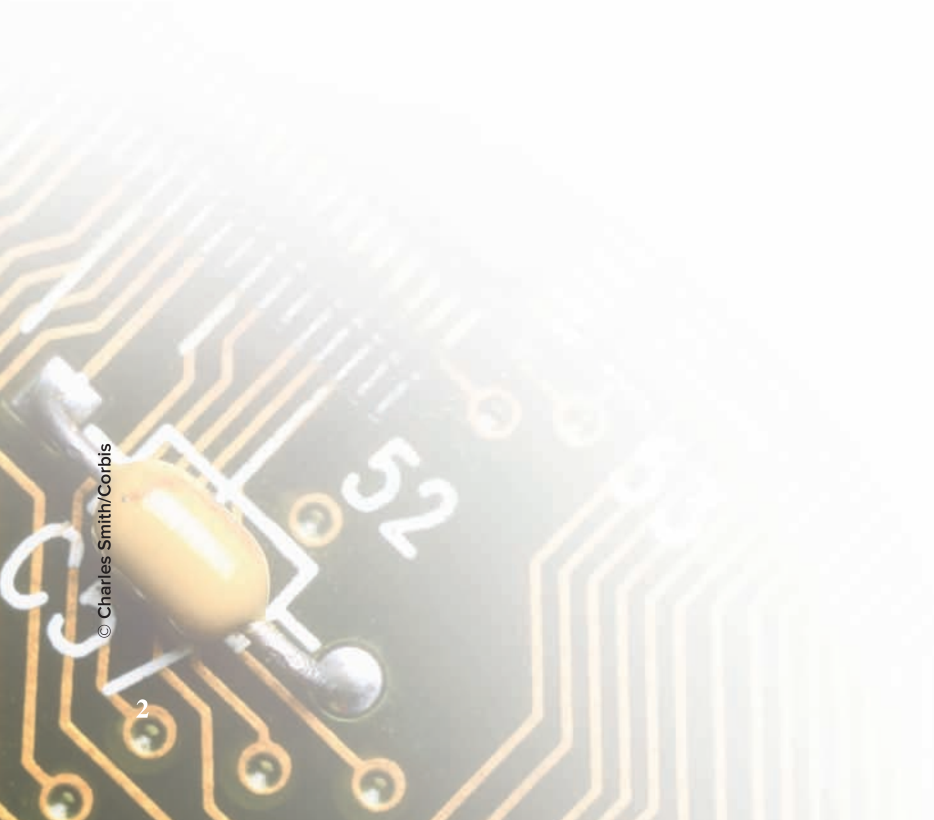
Electronic Principles

chapter 1

Introduction

This important chapter serves as a framework for the rest of the textbook. The topics in this chapter include formulas, voltage sources, current sources, two circuit theorems, and troubleshooting. Although some of the discussion will be review, you will find new ideas, such as circuit approximations, that can make it easier for you to understand semiconductor devices.



Chapter Outline

Objectives

After studying this chapter, you should be able to:

- Name the three types of formulas and explain why each is true.
- Explain why approximations are often used instead of exact formulas.
- Define an ideal voltage source and an ideal current source.
- Describe how to recognize a stiff voltage source and a stiff current source.
- State Thevenin's theorem and apply it to a circuit.
- State Norton's theorem and apply it to a circuit.
- List two facts about an open device and two facts about a shorted device.

Vocabulary

cold-solder joint
definition
derivation
duality principle
formula
ideal (first) approximation
law
Norton current
Norton resistance
open device
second approximation
shorted device
solder bridge
stiff current source
stiff voltage source
theorem
Thevenin resistance
Thevenin voltage
third approximation
troubleshooting

1-1 The Three Kinds of Formulas

A **formula** is a rule that relates quantities. The rule may be an equation, an inequality, or other mathematical description. You will see many formulas in this book. Unless you know why each one is true, you may become confused as they accumulate. Fortunately, there are only three ways formulas can come into existence. Knowing what they are will make your study of electronics more logical and satisfying.

GOOD TO KNOW

For all practical purposes, a formula is like a set of instructions written in mathematical shorthand. A formula describes how to go about calculating a particular quantity or parameter.

The Definition

When you study electricity and electronics, you have to memorize new words like *current, voltage,* and *resistance.* However, a verbal explanation of these words is not enough. Why? Because your idea of current must be mathematically identical to everyone else's. The only way to get this identity is with a **definition,** a formula invented for a new concept.

Here is an example of a definition. In your earlier course work, you learned that capacitance equals the charge on one plate divided by the voltage between plates. The formula looks like this:

$$C = \frac{Q}{V}$$

This formula is a definition. It tells you what capacitance C is and how to calculate it. Historically, some researcher made up this definition and it became widely accepted.

Here is an example of how to create a new definition out of thin air. Suppose we are doing research on reading skills and need some way to measure reading speed. Out of the blue, we might decide to define *reading speed* as the number of words read in a minute. If the number of words is W and the number of minutes is M, we could make up a formula like this:

$$S = \frac{W}{M}$$

In this equation, S is the speed measured in words per minute.

To be fancy, we could use Greek letters: ω for words, μ for minutes, and σ for speed. Our definition would then look like this:

$$\sigma = \frac{\omega}{\mu}$$

This equation still translates to speed equals words divided by minutes. When you see an equation like this and know that it is a definition, it is no longer as impressive and mysterious as it initially appears to be.

In summary, *definitions are formulas that a researcher creates.* They are based on scientific observation and form the basis for the study of electronics. They are simply accepted as facts. It's done all the time in science. A definition is true in the same sense that a word is true. Each represents something we want to talk about. When you know which formulas are definitions, electronics is easier to understand. Because definitions are starting points, all you need to do is understand and memorize them.

The Law

A **law** is different. It summarizes a relationship that already exists in nature. Here is an example of a law:

$$f = K\frac{Q_1Q_2}{d^2}$$

where f = force
K = a constant of proportionality, $9(10^9)$
Q_1 = first charge
Q_2 = second charge
d = distance between charges

This is Coulomb's law. It says that the force of attraction or repulsion between two charges is directly proportional to the charges and inversely proportional to the square of the distance between them.

This is an important equation, for it is the foundation of electricity. But where does it come from? And why is it true? To begin with, all the variables in this law existed before its discovery. Through experiments, Coulomb was able to prove that the force was directly proportional to each charge and inversely proportional to the square of the distance between the charges. Coulomb's law is an example of a relationship that exists in nature. Although earlier researchers could measure f, Q_1, Q_2, and d, Coulomb discovered the law relating the quantities and wrote a formula for it.

Before discovering a law, someone may have a hunch that such a relationship exists. After a number of experiments, the researcher writes a formula that summarizes the discovery. When enough people confirm the discovery through experiments, the formula becomes a law. *A law is true because you can verify it with an experiment.*

The Derivation

Given an equation like this:

$$y = 3x$$

we can add 5 to both sides to get:

$$y + 5 = 3x + 5$$

The new equation is true because both sides are still equal. There are many other operations like subtraction, multiplication, division, factoring, and substitution that preserve the equality of both sides of the equation. For this reason, we can derive many new formulas using mathematics.

A **derivation** *is a formula that we can get from other formulas.* This means that we start with one or more formulas and, using mathematics, arrive at a new formula not in our original set of formulas. A derivation is true because mathematics preserves the equality of both sides of every equation between the starting formula and the derived formula.

For instance, Ohm was experimenting with conductors. He discovered that the ratio of voltage to current was a constant. He named this constant *resistance* and wrote the following formula for it:

$$R = \frac{V}{I}$$

This is the original form of Ohm's law. By rearranging it, we can get:

$$I = \frac{V}{R}$$

This is a derivation. It is the original form of Ohm's law converted to another equation.

Here is another example. The definition for capacitance is:

$$C = \frac{Q}{V}$$

We can multiply both sides by V to get the following new equation:

$$Q = CV$$

This is a derivation. It says that the charge on a capacitor equals its capacitance times the voltage across it.

What to Remember

Why is a formula true? There are three possible answers. To build your understanding of electronics on solid ground, classify each new formula in one of these three categories:

Definition: A formula invented for a new concept
Law: A formula for a relationship in nature
Derivation: A formula produced with mathematics

1-2 Approximations

We use approximations all the time in everyday life. If someone asks you how old you are, you might answer 21 (ideal). Or you might say 21 going on 22 (second approximation). Or, maybe, 21 years and 9 months (third approximation). Or, if you want to be more accurate, 21 years, 9 months, 2 days, 6 hours, 23 minutes, and 42 seconds (exact).

The foregoing illustrates different levels of approximation: an ideal approximation, a second approximation, a third approximation, and an exact answer. The approximation to use will depend on the situation. The same is true in electronics work. In circuit analysis, we need to choose an approximation that fits the situation.

The Ideal Approximation

Did you know that 1 foot of AWG 22 wire that is 1 inch from a chassis has a resistance of 0.016 Ω, an inductance of 0.24 μH, and a capacitance of 3.3 pF? If we had to include the effects of resistance, inductance, and capacitance in every calculation for current, we would spend too much time on calculations. This is why everybody ignores the resistance, inductance, and capacitance of connecting wires in most situations.

The **ideal approximation,** sometimes called the **first approximation,** is the simplest equivalent circuit for a device. For instance, the ideal approximation of a piece of wire is a conductor of zero resistance. This ideal approximation is adequate for everyday electronics work.

The exception occurs at higher frequencies, where you have to consider the inductance and capacitance of the wire. Suppose 1 inch of wire has an inductance of 0.24 μH and a capacitance of 3.3 pF. At 10 MHz, the inductive reactance is 15.1 Ω, and the capacitive reactance is 4.82 kΩ. As you see, a circuit designer can no longer idealize a piece of wire. Depending on the rest of the circuit, the inductance and capacitive reactances of a connecting wire may be important.

As a guideline, we can idealize a piece of wire at frequencies under 1 MHz. This is usually a safe rule of thumb. But it does not mean that you can be careless about wiring. In general, keep connecting wires as short as possible, because at some point on the frequency scale, those wires will begin to degrade circuit performance.

When you are troubleshooting, the ideal approximation is usually adequate because you are looking for large deviations from normal voltages and currents. In this book, we will idealize semiconductor devices by reducing them to simple equivalent circuits. With ideal approximations, it is easier to analyze and understand how semiconductor circuits work.

The Second Approximation

The ideal approximation of a flashlight battery is a voltage source of 1.5 V. The **second approximation** adds one or more components to the ideal approximation. For instance, the second approximation of a flashlight battery is a voltage source of 1.5 V and a series resistance of 1 Ω. This series resistance is called the *source* or *internal* resistance of the battery. If the load resistance is less than 10 Ω, the load voltage will be noticeably less than 1.5 V because of the voltage drop across the source resistance. In this case, accurate calculations must include the source resistance.

The Third Approximation and Beyond

The **third approximation** includes another component in the equivalent circuit of the device. An example of the third approximation will be examined when we discuss semiconductor diodes.

Even higher approximations are possible with many components in the equivalent circuit of a device. Hand calculations using these higher approximations can become difficult and time consuming. Because of this, computers using circuit simulation software are often used. For instance, Multisim by National Instruments (NI) and PSpice are commercially available computer programs that use higher approximations to analyze and simulate semiconductor circuits. Many of the circuits and examples in this book can be analyzed and demonstrated using this type of software.

Conclusion

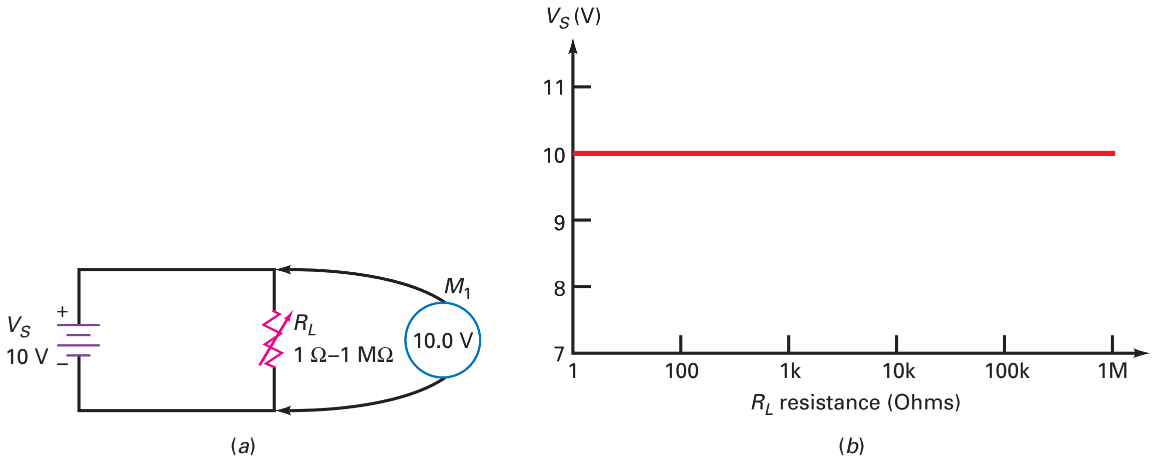
Which approximation to use depends on what you are trying to do. If you are troubleshooting, the ideal approximation is usually adequate. For many situations, the second approximation is the best choice because it is easy to use and does not require a computer. For higher approximations, you should use a computer and a program like Multisim. A Multisim tutorial can be found on the Instructor Resources section of *Connect for Electronic Principles*.

1-3 Voltage Sources

An *ideal dc voltage source* produces a load voltage that is constant. The simplest example of an ideal dc voltage source is a perfect battery, one whose internal resistance is zero. Figure 1-1*a* shows an ideal voltage source connected to a variable load resistance of 1 Ω to 10 MΩ. The voltmeter reads 10 V, exactly the same as the source voltage.

Figure 1-1*b* shows a graph of load voltage versus load resistance. As you can see, the load voltage remains fixed at 10 V when the load resistance changes from 1 Ω to 1 MΩ. In other words, an ideal dc voltage source produces a constant load voltage, regardless of how small or large the load resistance is. With an ideal voltage source, only the load current changes when the load resistance changes.

Figure 1-1 (*a*) Ideal voltage source and variable load resistance; (*b*) load voltage is constant for all load resistances.



Second Approximation

An ideal voltage source is a theoretical device; it cannot exist in nature. Why? When the load resistance approaches zero, the load current approaches infinity. No real voltage source can produce infinite current because a real voltage source always has some internal resistance. The second approximation of a dc voltage source includes this internal resistance.

Figure 1-2*a* illustrates the idea. A source resistance R_S of 1 Ω is now in series with the ideal battery. The voltmeter reads 5 V when R_L is 1 Ω. Why? Because the load current is 10 V divided by 2 Ω, or 5 A. When 5 A flows through the source resistance of 1 Ω, it produces an internal voltage drop of 5 V. This is why the load voltage is only half of the ideal value, with the other half being dropped across the internal resistance.

Figure 1-2*b* shows the graph of load voltage versus load resistance. In this case, the load voltage does not come close to the ideal value until the load resistance is much greater than the source resistance. But what does *much greater* mean? In other words, when can we ignore the source resistance?

Figure 1-2 (*a*) Second approximation includes source resistance; (*b*) load voltage is constant for large load resistances.

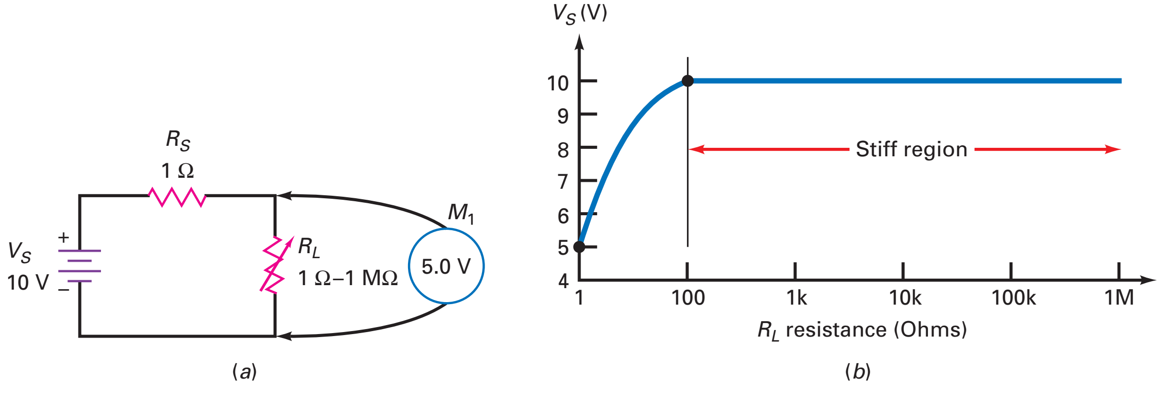
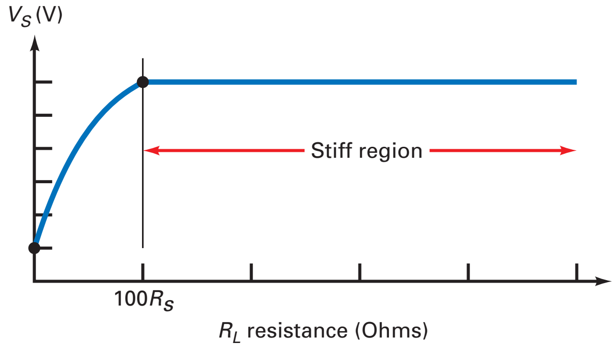


Figure 1-3 Stiff region occurs when load resistance is large enough.



Stiff Voltage Source

Now is the time when a new definition can be useful. So, let us invent one. We can ignore the source resistance when it is at least 100 times smaller than the load resistance. Any source that satisfies this condition is a **stiff voltage source.** As a definition,

$$\textbf{Stiff voltage source: } R_S < 0.01R_L \qquad \textbf{(1-1)}$$

This formula defines what we mean by a *stiff voltage source*. The boundary of the inequality (where $<$ is changed to $=$) gives us the following equation:

$$R_S = 0.01R_L$$

Solving for load resistance gives the minimum load resistance we can use and still have a stiff source:

$$R_{L(\min)} = 100R_S \qquad \textbf{(1-2)}$$

In words, the minimum load resistance equals 100 times the source resistance.

Equation (1-2) is a derivation. We started with the definition of a stiff voltage source and rearranged it to get the minimum load resistance permitted with a stiff voltage source. As long as the load resistance is greater than $100R_S$, the voltage source is stiff. When the load resistance equals this worst-case value, the calculation error from ignoring the source resistance is 1 percent, small enough to ignore in a second approximation.

Figure 1-3 visually summarizes a stiff voltage source. The load resistance has to be greater than $100R_S$ for the voltage source to be stiff.

GOOD TO KNOW

A well-regulated power supply is a good example of a stiff voltage source.

Example 1-1

The definition of a stiff voltage source applies to ac sources as well as to dc sources. Suppose an ac voltage source has a source resistance of 50 Ω. For what load resistance is the source stiff?

SOLUTION Multiply by 100 to get the minimum load resistance:

$$R_L = 100R_S = 100(50\ \Omega) = 5\ \text{k}\Omega$$