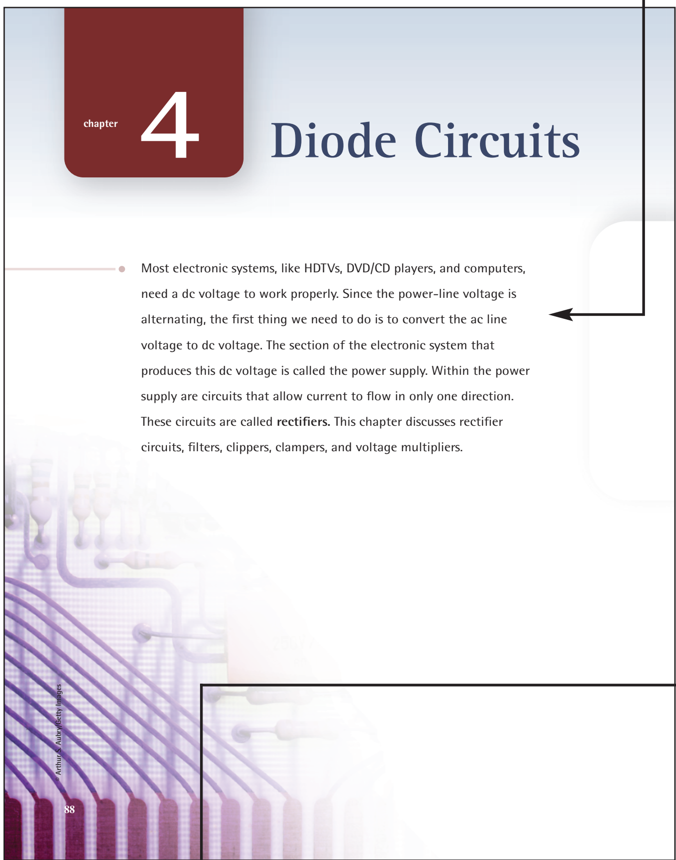
Guided Tour

Learning Features

Many new learning features have been incorporated into the seventh edition of *Electronic Principles*. These learning features, found throughout the chapters, include:

CHAPTER INTRODUCTION

Each chapter begins with a brief introduction setting the stage for what the student is about to learn.



chapter 4 Diode Circuits

Most electronic systems, like HDTVs, DVD/CD players, and computers, need a dc voltage to work properly. Since the power-line voltage is alternating, the first thing we need to do is to convert the ac line voltage to dc voltage. The section of the electronic system that produces this dc voltage is called the power supply. Within the power supply are circuits that allow current to flow in only one direction. These circuits are called **rectifiers.** This chapter discusses rectifier circuits, filters, clippers, clampers, and voltage multipliers.

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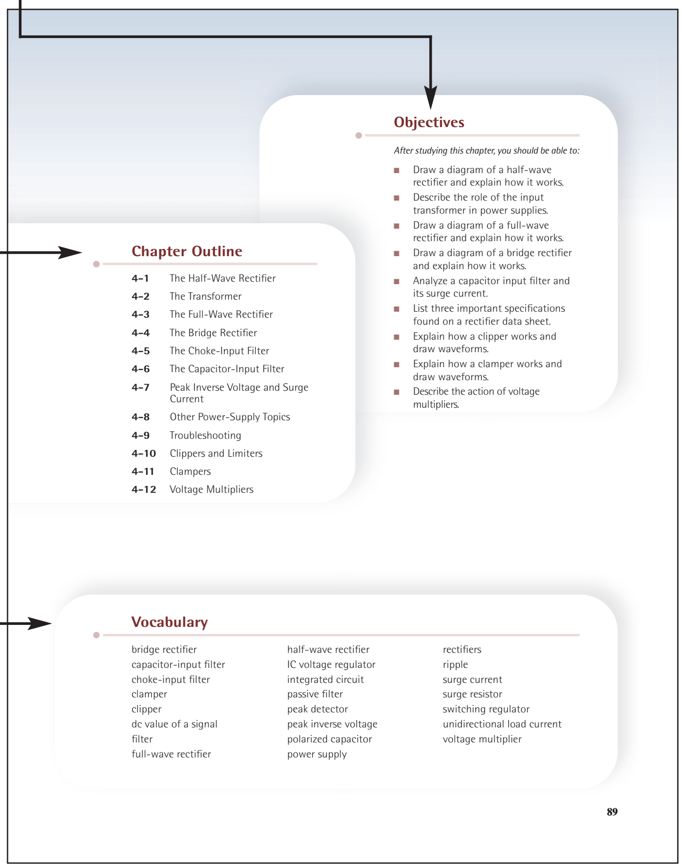
CHAPTER OBJECTIVES

Chapter Objectives provide a concise statement of expected learning outcomes.



Objectives

After studying this chapter, you should be able to:

- Draw a diagram of a half-wave rectifier and explain how it works.
- Describe the role of the input transformer in power supplies.
- Draw a diagram of a full-wave rectifier and explain how it works.
- Draw a diagram of a bridge rectifier and explain how it works.
- Analyze a capacitor input filter and its surge current.
- List three important specifications found on a rectifier data sheet.
- Explain how a clipper works and draw waveforms.
- Explain how a clamper works and draw waveforms.
- Describe the action of voltage multipliers.

Chapter Outline

Vocabulary

bridge rectifier	half-wave rectifier	rectifiers
capacitor-input filter	IC voltage regulator	ripple
choke-input filter	integrated circuit	surge current
clamper	passive filter	surge resistor
clipper	peak detector	switching regulator
dc value of a signal	peak inverse voltage	unidirectional load current
filter	polarized capacitor	voltage multiplier
full-wave rectifier	power supply	

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CHAPTER OUTLINE

Students use the outline to get a quick overview of the chapter, and to locate specific chapter topic content.

VOCABULARY

A comprehensive list of new vocabulary words alerts the students to key words found in the chapter. Within the chapter, these key words are highlighted in bold print the first time used.

EXAMPLES

Each chapter contains worked-out Examples that demonstrate important concepts or circuit operation, including circuit analysis, applications, troubleshooting, and basic design.

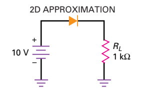
PRACTICE PROBLEMS

Students can obtain critical feedback by performing the Practice Problems that immediately follow most Examples. Answers to these problems are found at the end of each chapter.

Example 3-5

Use the second approximation to calculate the load voltage, load current, and diode power in Fig. 3-8.

Figure 3-8



SOLUTION Since the diode is forward biased, it is equivalent to a battery of 0.7 V. This means that the load voltage equals the source voltage minus the diode drop:

$$V_L = 10\text{ V} - 0.7\text{ V} = 9.3\text{ V}$$

With Ohm's law, the load current is:

$$I_L = \frac{9.3\text{ V}}{1\text{ k}\Omega} = 9.3\text{ mA}$$

The diode power is

$$P_D = (0.7\text{ V})(9.3\text{ mA}) = 6.51\text{ mW}$$

PRACTICE PROBLEM 3-5 Using Fig. 3-8, change the source voltage to 5 V and calculate the new load voltage, current, and diode power.

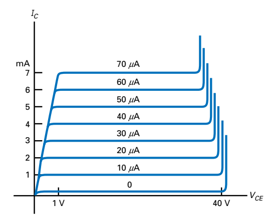
GOOD TO KNOW

Good To Know statements, found in the margins, provide interesting added insights to topics being presented.

GOOD TO KNOW

When displayed on a curve tracer, the collector curves in Fig. 6-10 actually have a slight upward slope as V_{CE} increases. This rise is the result of the base region becoming slightly smaller as V_{CE} increases. (As V_{CE} increases, the CB depletion layer widens, thus narrowing the base.) With a smaller base region, there are fewer holes available for recombination. Since each curve represents a constant base current, the effect looks like an increase in collector current.

Figure 6-10 Set of collector curves.



MULTISIM

Students can "bring to life" many of the circuits found in each chapter. A CD containing MultiSim files is included with the textbook; with these files students can change the value of circuit components and instantly see the effects, using realistic Tektronix and Agilent simulation instruments. Troubleshooting skills can be developed by inserting circuit faults and making circuit measurements. Students new to computer simulation software will find a MultiSim Primer in the appendix.

DATA SHEETS

Full and partial component data sheets are provided for many semiconductor devices; key specifications are examined and explained. Complete data sheets of these devices can be found on the Internet.

Example 4-1 MultiSim

Figure 4-3 shows a half-wave rectifier that you can build on the lab bench or on a computer screen with MultiSim. An oscilloscope is across the 1 kΩ. This will show us the half-wave load voltage. Also, a multimeter is across the 1 kΩ to read the dc load voltage. Calculate the theoretical values of peak load voltage and the dc load voltage. Then, compare these values to the readings on the oscilloscope and the multimeter.

SOLUTION Figure 4-3 shows an ac source of 10 V and 60 Hz. Schematic diagrams usually show ac source voltages as effective or rms values. Recall that the *effective value* is the value of a dc voltage that produces the same heating effect as the ac voltage.

Figure 4-3 Lab example of half-wave rectifier.

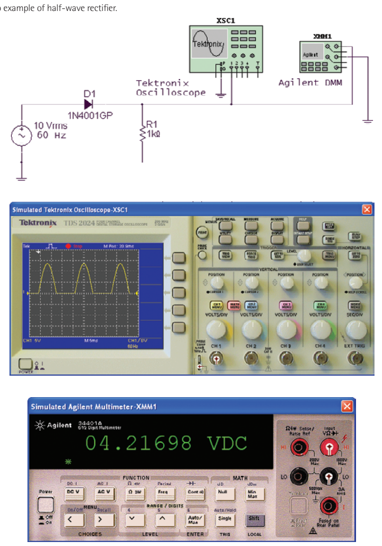


Figure 3-16 Data sheet for 1N4001–1N4007 diodes.

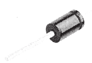
FAIRCHILD SEMICONDUCTOR®

1N4001-1N4007

1N4001 - 1N4007

Features

- Low forward voltage drop.
- High surge current capability.



DO-41
COLOR BAND DENOTES CATHODE

General Purpose Rectifiers

Absolute Maximum Ratings* T_A = 25°C unless otherwise noted

Symbol	Parameter	Value							Units
		4001	4002	4003	4004	4005	4006	4007	
V_{RRM}	Peak Repetitive Reverse Voltage	50	100	200	400	600	800	1000	V
$I_{F(AV)}$	Average Rectified Forward Current, .375 " lead length @ T_A = 75°C	1.0							A
I_{FSM}	Non-repetitive Peak Forward Surge Current 8.3 ms Single Half-Sine-Wave	30							A
T_{stg}	Storage Temperature Range	-55 to +175							°C
T_J	Operating Junction Temperature	-55 to +175							°C

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

Thermal Characteristics

Symbol	Parameter	Value	Units
P_D	Power Dissipation	3.0	W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	50	°C/W

Electrical Characteristics T_A = 25°C unless otherwise noted

Symbol	Parameter	Device							Units
		4001	4002	4003	4004	4005	4006	4007	
V_F	Forward Voltage @ 1.0 A	1.1							V
I_{rr}	Maximum Full Load Reverse Current, Full Cycle T_A = 75°C	30							μA
I_R	Reverse Current @ rated V_R T_A = 25°C T_A = 100°C	5.0 500							μA μA
C_T	Total Capacitance V_R = 4.0 V, f = 1.0 MHz	15							pF

©2003 Fairchild Semiconductor Corporation (*a*) 1N4001-1N4007, Rev. C1

COMPONENT PHOTOS

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

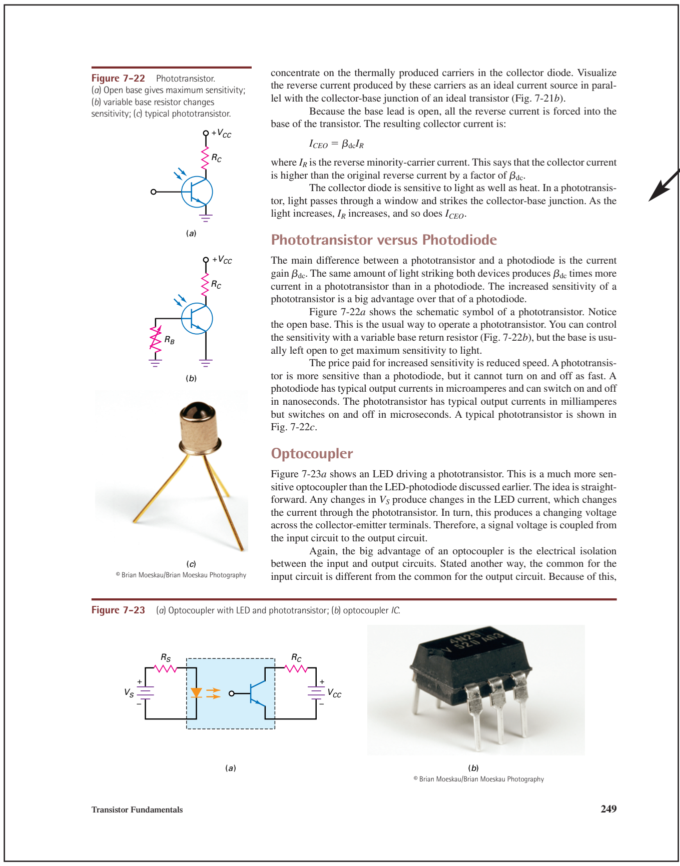


Figure 7-22 Phototransistor. (*a*) Open base gives maximum sensitivity; (*b*) variable base resistor changes sensitivity; (*c*) typical phototransistor.

concentrate on the thermally produced carriers in the collector diode. Visualize the reverse current produced by these carriers as an ideal current source in parallel with the collector-base junction of an ideal transistor (Fig. 7-21*b*).

Because the base lead is open, all the reverse current is forced into the base of the transistor. The resulting collector current is:

$$I_{CEO} = \beta_{dc} I_R$$

where I_R is the reverse minority-carrier current. This says that the collector current is higher than the original reverse current by a factor of β_{dc}.

The collector diode is sensitive to light as well as heat. In a phototransistor, light passes through a window and strikes the collector-base junction. As the light increases, I_R increases, and so does I_{CEO}.

Phototransistor versus Photodiode

The main difference between a phototransistor and a photodiode is the current gain β_{dc}. The same amount of light striking both devices produces β_{dc} times more current in a phototransistor than in a photodiode. The increased sensitivity of a phototransistor is a big advantage over that of a photodiode.

Figure 7-22*a* shows the schematic symbol of a phototransistor. Notice the open base. This is the usual way to operate a phototransistor. You can control the sensitivity with a variable base return resistor (Fig. 7-22*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. 7-22*c*.

Optocoupler

Figure 7-23*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,

Figure 7-23 (*a*) Optocoupler with LED and phototransistor; (*b*) optocoupler *IC*.

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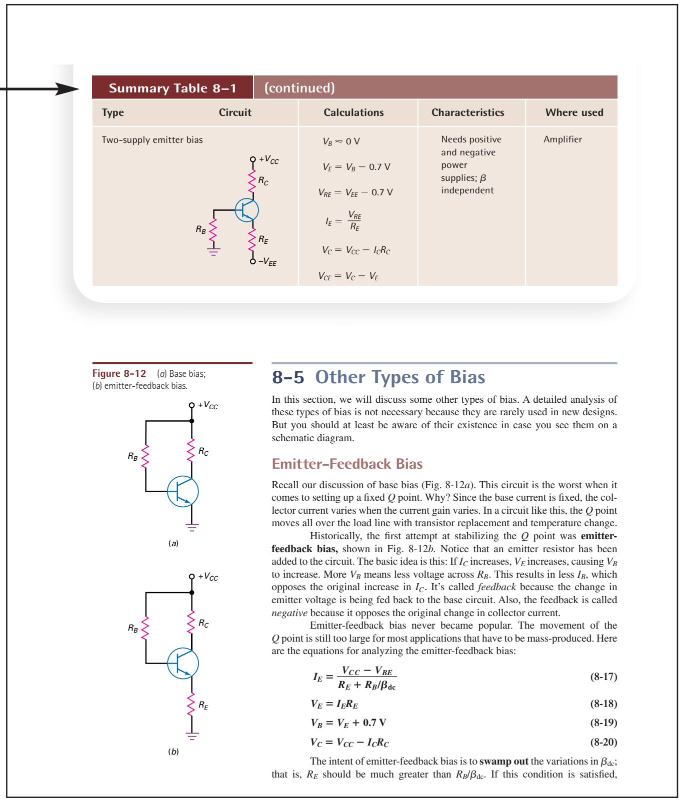
SUMMARY TABLES

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 8-1 (continued)

Type	Circuit	Calculations	Characteristics	Where used
Two-supply emitter bias		$V_B \approx 0$ V $V_E = V_B - 0.7$ V $V_{RE} = V_{EE} - 0.7$ V $I_E = \frac{V_{RE}}{R_E}$ $V_C = V_{CC} - I_C R_C$ $V_{CE} = V_C - V_E$	Needs positive and negative power supplies; β independent	Amplifier

Figure 8-12 (*a*) Base bias; (*b*) emitter-feedback bias.

8-5 Other Types of Bias

In this section, we will discuss some other types of bias. A detailed analysis of these types of bias is not necessary because they are rarely used in new designs. But you should at least be aware of their existence in case you see them on a schematic diagram.

Emitter-Feedback Bias

Recall our discussion of base bias (Fig. 8-12*a*). This circuit is the worst when it comes to setting up a fixed *Q* point. Why? Since the base current is fixed, the collector current varies when the current gain varies. In a circuit like this, the *Q* point moves all over the load line with transistor replacement and temperature change.

Historically, the first attempt at stabilizing the *Q* point was **emitter-feedback bias,** shown in Fig. 8-12*b*. Notice that an emitter resistor has been added to the circuit. The basic idea is this: If I_C increases, V_E increases, causing V_B to increase. More V_B means less voltage across R_B. This results in less I_B, which opposes the original increase in I_C. It's called *feedback* because the change in emitter voltage is being fed back to the base circuit. Also, the feedback is called *negative* because it opposes the original change in collector current.

Emitter-feedback bias never became popular. The movement of the *Q* point is still too large for most applications that have to be mass-produced. Here are the equations for analyzing the emitter-feedback bias:

$$I_E = \frac{V_{CC} - V_{BE}}{R_E + R_B/\beta_{dc}} \quad (8\text{-}17)$$

$$V_E = I_E R_E \quad (8\text{-}18)$$

$$V_B = V_E + 0.7 \text{ V} \quad (8\text{-}19)$$

$$V_C = V_{CC} - I_C R_C \quad (8\text{-}20)$$

The intent of emitter-feedback bias is to **swamp out** the variations in β_{dc}; that is, R_E should be much greater than R_B/β_{dc}. If this condition is satisfied,

COMPONENT TESTING

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

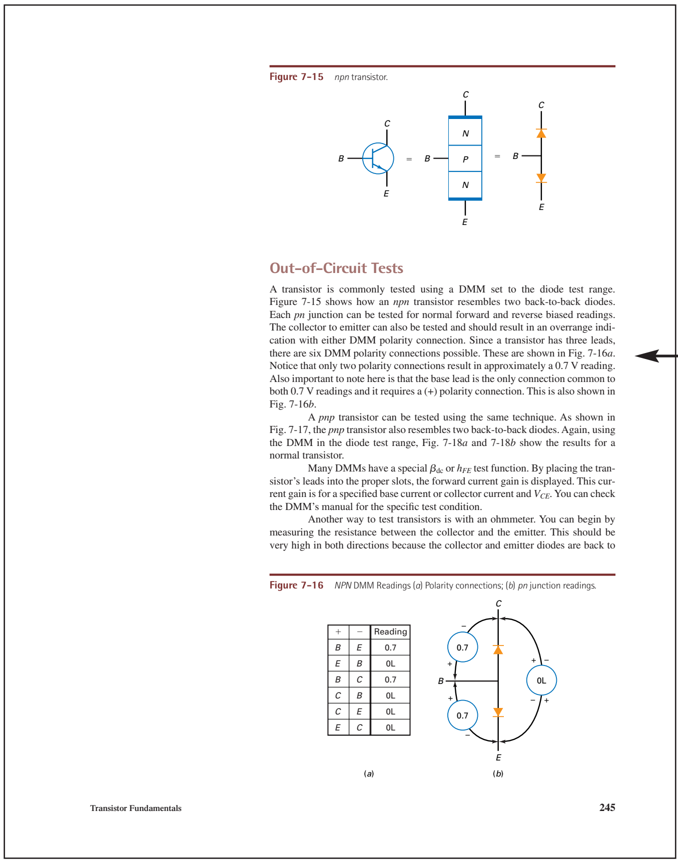


Figure 7-15 *npn* transistor.

Out-of-Circuit Tests

A transistor is commonly tested using a DMM set to the diode test range. Figure 7-15 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. 7-16*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. 7-16*b*.

A *pnp* transistor can be tested using the same technique. As shown in Fig. 7-17, the *pnp* transistor also resembles two back-to-back diodes. Again, using the DMM in the diode test range, Fig. 7-18*a* and 7-18*b* show the results for a normal transistor.

Many DMMs have a special β_{dc} or h_{FE} test function. By placing the transistor's leads into the proper slots, the forward current gain is displayed. This current gain is for a specified base current or collector current and V_{CE}. You can check the DMM's manual for the specific test condition.

Another way to test transistors is with an ohmmeter. You can begin by measuring the resistance between the collector and the emitter. This should be very high in both directions because the collector and emitter diodes are back to

Figure 7-16 *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

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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. 8-1 VOLTAGE-DIVIDER BIAS

The most famous circuit based on the emitter-bias prototype is called voltage-divider bias. You can recognize it by the voltage divider in the base circuit.

SEC. 8-2 ACCURATE VDB ANALYSIS

The key idea is for the base current to be much smaller than the current through the voltage divider. When this condition is satisfied, the voltage divider holds the base voltage almost constant and equal to the unloaded voltage out of the voltage divider. This produces a solid *Q* point under all operating conditions.

SEC. 8-3 VDB LOAD LINE AND *Q* POINT

The load line is drawn through saturation and cutoff. The *Q* point lies on the load line with the exact location determined by the biasing. Large variations in current gain have almost no effect on the *Q* point because this type of bias sets up a constant value of emitter current.

SEC. 8-4 TWO-SUPPLY EMITTER BIAS

This design uses two power supplies: one positive and the other negative. The idea is to set up a constant value of emitter current. The circuit is a variation of the emitter-bias prototype discussed earlier.

SEC. 8-5 OTHER TYPES OF BIAS

This section introduced negative feedback, a phenomenon that exists when an increase in an output quantity produces a decrease in an input quantity. It is a brilliant idea that led to voltage-divider bias. The other types of bias cannot use enough negative feedback, so they fail to attain the performance level of voltage-divider bias.

SEC. 8-6 TROUBLESHOOTING

Troubleshooting is an art. Because of this, it cannot be reduced to a set of rules. You learn troubleshooting mostly from experience.

SEC. 8-7 *PNP* TRANSISTORS

These *pnp* devices have all currents and voltages reversed from their *npn* counterparts. They may be used with negative power supplies; more commonly, they are used with positive power supplies in an upside-down configuration.

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

MultiSim Use Fig. 8-30 for the remaining problems.

8-35 Find Trouble 1.

8-36 Find Trouble 2.

8-37 Find Troubles 3 and 4.

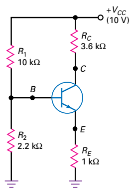
8-38 Find Troubles 5 and 6.

8-39 Find Troubles 7 and 8.

8-40 Find Troubles 9 and 10.

8-41 Find Troubles 11 and 12.

Figure 8-30



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; over 30% are new or revised in this edition. These include circuit analysis, troubleshooting, critical thinking, and job interview questions.

Job Interview Questions

1. Draw a VDB circuit. Then, tell me all the steps in calculating the collector-emitter voltage. Why does this circuit have a very stable *Q* point?
2. Draw a TSEB circuit and tell me how it works. What happens to the collector current when the transistor is replaced or the temperature changes?
3. Describe a few other kinds of bias. What can you tell me about their *Q* points?
4. What are the two types of feedback biasing, and why were they developed?
5. What is the primary type of biasing used with discrete bipolar transistor circuits?
6. Should transistors being used as switching circuits be biased in the active region? If not, what two points associated with the load line are important with switching circuits?
7. In a VDB circuit, the base current is not small compared to the current through the voltage divider. What is the shortcoming of this circuit? What should be changed to correct it?
8. What is the most commonly used transistor biasing configuration? Why?
9. Draw a VDB circuit using an *npn* transistor. Label directions of divider, base, emitter, and collector currents.
10. What is wrong with a VDB circuit in which R_1 and R_2 are 100 times greater than R_E?

Self-Test Answers

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

Practice Problem Answers

8-1 $V_B = 2.7$ V; $V_E = 2$ mA; $V_C = 7.78$ V; $V_{CE} = 5.78$ V

8-2 $V_{CE} = 5.85$ V; Very close to the predicted value

8-4 $R_E = 1\ \text{k}\Omega$; $R_C = 4\ \text{k}\Omega$; $R_2 = 700\ \Omega$ (680); $R_1 = 3.4\ \text{k}\Omega$ (3.3k)

8-5 $V_{CE} = 6.96$ V

8-6 $V_{CE} = 7.05$ V

8-7 For 8-19*a*: $V_B = 2.16$ V; $V_E = -1.46$ V; $V_C = -6.73$ V; $V_{CE} = -5.27$ V

For 8-19*b*: $V_B = 9.84$ V; $V_E = 10.54$ V; $V_C = 5.27$ V; $V_{CE} = -5.27$ V

Problems

SEC. 6-3 TRANSISTOR CURRENTS

6-1 A transistor has an emitter current of 10 mA and a collector current of 9.95 mA. What is the base current?

6-2 The collector current is 10 mA, and the base current is 0.1 mA. What is the current gain?

6-3 A transistor has a current gain of 150 and a base current of 30 μA. What is the collector current?

6-4 If the collector current is 100 mA and the current gain is 65, what is the emitter current?

SEC. 6-5 THE BASE CURVE

6-5 MultiSim What is the base current in Fig. 6-20?

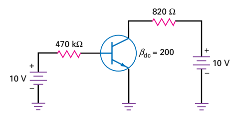


Figure 6-20

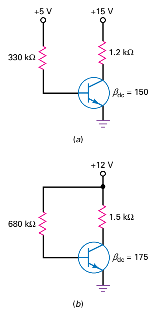


Figure 6-21

6-6 MultiSim If the current gain decreases from 200 to 100 in Fig. 6-20, what is the base current?

6-7 If the 470 kΩ of Fig. 6-20 has a tolerance of ±5 percent, what is the maximum base current?

SEC. 6-6 COLLECTOR CURVES

6-8 MultiSim A transistor circuit similar to Fig. 6-20 has a collector supply voltage of 20 V, a collector resistance of 1.5 kΩ, and a collector current of 6 mA. What is the collector-emitter voltage?

6-9 If a transistor has a collector current of 100 mA and a collector-emitter voltage of 3.5 V, what is its power dissipation?

SEC. 6-7 TRANSISTOR APPROXIMATIONS

6-10 What are the collector-emitter voltage and the transistor power dissipation in Fig. 6-20? (Give answers for the ideal and the second approximation.)

6-11 Figure 6-21*a* shows a simpler way to draw a transistor circuit. It works the same as the circuits already discussed. What is collector-emitter voltage? The transistor power dissipation? (Give answers for the ideal and the second approximation.)

6-12 When the base and collector supplies are equal, the transistor can be drawn as shown in Fig. 6-21*b*. What is the collector-emitter voltage in this circuit? The transistor power? (Give answers for the ideal and the second approximation.)

SEC. 6-8 READING DATA SHEETS

6-13 What is the storage temperature range of a 2N3904?

6-14 What is the minimum h_{FE} for a 2N3904 for a collector current of 1 mA and a collector-emitter voltage of 1 V?

6-15 A transistor has a power rating of 1 W. If the collector-emitter voltage is 10 V and the collector current is 120 mA, what happens to the transistor?

6-16 A 2N3904 has a power dissipation of 625 mW without a heat sink. If the ambient temperature is 65°C, what happens to the power rating?

SEC. 6-10 TROUBLESHOOTING

6-17 MultiSim In Fig. 6-20, does the collector-emitter voltage increase, decrease, or remain the same for each of these troubles?

a. 470 kΩ is shorted
b. 470 kΩ is open
c. 820 Ω is shorted
d. 820 Ω is open
e. No base supply voltage
f. No collector supply