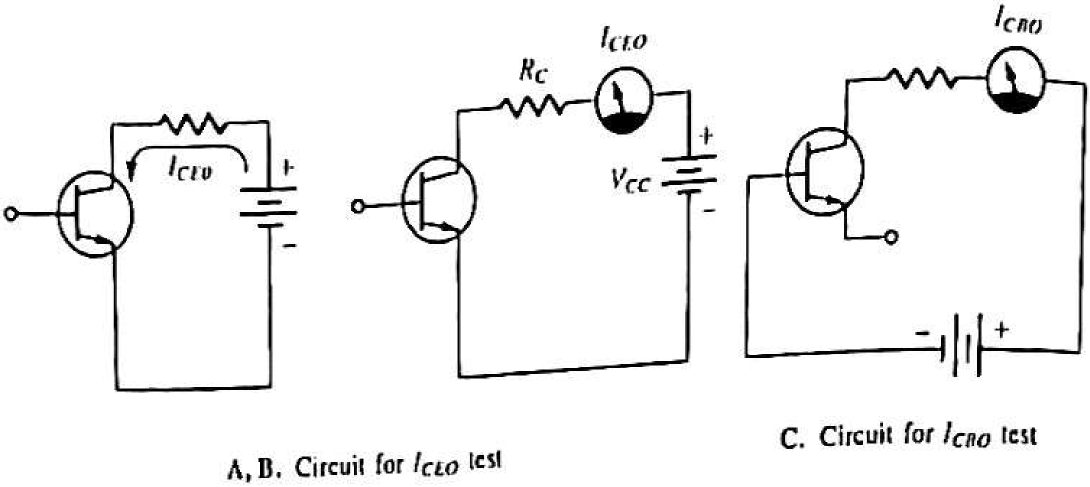


FIGURE 5-28 *Leakage current test circuits.*

When a transistor is connected as shown in Figure 5-28A with the base open ($I_B = 0$), it is in cutoff. Ideally $I_C = 0$; but actually there is a small current from collector to emitter, as mentioned earlier, called I_{CEO} (collector-to-emitter current with base open).

This leakage current is usually in the nA range for silicon. A faulty transistor will often have excessive leakage current and can be checked in a transistor tester which connects an ammeter as shown in part B.

Another leakage current in transistors is the reverse collector-to-base current, I_{CBO}. This is measured with the emitter open, as shown in part C. If it is excessive, a shorted collector-base junction is likely.

Gain Measurement

In addition to leakage tests, the typical transistor tester also checks the β_{dc}. A known I_B is applied and the resulting I_C is measured. The reading will indicate the value of the I_C/I_B ratio, although in some units only a relative indication is given.

Most testers provide for an in-circuit β_{dc} check, so that a suspected device does not have to be removed from the circuit for testing. Figure 5-29 shows two typical transistor testers.

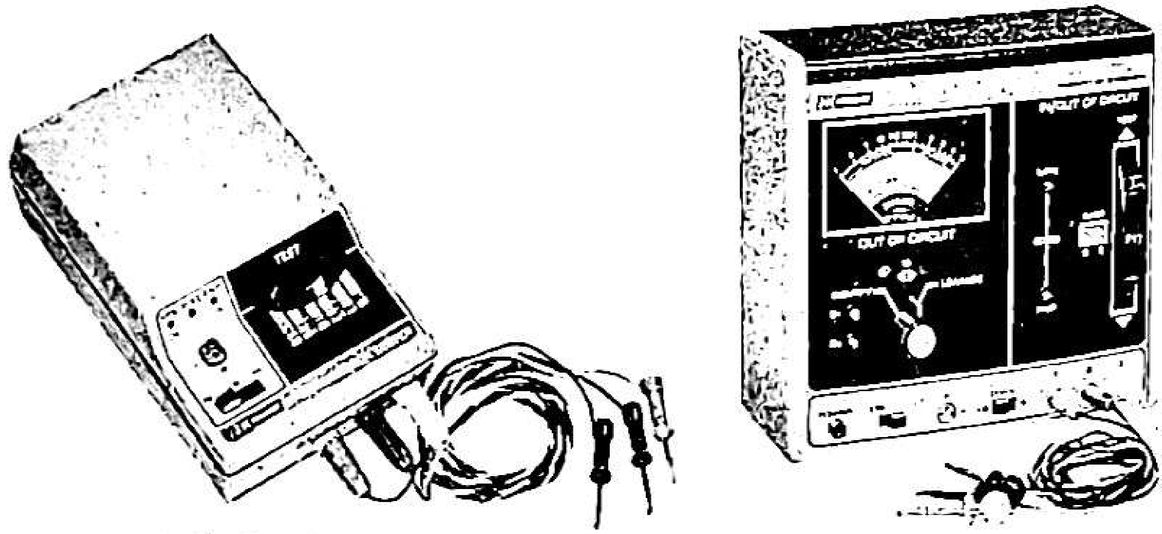


FIGURE 5-29 *Transistor testers.*

Curve Tracers

The *curve tracer* is an oscilloscope type of instrument that can display transistor characteristics such as a family of collector curves. In addition to the measurement and display of various transistor characteristics, diode curves can also be displayed, as well as the β_{dc}.

A typical curve tracer is shown in Figure 5–30.

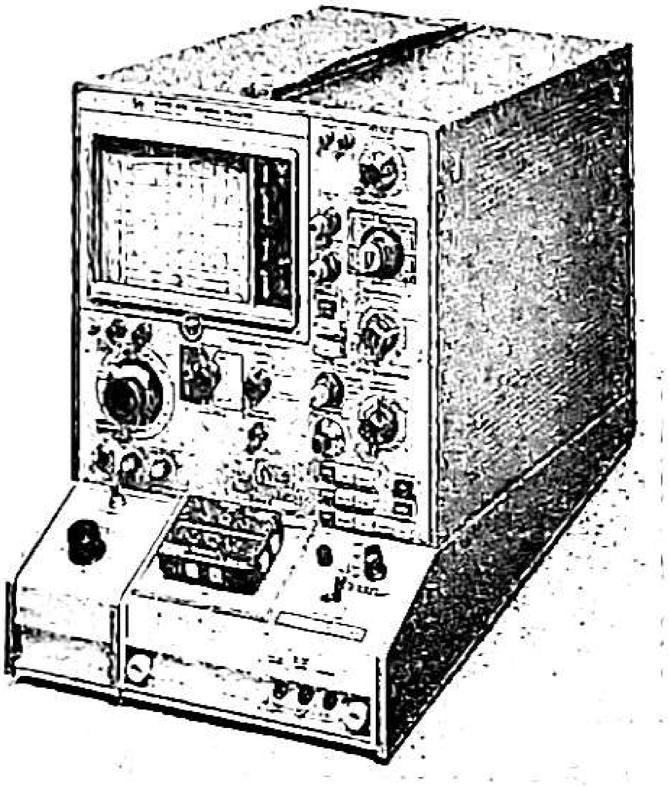


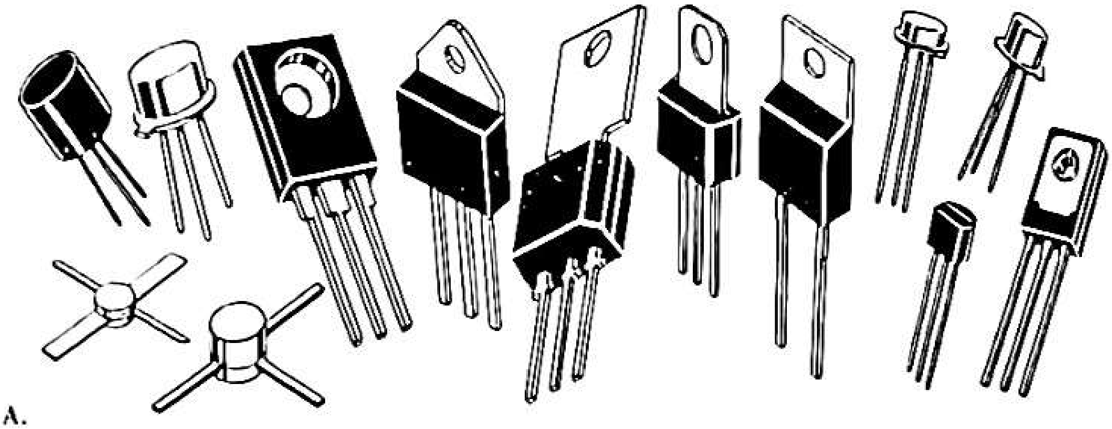
FIGURE 5–30 *Curve tracer.*

Review for 5–8

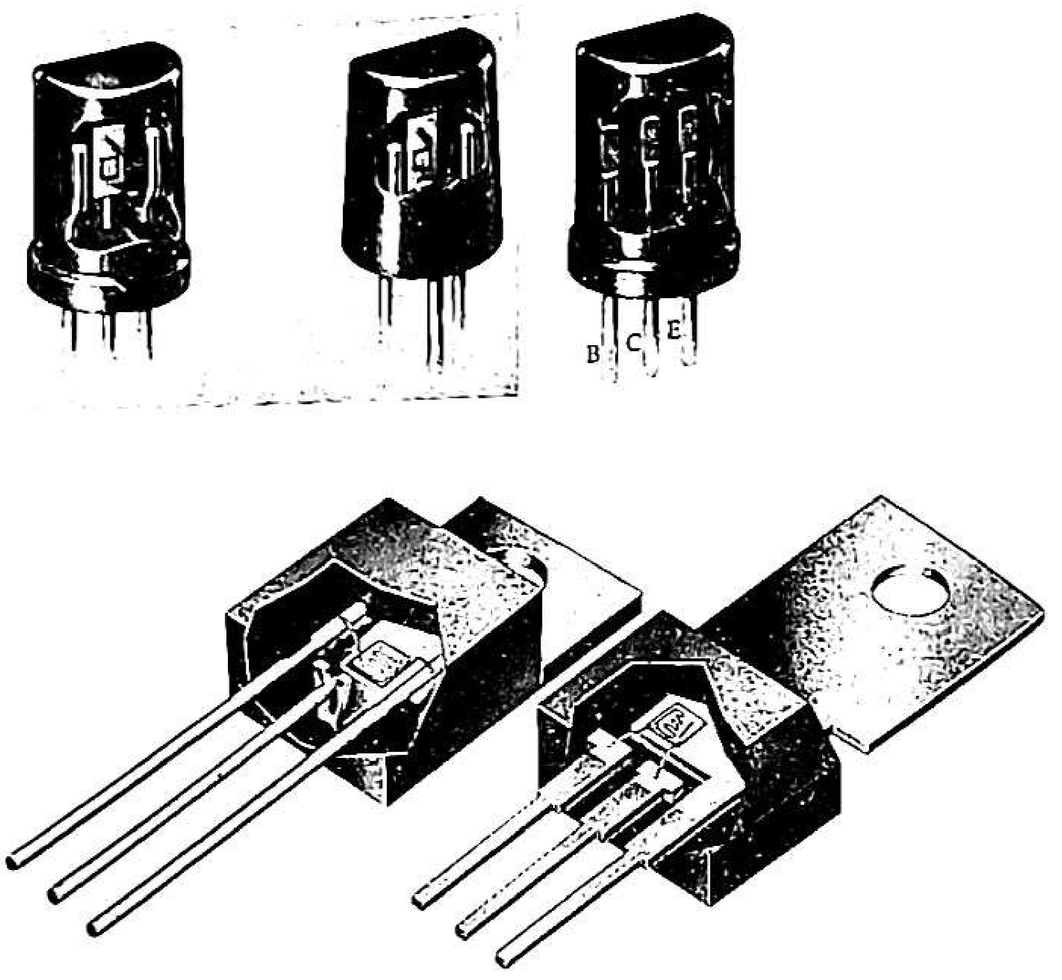
1. The positive lead of an ohmmeter is on a transistor's base, the negative lead on the emitter, and a low resistance reading is obtained. If the transistor is good, is it a pnp or an npn type?
2. Name two types of transistor leakage currents.

5–9 PACKAGES AND TERMINAL IDENTIFICATION

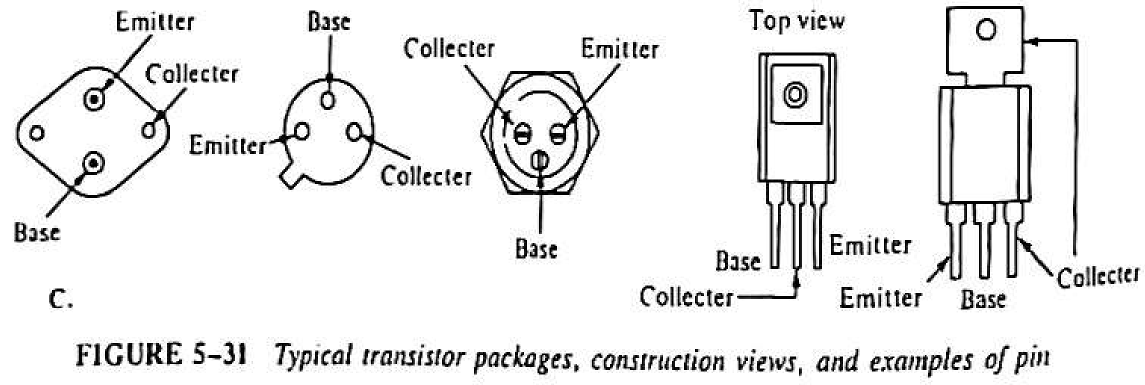
Transistors are available in a wide range of package types for various applications. Those with mounting studs or heat sinks are power transistors. Low and medium power transistors are usually found in smaller metal or plastic cases. Still another package classification is for high-frequency devices.



A.



B.



C.

FIGURE 5-31 *Typical transistor packages, construction views, and examples of pin arrangements.*

Figure 5–31 shows some typical transistor packages with some examples of construction views and pin arrangements. Generally, the heat sink mounting or stud on power transistors is the collector terminal. On the metal "top hat" cases, the tab is closest to the emitter lead and the collector is often connected to the case.

Review for 5–9

1. Identify the leads on the transistors in Figure 5–32.

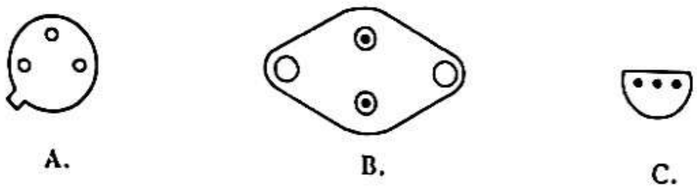


FIGURE 5–32

5–10 COMPUTER ANALYSIS

This section presents an example of a computer program for use in the analysis of a transistor bias circuit. As with all the programs in this book, it is intended to illustrate the potential of the computer as a problem-solving tool and does not represent an all-inclusive coverage of computer-aided circuit analysis.

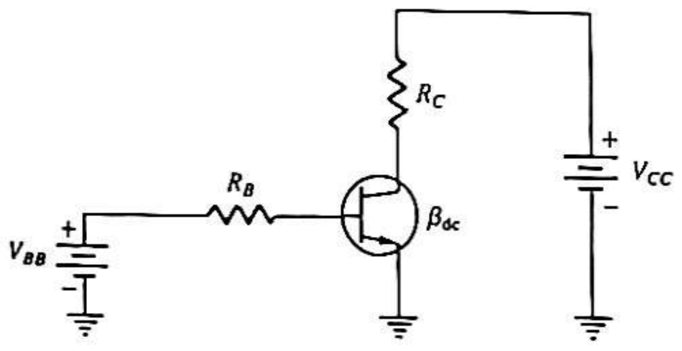


FIGURE 5–33

This program performs an analysis similar to that found in Example 5–4. The program computes the values of the dc currents and the dc voltages for a circuit like that in Figure 5–33. The required inputs are values for V_{BB}, R_B, R_C, V_{CC}, and β_{dc}.

Again, this program will run on TRS–80 Level II computers. By changing all CLS statements to HOME, it is compatible with the APPLE computer.

```
10  CLS
20  PRINT "THIS PROGRAM COMPUTES THE DIRECT CURRENTS"
30  PRINT "AND DC VOLTAGES FOR THE CIRCUIT IN FIGURE"
40  PRINT "5-33 GIVEN VALUES FOR VBB, VCC, RB, RC, "
50  PRINT "AND DC BETA."
60  PRINT:PRINT:PRINT
70  INPUT "TO CONTINUE PRESS 'ENTER'";X
80  CLS
90  INPUT "VBB IN VOLTS";VBB
100 INPUT "VCC IN VOLTS";VCC
110 INPUT "RB IN OHMS";RB
120 INPUT "RC IN OHMS";RC
130 INPUT "DC BETA";B
140 CLS
150 IB=(VBB-.7)/RB
160 IC=B*IB
170 ALPHA=B/(B+1)
180 IE=IC/ALPHA
190 VCE=VCC-IC*RC
200 IF VCE<=0 THEN PRINT "TRANSISTOR IS SATURATED" ELSE 220
210 END
220 VBC=.7-VCE
230 PRINT "IB =";IB;"A"
240 PRINT "IC =";IC;"A"
250 PRINT "IE =";IE;"A"
260 PRINT "VCE =";VCE;"V"
270 PRINT "VCB =";VCB;"V"
```

Review for 5–10

1. Which lines in the program allow the data to be input to the computer?
2. When is line 210 executed?

Formulas

(5–1)	$I_E = I_C + I_B$	Transistor currents
(5–2)	$I_E \cong I_C$	Approximation of equation (5–1)
(5–3)	$A_v = \dfrac{V_{out}}{V_{in}}$	Voltage gain
(5–4)	$A_v \cong \dfrac{R_C}{r_e}$	Voltage gain
(5–5)	$\alpha_{dc} = \dfrac{I_C}{I_E}$	dc alpha
(5–6)	$\beta_{dc} = \dfrac{I_C}{I_B}$	dc current gain

(5–7)	$\alpha_{dc} = \dfrac{\beta_{dc}}{\beta_{dc} + 1}$	β_{dc} to α_{dc} conversion
(5–8)	$\beta_{dc} = \dfrac{\alpha_{dc}}{1 - \alpha_{dc}}$	α_{dc} to β_{dc} conversion
(5–9)	$V_{BE} = 0.7\ \text{V}$	Base-emitter voltage (silicon)
(5–10)	$I_B = \dfrac{V_{BB} - V_{BE}}{R_B}$	Base current
(5–11)	$V_{CE} = V_{CC} - I_C R_C$	Collector-emitter voltage (common-emitter)
(5–12)	$V_{CB} = V_{CE} - V_{BE}$	Collector-base voltage
(5–13)	$I_E = \dfrac{V_{BB} - V_{BE}}{R_E}$	Emitter current (common-collector)
(5–14)	$I_B \cong \dfrac{I_E}{\beta_{dc}}$	Base current
(5–15)	$V_{CE} = V_{CC} - I_E R_E$	Collector-emitter voltage (common-collector)
(5–16)	$V_{CB} = V_{CC} - V_E - V_{BE}$	Collector-base voltage
(5–17)	$I_C = \dfrac{P_{D(max)}}{V_{CE}}$	Maximum I_C for given V_{CE}
(5–18)	$V_{CE} = \dfrac{P_{D(max)}}{I_C}$	Maximum V_{CE} for given I_C

Summary

1. A bipolar transistor consists of three regions: emitter, base, and collector.
2. Current in a transistor consists of both electron and hole flow, thus the term *bipolar*.
3. A bipolar transistor has two pn junctions: one between the emitter and base, and another between the base and collector.
4. The two types of bipolar transistors are the npn and the pnp.
5. The base current is normally much less than either the emitter current or the collector current.
6. The dc alpha (α_{dc}) is the ratio of collector current to emitter current and has a value close to 1.
7. The dc beta (β_{dc}) is the ratio of collector current to base current. This current gain can have values from less than 20 to several hundred.
8. A transistor can be connected in any of three basic types of circuit configurations: common-base, common-emitter, and common-collector.

Self-Test

1. In an npn transistor, the n-type semiconductor regions are the ________ and ________.
2. For normal operation of a pnp transistor, the base must be (+ or −) with respect to the emitter, and (+ or −) with respect to the collector.
3. What is the exact value of I_C for $I_E = 5.34$ mA and $I_B = 475$ μA?
4. What is the α_{dc} when $I_C = 8.23$ mA and $I_E = 8.69$ mA?
5. A certain transistor has an $I_C = 25$ mA and an $I_B = 200$ μA. Determine the β_{dc}.
6. If the silicon transistor in problem 5 is connected in a common-emitter configuration with $I_B = 0.15$ mA, $V_{CC} = 25$ V, and $R_C = 1$ kΩ, what is the voltage at the collector? At the emitter? At the base?
7. What is the β_{dc} of a transistor if α_{dc} is 0.96?
8. A transistor is connected in a common-collector configuration. Determine the approximate V_E when $I_B = 10$ μA. Assume $R_E = 500$ Ω and $\beta_{dc} = 200$.
9. For the circuit in problem 8, what is the effect on V_E of a rise in temperature if the resistor values, supply voltages, and base current remain constant? Why?
10. A certain transistor has a maximum power rating of 0.5 W. If V_{CE} is 8 V, how much collector current can there be without exceeding the power rating?
11. An ohmmeter is connected to a pnp transistor with the positive lead on the base and the negative lead on the emitter. The meter shows a very high resistance. Is this a good indication?
12. Name two checks that most transistor testers perform on a device under test.
13. If you have a computer available, enter the program in section 5–10. Run the program, entering variable values from Example 5–4, and observe the results.

Problems

Section 5–1

5–1. The majority carriers in the base region of an npn transistor are ________.

5–2. Explain the purpose of a thin, lightly doped base.

Section 5–2

5–3. Why is the base current in a transistor so much less than the collector current?

5–4. In a certain transistor circuit, the base current is 2 percent of the 30 mA emitter current. Determine the collector current.

Section 5–3

5–5. A transistor amplifier has a voltage gain of 50. What is the output voltage when the input voltage is 100 mV?

5–6. To achieve an output of 10 V with an input of 300 mV, what voltage gain is required?

5–7. A 50 mV signal is applied to the base of a properly biased transistor with r_e = 10 Ω and R_C = 500 Ω. Determine the signal voltage at the collector.

Section 5–4

5–8. A certain transistor exhibits an α_{dc} of 0.96. Determine I_C when I_E = 9.35 mA.

5–9. Show the proper biasing for a pnp transistor in a common-base configuration. Repeat for an npn.

5–10. What important approximation derives from the fact that α_{dc} is very close to unity (1) in value?

Section 5–5

5–11. A base current of 50 μA is applied to the transistor in Figure 5–34, and a voltage of 5 V is dropped across R_C. Determine the β_{dc} of the transistor.

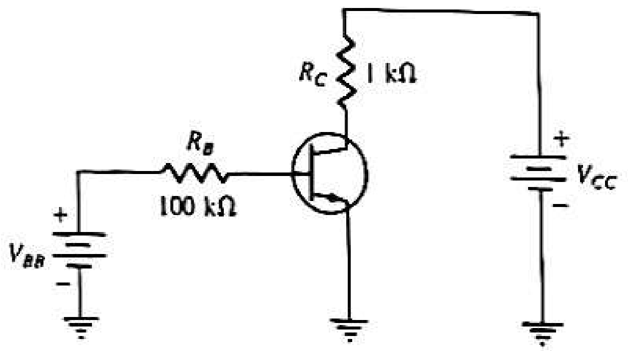


FIGURE 5–34

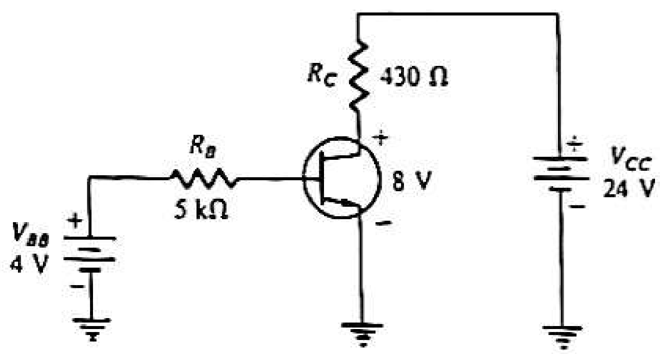


FIGURE 5–35

5–12. Calculate α_{dc} for the transistor in problem 5–11.

5–13. Determine each current in Figure 5–35. What is the β_{dc}?

5–14. Find V_{CE}, V_{BE}, and V_{CB} in both circuits of Figure 5–36.

5–15. Determine whether or not the transistors in Figure 5–36 are saturated.

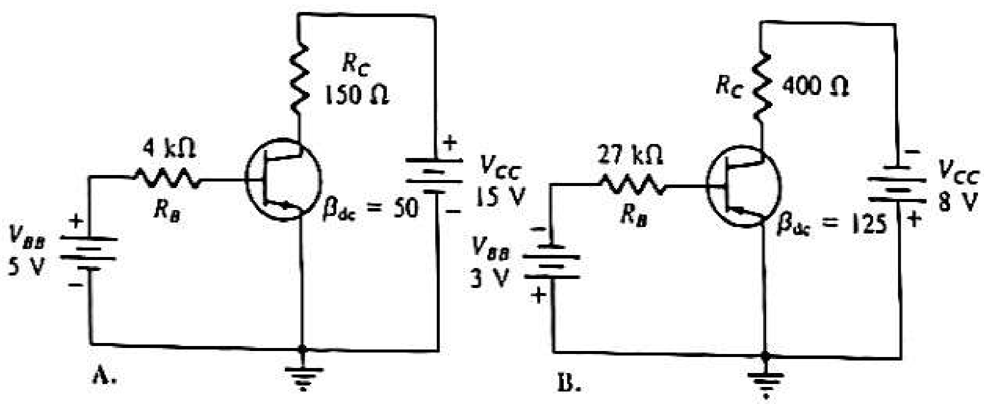


FIGURE 5–36

Section 5–6

5–16. Find I_B, I_E, and I_C in Figure 5–37. $\alpha_{dc} = 0.98$.

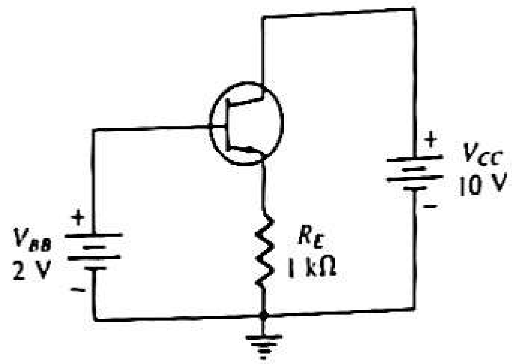


FIGURE 5–37

5–17. Determine the terminal voltages of each transistor with respect to ground for each circuit in Figure 5–38. Also determine V_{CE}, V_{BE}, and V_{BC}.

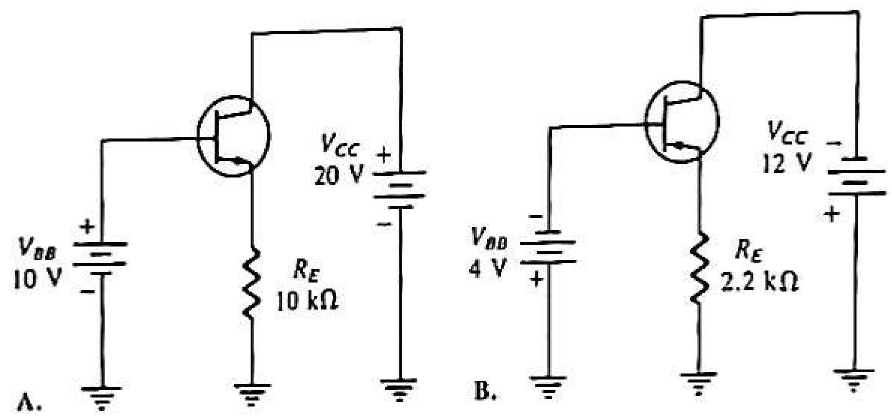


FIGURE 5–38

Section 5–7

5–18. If the β_{dc} in Figure 5–38A changes from 100 to 150 due to a temperature increase, what is the change in collector current?

5–19. A certain transistor is to be operated at a collector current of 50 mA. How high can V_{CE} go without exceeding a $P_{D(max)}$ of 1.2 W?

5–20. The power dissipation derating factor for a certain transistor is 1 mW/°C. The $P_{D(max)}$ is 0.5 W at 25°C. What is $P_{D(max)}$ at 100°C?

Section 5–8

5–21. Which, if any, of the transistors in Figure 5–39 are bad?

5–22. Is the transistor in Figure 5–40 an npn or a pnp device? Assume that it is good.

Section 5–10

5–23. Write a program in BASIC to calculate the voltage gain and the output voltage for a circuit like that in Figure 5–7 for any value of R_C, r_e, and V_{in}.

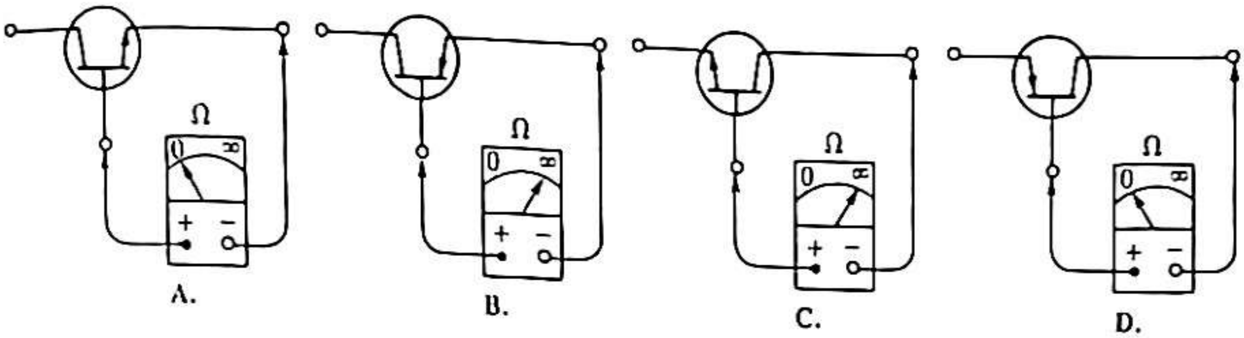


FIGURE 5–39

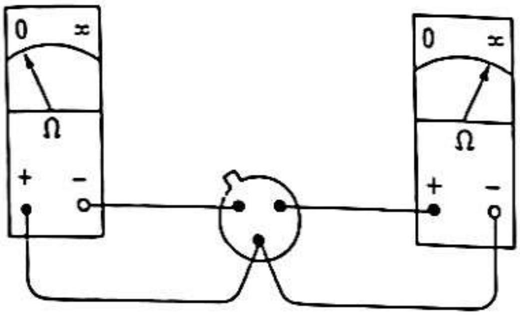


FIGURE 5–40

5–24. Write a program in BASIC to convert a specified value of β_{dc} to the corresponding value of α_{dc}.

5–25. Develop a BASIC computer program to perform the dc analysis (find I_B, I_C, I_E, V_E, V_B, and V_C) for a common-collector circuit like that in Figure 5–21.

Answers to Section Reviews

Section 5–1

1. pnp, npn. **2.** Emitter, base, and collector.

Section 5–2

1. Forward, reverse. **2.** 1.001 mA.

Section 5–3

1. The process of increasing the amplitude of an electrical signal. **2.** 20. **3.** 60.

Section 5–4

1. 0.967. **2.** Emitter, collector.

Section 5–5

1. 80. **2.** 35. **3.** 365 μA.

Section 5–6

1. 0.18 mA. **2.** 12 V, 5 V.

Section 5–7

1. True. 2. β_{dc} increases with I_C to a certain value, and then decreases. 3. 40 mA.

Section 5–8

1. npn. 2. I_{CBO}, I_{CEO}.

Section 5–9

1. See Figure 5–41.

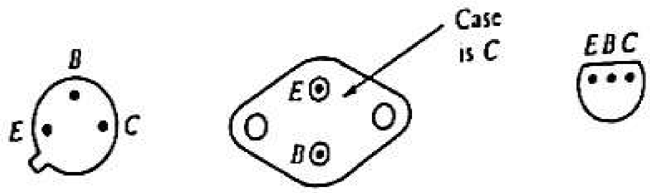


FIGURE 5–41

Section 5–10

1. Lines 90–130. 2. When $V_{CE} \leqq 0$.