## Computer Simulations Problems

SIM Problems identified by the Multisim/PSpice icon are intended to demonstrate the value of using SPICE simulation to verify hand analysis and design, and to investigate important issues such as allowable signal swing and amplifier nonlinear distortion. Instructions to assist in setting up PSPice and Multisim simulations for all the indicated problems can be found in the corresponding files on the website. Note that if a particular parameter value is not specified in the problem statement, you are to make a reasonable assumption.

## Section 6.1: Device Structure and Physical Operation

**6.1** The terminal voltages of various *npn* transistors are measured during operation in their respective circuits with the following results:

| Case | E | B | C | Mode |
|---|---|---|---|---|
| 1 | 0 | 0.7 | 0.7 | |
| 2 | 0 | 0.8 | 0.1 | |
| 3 | −0.7 | 0 | 1.0 | |
| 4 | −0.7 | 0 | −0.6 | |
| 5 | 1.3 | 2.0 | 5.0 | |
| 6 | 0 | 0 | 5.0 | |

In this table, where the entries are in volts, 0 indicates the reference terminal to which the black (negative) probe of the voltmeter is connected. For each case, identify the mode of operation of the transistor.

**6.2** Two transistors, fabricated with the same technology but having different junction areas, when operated at a base-emitter voltage of 0.75 V, have collector currents of 0.5 mA and 2 mA. Find $I_S$ for each device. What are the relative junction areas?

**6.3** In a particular technology, a small BJT operating at $v_{BE} = 30V_T$ conducts a collector current of 200 μA. What is the corresponding saturation current? For a transistor in the same technology but with an emitter junction that is 32 times larger, what is the saturation current? What current will this transistor conduct at $v_{BE} = 30V_T$? What is the base–emitter voltage of the latter transistor at $i_C = 1$ mA? Assume active-mode operation in all cases.

**6.4** Two transistors have EBJ areas as follows: $A_{E1} = 200\ \mu m \times 200\ \mu m$ and $A_{E2} = 0.4\ \mu m \times 0.4\ \mu m$. If the two transistors are operated in the active mode and conduct equal collector currents, what do you expect the difference in their $v_{BE}$ values to be?

**6.5** Find the collector currents that you would expect for operation at $v_{BE} = 700$ mV for transistors for which $I_S = 10^{-13}$ A and $I_S = 10^{-18}$ A. For the transistor with the larger EBJ, what is the $v_{BE}$ required to provide a collector current equal to that provided by the smaller transistor at $v_{BE} = 700$ mV? Assume active-mode operation in all cases.

**6.6** In this problem, we contrast two BJT integrated-circuit fabrication technologies: For the "old" technology, a typical *npn* transistor has $I_S = 2 \times 10^{-15}$ A, and for the "new" technology, a typical *npn* transistor has $I_S = 2 \times 10^{-18}$ A. These typical devices have vastly different junction areas and base width. For our purpose here we wish to determine the $v_{BE}$ required to establish a collector current of 1 mA in each of the two typical devices. Assume active-mode operation.

**6.7** Consider an *npn* transistor whose base–emitter drop is 0.76 V at a collector current of 5 mA. What current will it conduct at $v_{BE} = 0.70$ V? What is its base–emitter voltage for $i_C = 5\ \mu A$?

**6.8** In a particular BJT, the base current is 10 μA, and the collector current is 800 μA. Find $\beta$ and $\alpha$ for this device.

**6.9** Find the values of $\beta$ that correspond to $\alpha$ values of 0.5, 0.8, 0.9, 0.95, 0.98, 0.99, 0.995, and 0.999.

**6.10** Find the values of $\alpha$ that correspond to $\beta$ values of 1, 2, 10, 20, 50, 100, 200, 500, and 1000.

***6.11** Show that for a transistor with $\alpha$ close to unity, if $\alpha$ changes by a small per-unit amount $(\Delta\alpha/\alpha)$, the corresponding per-unit change in $\beta$ is given approximately by

$$\frac{\Delta\beta}{\beta} \simeq \beta\left(\frac{\Delta\alpha}{\alpha}\right)$$

Now, for a transistor whose nominal $\beta$ is 100, find the percentage change in its $\alpha$ value corresponding to a drop in its $\beta$ of 10%.

**6.12** An *npn* transistor of a type whose $\beta$ is specified to range from 50 to 300 is connected in a circuit with emitter grounded, collector at + 10 V, and a current of 10 μA injected into the base. Calculate the range of collector and emitter currents that can result. What is the maximum power dissipated in the transistor? (*Note:* Perhaps you can see why this is a bad way to establish the operating current in the collector of a BJT.)

SIM = Multisim/PSpice; * = difficult problem; ** = more difficult; *** = very challenging; D = design problem

transistor that conducts $i_C = 1$ mA with $v_{EB} = 0.70$ V. How much larger is it?

6.26 While Fig. 6.5 provides four possible large-signal equivalent circuits for the *npn* transistor, only two equivalent circuits for the *pnp* transistor are provided in Fig. 6.11. Supply the missing two.

6.27 By analogy to the *npn* case shown in Fig. 6.9, give the equivalent circuit of a *pnp* transistor in saturation.

## Section 6.2: Current–Voltage Characteristics

6.28 For the circuits in Fig. P6.28, assume that the transistors have very large $\beta$. Some measurements have been made on these circuits, with the results indicated in the figure. Find the values of the other labeled voltages and currents.

6.29 Measurements on the circuits of Fig. P6.29 produce labeled voltages as indicated. Find the value of $\beta$ for each transistor.

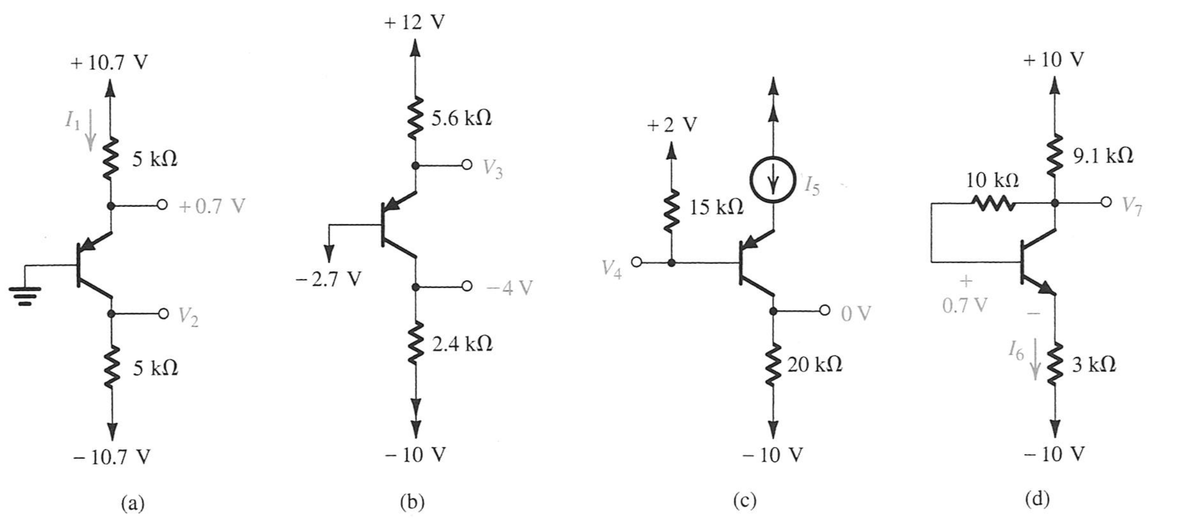



Figure P6.28

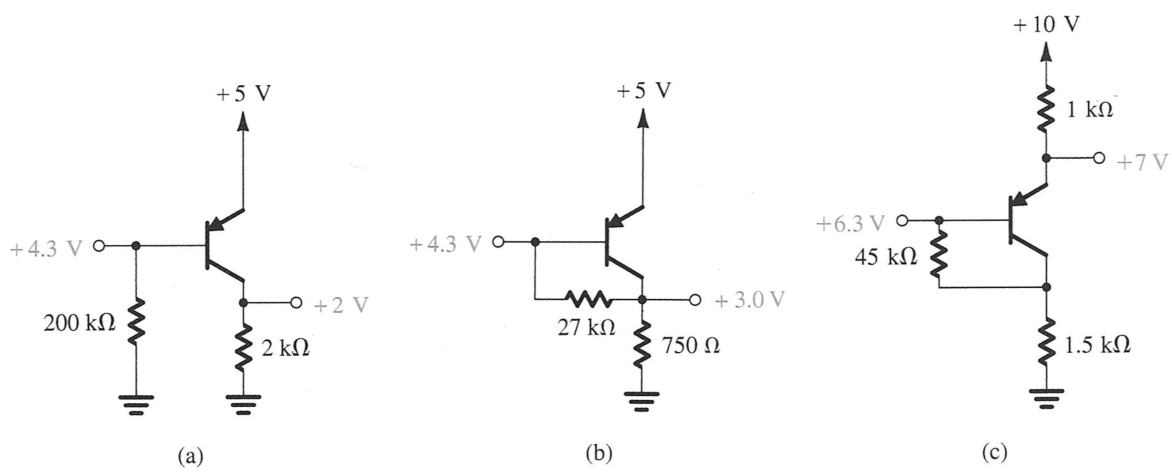



Figure P6.29

SIM = Multisim/PSpice; * = difficult problem; ** = more difficult; *** = very challenging; D = design problem

**6.30** A very simple circuit for measuring $\beta$ of an *npn* transistor is shown in Fig. P6.30. In a particular design, $V_{CC}$ is provided by a 9-V battery; M is a current meter with a 50-µA full scale and relatively low resistance that you can neglect for our purposes here. Assuming that the transistor has $V_{BE} = 0.7$ V at $I_E = 1$ mA, what value of $R_C$ would establish a resistor current of 1 mA? Now, to what value of $\beta$ does a meter reading of full scale correspond? What is $\beta$ if the meter reading is 1/5 of full scale? 1/10 of full scale?

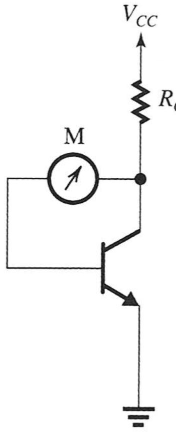



Figure P6.30

**6.31** Repeat Exercise 6.13 for the situation in which the power supplies are reduced to ±2.5 V.

**D 6.32** Design the circuit in Fig. P6.32 to establish a current of 0.5 mA in the emitter and a voltage of −0.5 V at the collector. The transistor $v_{EB} = 0.64$ V at $I_E = 0.1$ mA, and $\beta = 100$. To what value can $R_C$ be increased while the collector current remains unchanged?

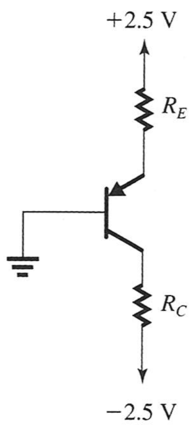



Figure P6.32

**D 6.33** Examination of the table of standard values for resistors with 5% tolerance in Appendix J reveals that the closest values to those found in the design of Example 6.2 are 5.1 kΩ and 6.8 kΩ. For these values, use approximate calculations (e.g., $V_{BE} \simeq 0.7$ V and $\alpha \simeq 1$) to determine the values of collector current and collector voltage that are likely to result.

**D 6.34** Design the circuit in Fig. P6.34 to establish $I_C = 0.2$ mA and $V_C = 0.5$ V. The transistor exhibits $v_{BE}$ of 0.8 V at $i_C = 1$ mA, and $\beta = 100$.

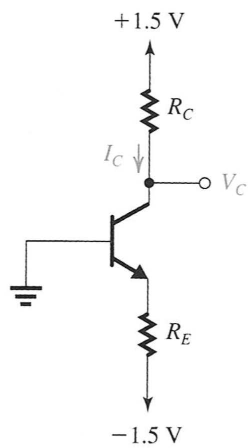



Figure P6.34

**6.35** For each of the circuits shown in Fig. P6.35, find the emitter, base, and collector voltages and currents. Use $\beta = 50$, but assume $|V_{BE}| = 0.8$ V independent of current level.

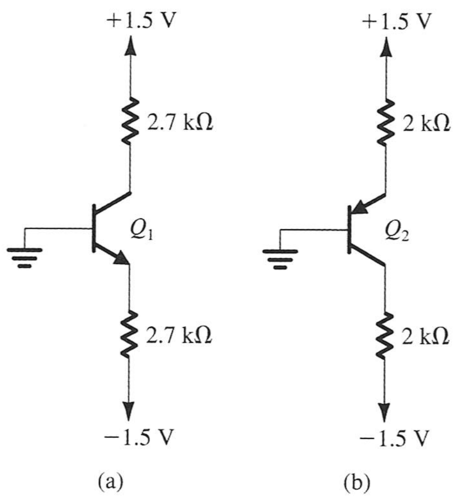



Figure P6.35

its value for $V_B = 0$ V? For what value of $V_B$ is the transistor just at the edge of conduction? ($v_{BE} = 0.5$ V) What values of $V_E$ and $V_C$ correspond? For what value of $V_B$ does the transistor reach the edge of saturation? What values of $V_C$ and $V_E$ correspond? Find the value of $V_B$ for which the transistor operates in saturation with a forced $\beta$ of 2.

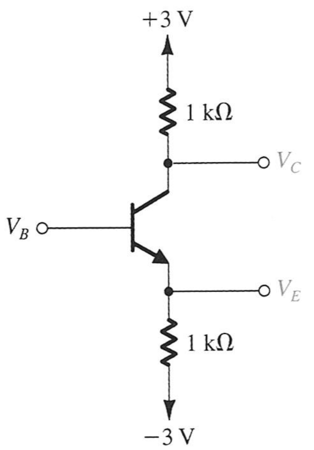



Figure P6.53

**6.54** For the transistor shown in Fig. P6.54, assume $\alpha \simeq 1$ and $v_{BE} = 0.5$ V at the edge of conduction. What are the values of $V_E$ and $V_C$ for $V_B = 0$ V? For what value of $V_B$ does the transistor cut off? Saturate? In each case, what values of $V_E$ and $V_C$ result?

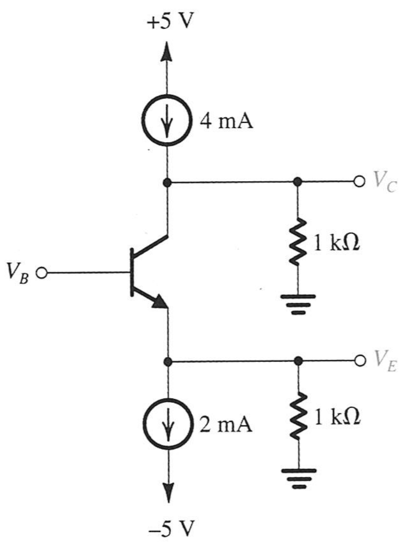



Figure P6.54

**D 6.55** Consider the circuit in Fig. P6.51 with the base voltage $V_B$ obtained using a voltage divider across the 3-V supply. Assuming the transistor $\beta$ to be very large (i.e., ignoring the base current), design the voltage divider to obtain $V_B = 1.2$ V. Design for a 0.1-mA current in the voltage divider. Now, if the BJT $\beta = 100$, analyze the circuit to determine the collector current and the collector voltage.

**6.56** A single measurement indicates the emitter voltage of the transistor in the circuit of Fig. P5.56 to be 1.0 V. Under the assumption that $|V_{BE}| = 0.7$ V, what are $V_B$, $I_B$, $I_E$, $I_C$, $V_C$, $\beta$, and $\alpha$ ? (*Note:* Isn't it surprising what a little measurement can lead to?)

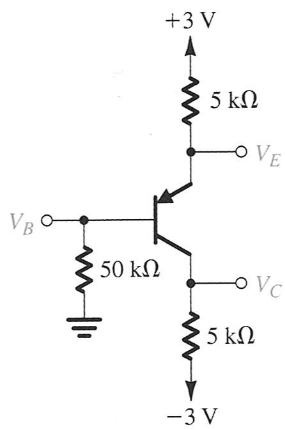



Figure P6.56

**D 6.57** Design a circuit using a *pnp* transistor for which $\alpha \simeq 1$ using two resistors connected appropriately to ±3 V so that $I_E = 0.5$ mA and $V_{BC} = 1$ V. What exact values of $R_E$ and $R_C$ would be needed? Now, consult a table of standard 5% resistor values (e.g., that provided in Appendix J) to select suitable practical values. What values of resistors have you chosen? What are the values of $I_E$ and $V_{BC}$ that result?

**6.58** In the circuit shown in Fig. P6.58, the transistor has $\beta = 40$. Find the values of $V_B$, $V_E$, and $V_C$. If $R_B$ is raised to 100 kΩ, what voltages result? With $R_B = 100$ kΩ, what value of $\beta$ would return the voltages to the values first calculated?

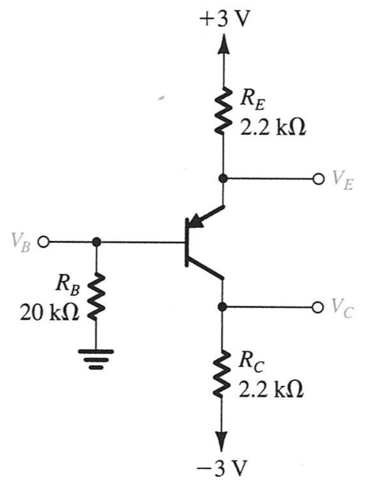



Figure P6.58

**6.59** In the circuit shown in Fig. P6.58, the transistor has $\beta = 50$. Find the values of $V_B$, $V_E$, and $V_C$, and verify that the transistor is operating in the active mode. What is the largest value that $R_C$ can have while the transistor remains in the active mode?

SIM **6.60** For the circuit in Fig. P6.60, find $V_B$, $V_E$, and $V_C$ for $R_B = 100$ kΩ, 10 kΩ, and 1 kΩ. Let $\beta = 100$.

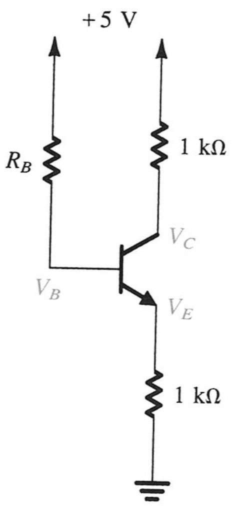



Figure P6.60

**6.61** For the circuits in Fig. P6.61, find values for the labeled node voltages and branch currents. Assume $\beta$ to be very high.

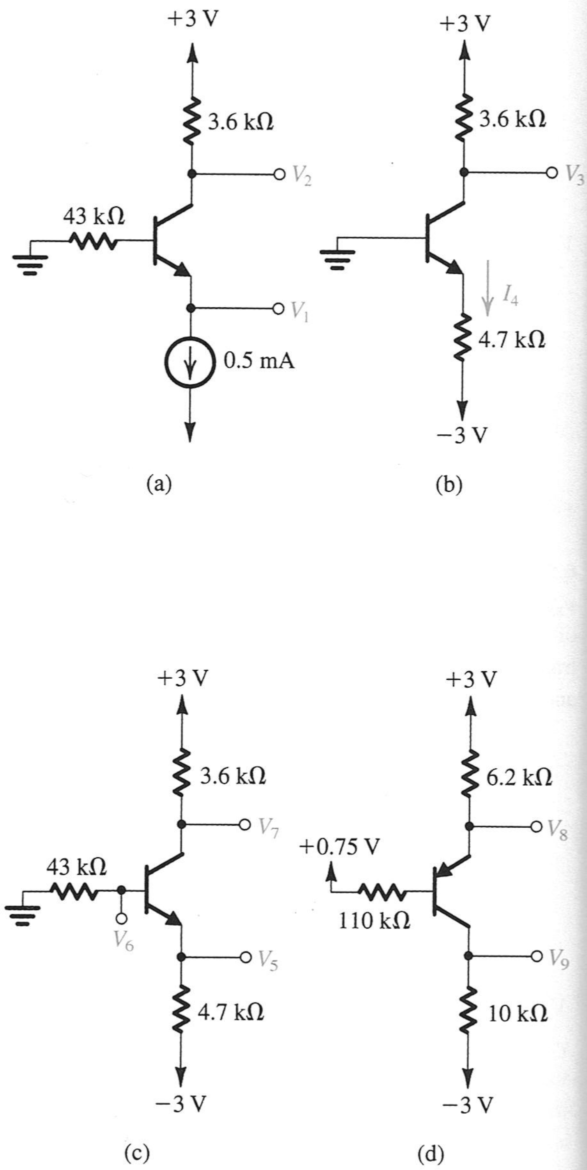
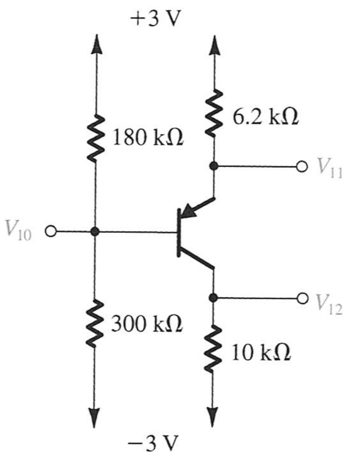



Figure P6.61




(e)

Figure P6.61 *continued*

*6.62 Repeat the analysis of the circuits in Problem 6.61 using $\beta = 100$. Find all the labeled node voltages and branch currents.

**D** **6.63 It is required to design the circuit in Fig. P6.63 so that a current of 1 mA is established in the emitter and a voltage of −1 V appears at the collector. The transistor type used has a nominal $\beta$ of 100. However, the $\beta$ value can be as low as 50 and as high as 150. Your design should ensure that the specified emitter current is obtained when $\beta = 100$ and that at the extreme values of $\beta$ the emitter current does not change by more than 10% of its nominal value. Also, design for as large a value for $R_B$ as possible. Give the values of $R_B$, $R_E$, and $R_C$ to the nearest kilohm. What is the expected range of collector current and collector voltage corresponding to the full range of $\beta$ values?

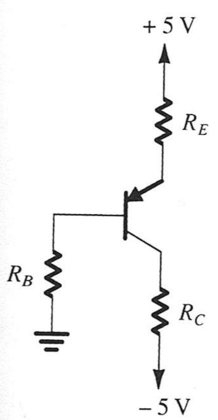



Figure P6.63

**D** 6.64 The *pnp* transistor in the circuit of Fig. P6.64 has $\beta = 50$. Find the value for $R_C$ to obtain $V_C = +2$ V. What happens if the transistor is replaced with another having $\beta = 100$? Give the value of $V_C$ in the latter case.

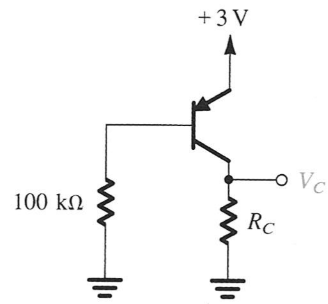



Figure P6.64

***6.65 Consider the circuit shown in Fig. P6.65. It resembles that in Fig. 6.30 but includes other features. First, note diodes $D_1$ and $D_2$ are included to make design (and analysis) easier and to provide temperature compensation for the emitter–base voltages of $Q_1$ and $Q_2$. Second, note resistor $R$, whose purpose is to provide negative feedback (more on this later in the book!). Using $|V_{BE}|$ and $V_D = 0.7$ V independent of current, and $\beta = \infty$, find the voltages $V_{B1}$, $V_{E1}$, $V_{C1}$, $V_{B2}$, $V_{E2}$, and $V_{C2}$, initially with $R$ open-circuited and then with $R$ connected. Repeat for $\beta = 100$, with $R$ open-circuited initially, then connected.

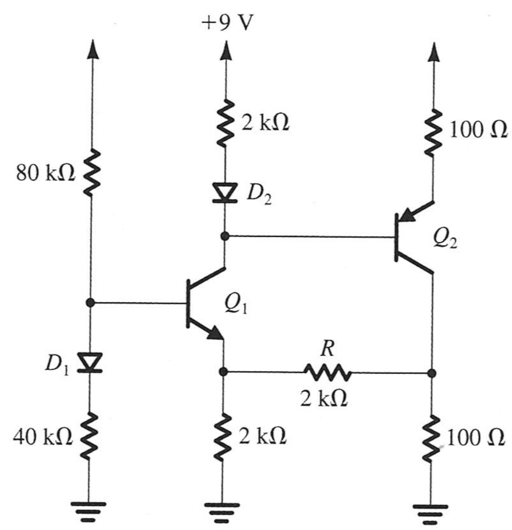



Figure P6.65

*6.66 For the circuit shown in Fig. P6.66, find the labeled node voltages for:

(a) $\beta = \infty$
(b) $\beta = 100$

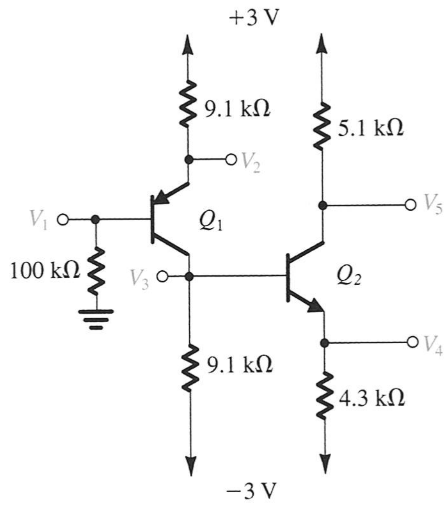



Figure P6.66

D *6.67 Using $\beta = \infty$, design the circuit shown in Fig. P6.67 so that the emitter currents of $Q_1$, $Q_2$, and $Q_3$ are 0.5 mA, 0.5 mA, and 1 mA, respectively, and $V_3 = 0$, $V_5 = -2$ V, and $V_7 = 1$ V. For each resistor, select the nearest standard value utilizing the table of standard values for 5% resistors in Appendix J. Now, for $\beta = 100$, find the values of $V_3$, $V_4$, $V_5$, $V_6$, and $V_7$.

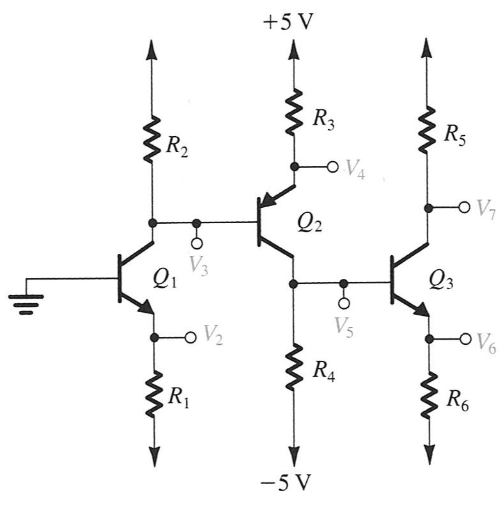



Figure P6.67

*6.68 For the circuit in Fig. P6.68, find $V_B$ and $V_E$ for $v_I$ = 0 V, +2 V, −2.5 V, and −5 V. The BJTs have $\beta = 50$.

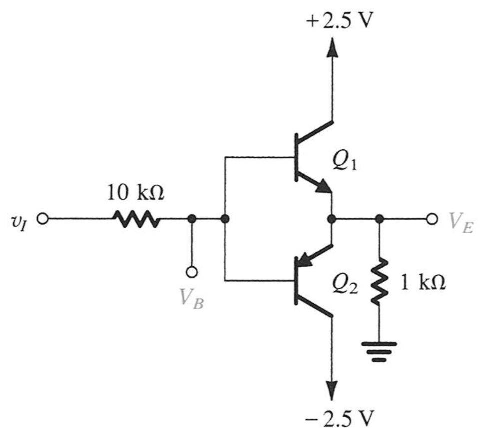



Figure P6.68

**6.69 All the transistors in the circuits of Fig. P6.69 are specified to have a minimum $\beta$ of 50. Find approximate values for the collector voltages and calculate forced $\beta$ for each of the transistors. (*Hint:* Initially, assume all transistors are operating in saturation, and verify the assumption.)

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