P:7, 17, 18, 20, 22, 23, 24, 25, 38

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	0.7	
4	−0.7	0	−0.6	
5	0.7	0.7	0	
6	−2.7	−2.0	0	
7	0	0	5.0	
8	−0.1	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. (Note that case 5 is a little tricky: To understand this situation, note that although the transistor is not symmetrical it can be operated with the roles of the emitter and collector interchanged in a so-called inverted mode.)

2- An *npn* transistor has an emitter area of 10 μm × 10 μm. The doping concentrations are: in the emitter $N_D = 10^{19}/\text{cm}^3$, in the base $N_A = 10^{17}/\text{cm}^3$, and in the collector $N_D = 10^{15}/\text{cm}^3$. The transistor is operating at $T = 300$ K, where $n_i = 1.5 \times 10^{10}/\text{cm}^3$. For electrons diffusing in the base: $L_n = 19\ \mu$m and $D_n = 21.3\ \text{cm}^2/\text{s}$. For holes diffusing in the emitter: $L_p = 0.6\ \mu$m and $D_p = 1.7\ \text{cm}^2/\text{s}$. Calculate I_S and β assuming that the base-width W is:
(a) 1 μm.
(b) 2 μm.
(c) 5 μm.

3- For case (b), if $I_C = 1$ mA, find I_B, I_E, V_{BE}, and the minority-carrier charge stored in the base. (*Hint:* $\tau_b = L_n^2/D_n$. Recall that the electron charge $q = 1.6 \times 10^{-19}$ Coulomb.)

4- Two transistors, fabricated with the same technology but having different junction areas, when operated at a base-emitter voltage of 0.69 V, have collector currents of 0.13 and 10.9 mA. Find I_S for each device. What are the relative junction areas?

5- In a particular BJT, the base current is 7.5 μA, and the collector current is 940 μA. Find β and α for this device.

6- For a particular *npn* transistor, properly biased, the collector current is measured to be 1 mA and 10 mA for base-to-emitter voltages of 0.63 V and 0.70 V, respectively. Find corresponding values of n and I_S for this transistor. If two such devices are connected in parallel and 0.65 V applied between the combined base and emitter in the conducting direction, what total collector current do you expect?

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

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

Find $\Delta\beta/\beta$ for $\beta = 100$ and α changes by 0.1%.

8- Consider the large-signal BJT models shown in Figs. 4.5(b) and (d). What are the relative sizes of the diodes D_E and D_B for transistors for which $\beta = 10$? $\beta = 1000$?

9- A particular BJT when conducting a collector current of 10 mA is known to have $v_{BE} = 0.70$ V and $i_B = 100\ \mu$A. Use these data to create specific transistor models of the form shown in Figs. 4.5(a) and (d).

10- Using the *npn* transistor model of Fig. 4.5(b), consider the case of a transistor for which the base is connected to ground, the collector is connected to a 10-V dc source through a 1-kΩ resistor, and a 5-mA current source is connected to the emitter with the polarity so that current is drawn out of the emitter terminal. If $\beta = 100$ and $I_S = 10^{-14}$ A, find the voltages at the emitter and the collector and calculate the base current.

11- The current I_{CBO} of a small transistor is measured to be 15 nA at 25°C. If the temperature of the device is raised to 75°C, what do you expect I_{CBO} to become?

12- Augment the model of the *npn* BJT shown in Fig. 4.5(c) by a current source representing I_{CBO}. In terms of this addition, what do the terminal currents i_B, i_C, and i_E become? If the base lead is open-circuited while the emitter is connected to ground, and the collector is connected to a positive supply, find the emitter and collector currents.

13- From Fig. 4.6 we note that the transistor is not a symmetrical device. Thus interchanging the collector and emitter terminals will result in a device with different values of α and β, called the inverse or reverse values and denoted α_R and β_R. An *npn* transistor is accidentally connected with collector and emitter leads interchanged. The resulting currents in the normal emitter and base leads are 5 mA and 1 mA, respectively. What are the values of α_R and β_R?

14- Sketch two additional models that parallel those given for the *npn* transistor in Fig. 4.5(b) and (d).

15- Consider the *pnp* large-signal model of Fig. 4.8(b) applied to a transistor having $I_S = 10^{-13}$ A and $\beta = 40$. If the emitter is connected to ground, the base is connected to a current source that pulls out of the base terminal a current of 10 μA, and the collector is connected to a negative supply of −10 V via a 10-kΩ resistor, find the base voltage, the collector voltage, and the emitter current.

16- A *pnp* transistor has $v_{EB} = 0.8$ V at a collector current of 1 A. What do you expect v_{EB} to become at $i_C = 10$ mA? at $i_C = 5$ A?

17- For the circuits in Fig. P4.19 assume that the transistors have very large β. Some measurements have been made on these circuits, the results are indicated in the figure. Find the values of the other labeled voltages and currents.

18- Measurements on the circuits of Fig. P4.20 produce labeled voltages as indicated. Find the value of β for each transistor.

19- For a BJT having an Early voltage of 200 V, what is its output resistance at 1 mA? at 100 μA?

20- For a BJT having an output resistance of 10 MΩ at 10 μA, what must its Early voltage be? If the current is raised to 10 mA, what does the output resistance become?

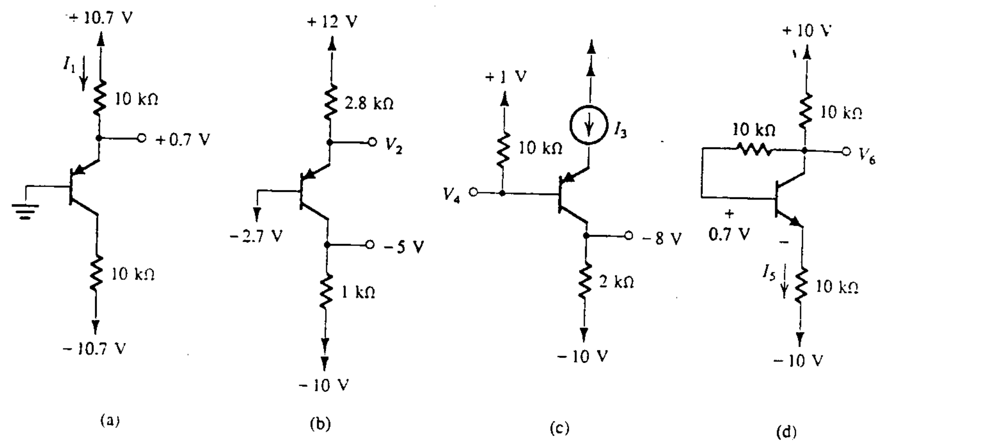


Fig. P4.19

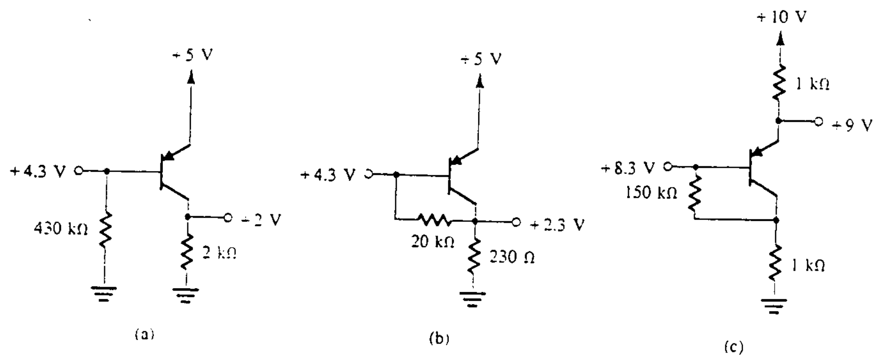


Fig. P4.20

21- For the conceptual circuit shown in Fig. 4.25, $R_C = 1\ k\Omega$, $g_m = 100$ mA/V, and $\beta = 50$. If a peak-to-peak output voltage of 1.5 V is measured at the collector, what ac input voltage and current must be associated with the base?

22- For a BJT operating at a base current of 7.6 μA and a β of 104, what values of r_π and g_m apply? What are the values of r_e and α that correspond?

23- For a *pnp* BJT operating at an emitter current of 0.80 mA with an α of 0.99, what values of r_e, r_π, and β correspond?

24- A *pnp* BJT is biased to operate at $I_C = 2.5$ mA. What is the associated value of g_m? If $\beta = 50$, what is the value of the small-signal resistance seen looking into the emitter (r_e)? Into the base (r_π)? If the collector is connected to a 10-kΩ load, with a signal of 10-mV peak applied between base and emitter, what output signal voltage results?

25- For the circuit in Fig. P4.97 select a value for R_B so that the transistor saturates with an overdrive factor of 10. The BJT is specified to have a minimum β of 30 and $V_{CEsat} = 0.2$ V. What is the value of forced β achieved?

26- For the circuit in Fig. P4.98 select a value for R_E so that the transistor saturates with a forced β of 5.

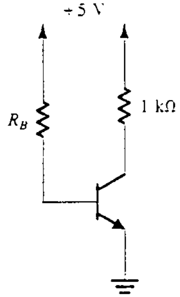


Fig. P4.97

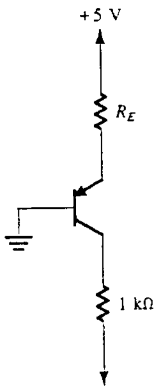


Fig. P4.98

27- A BJT operating at $i_B = 8\ \mu$A and $i_C = 1.2$ mA undergoes a reduction in base current of 0.8 μA. It is found that when v_{CE} is held constant the corresponding reduction in collector current is 0.1 mA. What are the values of h_{FE} and h_{fe} that apply? If the base current is increased from 8 μA to 10 μA and v_{CE} is increased from 8 to 10 V, what collector current results? (Assume $V_A = 100$ V and neglect the effect of r_μ.)

28- Measurement of h_{fe} of an *npn* transistor at 500 MHz shows that $|h_{fe}| = 2.5$ at $I_C = 0.2$ mA and 11.6 at $I_C = 1.0$ mA. Further, C_μ was measured and found to be 0.05 pF. Find f_T at each of the two collector currents used. What must τ_F and C_{je} be?

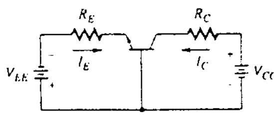
29- A particular BJT operating at $I_C = 1$ mA has $C_\mu = 1$ pF, $C_\pi = 10$ pF, and $\beta = 150$. What are ω_T and ω_β for this situation?

30- Complete the table entries below for transistors (a) through (g), under the conditions indicated. Neglect r_x.

Transistor	I_E (mA)	r_e (Ω)	g_m (mA/V)	r_π (kΩ)	β_0	f_T (MHz)	C_μ (pF)	C_π (pF)	f_β (MHz)
(a)	1				100	400	2		
(b)		25					2	10.7	4
(c)				2.525		400		13.8	4
(d)	10				100	400	2		
(e)	0.1				100	100	2		
(f)	1				10	400	2		
(g)						800	1	9	80

31- The transistor in Fig. 4.43 has the characteristics shown in Figs. 4.10 and 4.11. Let $V_{EE} = 2$ V, $V_{CC} = 12$ V, $R_E = 270\ \Omega$, and $R_C = 1200\ \Omega$.

(a) Find I_E and V_{BE}.
(b) Find I_C and V_{CB}.



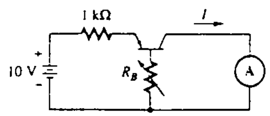
■ FIGURE 4.43

32- For the transistor in Fig. 4.43, $V_{BE} = 0.65$, $\alpha_F = 0.99$, and $I_{CBO} = 10$ nA. Let $V_{EE} = 5$ V, $V_{CC} = 10$ V, $R_E = 500\ \Omega$, and $R_C = 1\ k\Omega$.

(a) Find I_C and V_{CB}.
(b) Change R_C to 2 kΩ and repeat part (a).

33- The transistor in Fig. 4.44 is silicon: $V_{EB} = 0.7$ V, $\alpha_F = 0.99$, and $I_{CBO} = 10$ nA.

(a) Find R_B such that the ammeter current is 1 mA.
(b) Write an expression for I as a function of R_B.



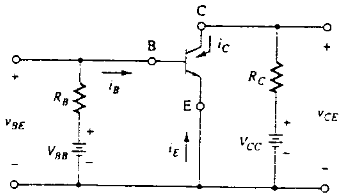
■ FIGURE 4.44

34- Sketch the collector characteristics (I_C versus V_{CE}) for an *npn* BJT having $\beta_F = 100$ and $I_{CEO} = 0.5$ mA. Let $i_B = 10, 20, 30$, and 40 μA. Ignore the Early effect.

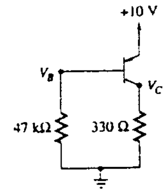
35- Write a SPICE program to plot the curves of Fig. 4.25. Let $\beta_R = \alpha_R/(1 - \alpha_R) = 0.11$
Hint: Set the base current to 1 mA and let SPICE step the collector current.

36- Design the circuit of Fig. 4.45 using an *npn* transistor having a $\beta_F = 100$ and a $V_{BE} = 0.7$ V. Let $V_{CC} = V_{BB} = 6$ V, and choose values of R_B and R_C such that $V_{CE} = 3$ V and $I_C = 10$ mA.

37- The *pnp* transistor of Fig. 4.46 has $\beta_F = 100$ and $V_{BE} = -0.65$ V. Find the quiescent I_B, I_C, and V_{CE}.



■ FIGURE 4.45

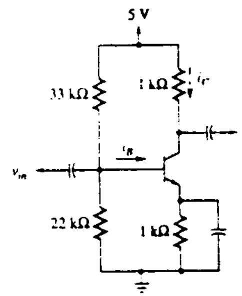


■ FIGURE 4.46

38- Is there any difference between the small-signal ac model for an *npn* transistor and that for a *pnp* transistor? Explain.

Consider the amplifier circuit of Fig. 4.50 for which $\beta_F = 75$ and $V_A = 200$ V. Assume that the capacitors are open circuits to dc, and short circuits to the ac frequency of interest.

(a) Draw a dc model and find the operating point.
(b) Find the small-signal ac model parameters, and draw an ac small-signal model for the circuit.
(c) Find the voltage amplification v_{out}/v_{in}.



■ FIGURE 4.50