Chapter 1 (Odd)

1. Copper has 20 orbiting electrons with only one electron in the outermost shell. The fact that the outermost shell with its 29th electron is incomplete (subshell can contain 2 electrons) and distant from the nucleus reveals that this electron is loosely bound to its parent atom. The application of an external electric field of the correct polarity can easily draw this loosely bound electron from its atomic structure for conduction.

   Both intrinsic silicon and germanium have complete outer shells due to the sharing (covalent bonding) of electrons between atoms. Electrons that are part of a complete shell structure require increased levels of applied attractive forces to be removed from their parent atom.

3. –

5. 48 eV = 48(1.6×10^{-19} J) = $\mathbf{76.8 \times 10^{-19}}$ **J**

   $$Q = \frac{W}{V} = \frac{76.8 \times 10^{-19}\ \text{J}}{12\ \text{V}} = \mathbf{6.40 \times 10^{-19}\ C}$$

   6.4×10^{-19} C is the charge associated with 4 electrons.

7. An *n*-type semiconductor material has an excess of electrons for conduction established by doping an intrinsic material with donor atoms having more valence electrons than needed to establish the covalent bonding. The majority carrier is the electron while the minority carrier is the hole.

   A *p*-type semiconductor material is formed by doping an intrinsic material with acceptor atoms having an insufficient number of electrons in the valence shell to complete the covalent bonding thereby creating a hole in the covalent structure. The majority carrier is the hole while the minority carrier is the electron.

9. Majority carriers are those carriers of a material that far exceed the number of any other carriers in the material.
   Minority carriers are those carriers of a material that are less in number than any other carrier of the material.

11. Same basic appearance as Fig. 1.9 since boron also has 3 valence electrons (trivalent).

13. –

15. $T_K = 20 + 273 = 293$
   $k = 11{,}600/n = 11{,}600/2$ (low value of V_D) = 5800

   $$I_D = I_s\left(e^{\frac{kV_D}{T_K}} - 1\right) = 50 \times 10^{-9}\left(e^{\frac{(5800)(0.6)}{293}} - 1\right)$$

   $$= 50 \times 10^{-9}\,(e^{11.877} - 1) = \mathbf{7.197\ mA}$$

17. (a) $T_K = 20 + 273 = 293$

$k = 11{,}600/n = 11{,}600/2 = 5800$

$$I_D = I_s\left(e^{\frac{kV_D}{T_K}} - 1\right) = 0.1\mu\text{A}\left(e^{\frac{(5800)(-10\text{ V})}{293}} - 1\right)$$

$$= 0.1 \times 10^{-6}(e^{-197.95} - 1) = 0.1 \times 10^{-6}(1.07 \times 10^{-86} - 1)$$

$$\cong 0.1 \times 10^{-6}\ 0.1\mu\text{A}$$

$I_D = I_s =$ **0.1 μA**

(b) The result is expected since the diode current under reverse-bias conditions should equal the saturation value.

19. $T = 20°\text{C}$: $I_s = 0.1\ \mu\text{A}$

$T = 30°\text{C}$: $I_s = 2(0.1\ \mu\text{A}) = 0.2\ \mu\text{A}$ (Doubles every 10°C rise in temperature)

$T = 40°\text{C}$: $I_s = 2(0.2\ \mu\text{A}) = 0.4\ \mu\text{A}$

$T = 50°\text{C}$: $I_s = 2(0.4\ \mu\text{A}) = 0.8\ \mu\text{A}$

$T = 60°\text{C}$: $I_s = 2(0.8\ \mu\text{A}) =$ **1.6 μA**

1.6 μA: 0.1 μA $\Rightarrow$ 16:1 increase due to rise in temperature of 40°C.

21. From 1.19:

	−75°C	25°C	100°C	200°C
V_F @ 10 mA	1.7 V	1.3 V	1.0 V	0.65 V
I_s	0.1 μA	0.5 μA	1 μA	2 μA

V_F decreased with increase in temperature

1.7 V: 0.65 V $\cong$ **2.6:1**

I_s increased with increase in temperature

2 μA: 0.1 μA = **20:1**

23. In the forward-bias region the 0 V drop across the diode at any level of current results in a resistance level of zero ohms – the “on” state – conduction is established. In the reverse-bias region the zero current level at any reverse-bias voltage assures a very high resistance level – the open circuit or “off” state – conduction is interrupted.

25. $V_D \cong 0.66\text{ V}$, $I_D = 2\text{ mA}$

$$R_{DC} = \frac{V_D}{I_D} = \frac{0.65\text{ V}}{2\text{ mA}} = \mathbf{325\ \Omega}$$

27. $V_D = -10\text{ V}$, $I_D = I_s =$ **−0.1 μA**

$$R_{DC} = \frac{V_D}{I_D} = \frac{10\text{ V}}{0.1\ \mu\text{A}} = \mathbf{100\ M\Omega}$$

$V_D = -30\text{ V}$, $I_D = I_s =$ **−0.1 μA**

$$R_{DC} = \frac{V_D}{I_D} = \frac{30\text{ V}}{0.1\mu\text{A}} = \mathbf{300\ M\Omega}$$

As the reverse voltage increases, the reverse resistance increases directly (since the diode leakage current remains constant).

29. $I_D = 10$ mA, $V_D = 0.76$ V

$$R_{DC} = \frac{V_D}{I_D} = \frac{0.76\text{ V}}{10\text{ mA}} = \mathbf{76\ \Omega}$$

$$r_d = \frac{\Delta V_d}{\Delta I_d} \cong \frac{0.79\text{ V} - 0.76\text{ V}}{15\text{ mA} - 5\text{ mA}} = \frac{0.03\text{ V}}{10\text{ mA}} = \mathbf{3\ \Omega}$$

$R_{DC} >> r_d$

31. $I_D = 1$ mA, $r_d = 2\left(\dfrac{26\text{ mV}}{I_D}\right) = 2(26\ \Omega) = \mathbf{52\ \Omega}$ vs 55 Ω (#30)

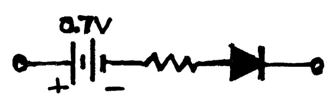
$I_D = 15$ mA, $r_d = \dfrac{26\text{ mV}}{I_D} = \dfrac{26\text{ mV}}{15\text{ mA}} = \mathbf{1.73\ \Omega}$ vs 2 Ω (#30)

33. $$r_d = \frac{\Delta V_d}{\Delta I_d} \cong \frac{0.8\text{ V} - 0.7\text{ V}}{7\text{ mA} - 3\text{ mA}} = \frac{0.09\text{ V}}{4\text{ mA}} = \mathbf{22.5\ \Omega}$$

(relatively close to average value of 24.4 Ω (#32))

35. Using the best approximation to the curve beyond $V_D = 0.7$ V:

$$r_{av} = \frac{\Delta V_d}{\Delta I_d} \cong \frac{0.8\text{ V} - 0.7\text{ V}}{25\text{ mA} - 0\text{ mA}} = \frac{0.1\text{ V}}{25\text{ mA}} = \mathbf{4\ \Omega}$$



37. From Fig. 1.33

$V_D = 0$ V, $C_D = \mathbf{3.3\ pF}$

$V_D = 0.25$ V, $C_D = \mathbf{9\ pF}$

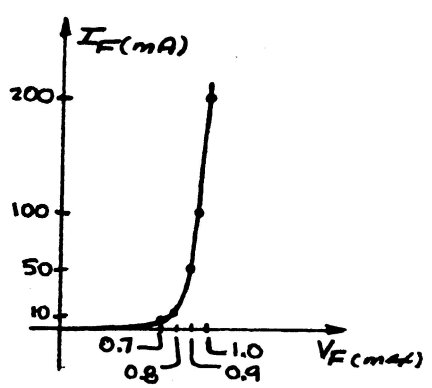
39. $V_D = 0.2$ V, $C_D = 7.3$ pF

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(6\text{ MHz})(7.3\text{ pF})} = \mathbf{3.64\ k\Omega}$$

$V_D = -20$ V, $C_T = 0.9$ pF

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(6\text{ MHz})(0.9\text{ pF})} = \mathbf{29.47\ k\Omega}$$

41.



43. At $V_D = -25$ V, $I_D = -0.2$ nA and at $V_D = -100$ V, $I_D \cong -0.45$ nA. Although the change in I_R is more than 100%, the level of I_R and the resulting change is relatively small for most applications.

45. $I_F = 0.1$ mA: $r_d \cong$ **700 Ω**
$I_F = 1.5$ mA: $r_d \cong$ **70 Ω**
$I_F = 20$ mA: $r_d \cong$ **6 Ω**

The results support the fact that the dynamic or ac resistance decreases rapidly with increasing current levels.

47. Using the bottom right graph of Fig. 1.37:
$I_F = 500$ mA @ $T = 25$°C
At $I_F = 250$ mA, $T \cong$ **104°C**

49. $T_C = +0.072\% = \dfrac{\Delta V_Z}{V_Z(T_1 - T_0)} \times 100\%$

$$0.072 = \frac{0.75\text{ V}}{10\text{ V}(T_1 - 25)} \times 100$$

$$0.072 = \frac{7.5}{T_1 - 25}$$

$$T_1 - 25° = \frac{7.5}{0.072} = 104.17°$$

$T_1 = 104.17° + 25° =$ **129.17°**

51. $\dfrac{(20\text{ V} - 6.8\text{ V})}{(24\text{ V} - 6.8\text{ V})} \times 100\% = 77\%$

The 20 V Zener is therefore ≅ 77% of the distance between 6.8 V and 24 V measured from the 6.8 V characteristic.

At $I_Z = 0.1$ mA, $T_C \cong 0.06\%/°$C

$\dfrac{(5\text{ V} - 3.6\text{ V})}{(6.8\text{ V} - 3.6\text{ V})} \times 100\% = 44\%$

The 5 V Zener is therefore ≅ 44% of the distance between 3.6 V and 6.8 V measured from the 3.6 V characteristic.
At $I_Z = 0.1$ mA, $T_C \cong$ **–0.025%/°C**

53. 24 V Zener:
0.2 mA: ≅ **400 Ω**
1 mA: ≅ **95 Ω**
10 mA: ≅ **13 Ω**
The steeper the curve (higher dI/dV) the less the dynamic resistance.

55. Fig. 1.53 (f) $I_F \cong$ **13 mA**
Fig. 1.53 (e) $V_F \cong$ **2.3 V**

57. (a) $\dfrac{0.75}{3.0} = 0.25$

From Fig. 1.53 (i) $\measuredangle \cong$ **75°**

(b) $0.5 \Rightarrow \measuredangle =$ **40 °**

Chapter 1 (Even)

2. Intrinsic material: an intrinsic semiconductor is one that has been refined to be as pure as physically possible. That is, one with the fewest possible number of impurities.

   Negative temperature coefficient: materials with negative temperature coefficients have decreasing resistance levels as the temperature increases.

   Covalent bonding: covalent bonding is the sharing of electrons between neighboring atoms to form complete outermost shells and a more stable lattice structure.

4. $W = QV = (6\text{ C})(3\text{ V}) = \mathbf{18\ J}$

6.

GaP	Gallium Phosphide	$E_g =$ **2.24 eV**
ZnS	Zinc Sulfide	$E_g =$ **3.67 eV**

8. A donor atom has five electrons in its outermost valence shell while an acceptor atom has only 3 electrons in the valence shell.

10. Same basic appearance as Fig. 1.7 since arsenic also has 5 valence electrons (pentavalent).

12. –

14. For forward bias, the positive potential is applied to the *p*-type material and the negative potential to the *n*-type material.

16. $k = 11{,}600/n = 11{,}600/2 = 5800$ ($n = 2$ for $V_D = 0.6$ V)
    $T_K = T_C + 273 = 100 + 273 = 373$

$$e^{kV/T_K} = e^{\frac{(5800)(0.6\text{ V})}{373}} = e^{9.33} = 11.27 \times 10^3$$

$$I = I_s(e^{kV/T_K} - 1) = 5\ \mu\text{A}(11.27 \times 10^3 - 1) = \mathbf{56.35\ mA}$$

18. (a)

x	$y = e^x$
0	1
1	2.7182
2	7.389
3	20.086
4	54.6
5	148.4

(b) $y = e^0 = 1$

(c) For $V = 0$ V, $e^0 = 1$ and $I = I_s(1 - 1) =$ **0 mA**

20. For most applications the silicon diode is the device of choice due to its higher temperature capability. Ge typically has a working limit of about 85 degrees centigrade while Si can be used at temperatures approaching 200 degrees centigrade. Silicon diodes also have a higher current handling capability. Germanium diodes are the better device for some RF small signal applications, where the smaller threshold voltage may prove advantageous.

22. An "ideal" device or system is one that has the characteristics we would prefer to have when using a device or system in a practical application. Usually, however, technology only permits a close replica of the desired characteristics. The "ideal" characteristics provide an excellent basis for comparison with the actual device characteristics permitting an estimate of how well the device or system will perform. On occasion, the "ideal" device or system can be assumed to obtain a good estimate of the overall response of the design. When assuming an "ideal" device or system there is no regard for component or manufacturing tolerances or any variation from device to device of a particular lot.

24. The most important difference between the characteristics of a diode and a simple switch is that the switch, being mechanical, is capable of conducting current in either direction while the diode only allows charge to flow through the element in one direction (specifically the direction defined by the arrow of the symbol using conventional current flow).

26. At $I_D = 15$ mA, $V_D = 0.82$ V

$$R_{DC} = \frac{V_D}{I_D} = \frac{0.82\text{ V}}{15\text{ mA}} = \mathbf{54.67\ \Omega}$$

As the forward diode current increases, the static resistance decreases.

28. (a) $$r_d = \frac{\Delta V_d}{\Delta I_d} = \frac{0.79\text{ V} - 0.76\text{ V}}{15\text{ mA} - 5\text{ mA}} = \frac{0.03\text{ V}}{10\text{ mA}} = \mathbf{3\ \Omega}$$

(b) $$r_d = \frac{26\text{ mV}}{I_D} = \frac{26\text{ mV}}{10\text{ mA}} = \mathbf{2.6\ \Omega}$$

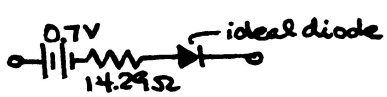
(c) quite close

30. $$I_D = 1\text{ mA},\ r_d = \frac{\Delta V_d}{\Delta I_d} = \frac{0.72\text{ V} - 0.61\text{ V}}{2\text{ mA} - 0\text{ mA}} = \mathbf{55\ \Omega}$$

$$I_D = 15\text{ mA},\ r_d = \frac{\Delta V_d}{\Delta I_d} = \frac{0.8\text{ V} - 0.78\text{ V}}{20\text{ mA} - 10\text{ mA}} = \mathbf{2\ \Omega}$$

32. $$r_{av} = \frac{\Delta V_d}{\Delta I_d} = \frac{0.9\text{ V} - 0.6\text{ V}}{13.5\text{ mA} - 1.2\text{ mA}} = \mathbf{24.4\ \Omega}$$

34. $$r_{av} = \frac{\Delta V_d}{\Delta I_d} = \frac{0.9\text{ V} - 0.7\text{ V}}{14\text{ mA} - 0\text{ mA}} = \frac{0.2\text{ V}}{14\text{ mA}} = \mathbf{14.29\ \Omega}$$



36. (a) $V_R = -25\text{ V}$: $C_T \cong$ **0.75 pF**
$V_R = -10\text{ V}$: $C_T \cong$ **1.25 pF**

$$\left|\frac{\Delta C_T}{\Delta V_R}\right| = \left|\frac{1.25\text{ pF} - 0.75\text{ pF}}{10\text{ V} - 25\text{ V}}\right| = \frac{0.5\text{ pF}}{15\text{ V}} = \mathbf{0.033\ pF/V}$$

(b) $V_R = -10\text{ V}$: $C_T \cong$ **1.25 pF**
$V_R = -1\text{ V}$: $C_T \cong$ **3 pF**

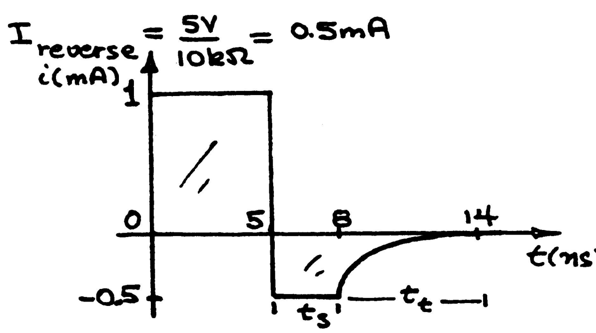
$$\left|\frac{\Delta C_T}{\Delta V_R}\right| = \left|\frac{1.25\text{ pF} - 3\text{ pF}}{10\text{ V} - 1\text{ V}}\right| = \frac{1.75\text{ pF}}{9\text{ V}} = \mathbf{0.194\ pF/V}$$

(c) 0.194 pF/V: 0.033 pF/V = 5.88:1 $\cong$ **6:1**
Increased sensitivity near $V_D = 0$ V

38. The transition capacitance is due to the depletion region acting like a dielectric in the reverse-bias region, while the diffusion capacitance is determined by the rate of charge injection into the region just outside the depletion boundaries of a forward-biased device. Both capacitances are present in both the reverse- and forward-bias directions, but the transition capacitance is the dominant effect for reverse-biased diodes and the diffusion capacitance is the dominant effect for forward-biased conditions.

40. $I_f = \dfrac{10\text{ V}}{10\text{ k}\Omega} = 1\text{ mA}$

$t_s + t_t = t_{rr} = 9$ ns
$t_s + 2t_s = 9$ ns
$t_s =$ **3 ns**
$t_t = 2t_s =$ **6 ns**



42. As the magnitude of the reverse-bias potential increases, the capacitance drops rapidly from a level of about 5 pF with no bias. For reverse-bias potentials in excess of 10 V the capacitance levels off at about 1.5 pF.

44. Log scale: $T_A = 25°\text{C}$, $I_R =$ **0.5 nA**
$T_A = 100°\text{C}$, $I_R =$ **60 nA**

The change is significant.
60 nA: 0.5 nA = **120:1**

Yes, at 95°C I_R would increase to 64 nA starting with 0.5 nA (at 25°C) (and double the level every 10°C).

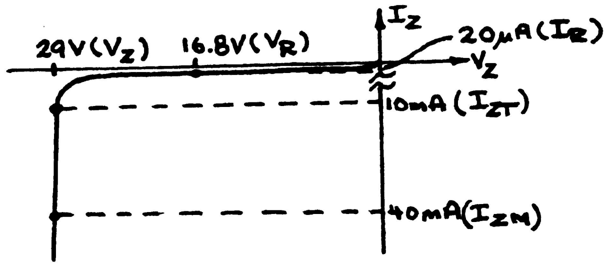
46. $T = 25°C$: $P_{max} = 500$ mW
$T = 100°C$: $P_{max} = 260$ mW
$P_{max} = V_F I_F$

$$I_F = \frac{P_{max}}{V_F} = \frac{500 \text{ mW}}{0.7 \text{ V}} = \mathbf{714.29 \text{ mA}}$$

$$I_F = \frac{P_{max}}{V_F} = \frac{260 \text{ mW}}{0.7 \text{ V}} = \mathbf{371.43 \text{ mA}}$$

714.29 mA: 371.43 mA = 1.92:1 ≅ **2:1**

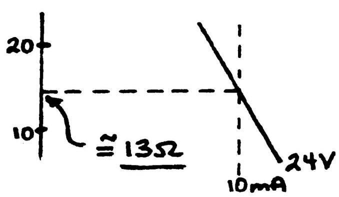
48.



50. $$T_C = \frac{\Delta V_Z}{V_Z(T_1 - T_0)} \times 100\%$$

$$= \frac{(5 \text{ V} - 4.8 \text{ V})}{5 \text{ V}(100° - 25°)} \times 100\% = \mathbf{0.053\%/°C}$$

52.



54. $V_T \cong 2.0$ V, which is considerably higher than germanium (≅ 0.3 V) or silicon (≅ 0.7 V). For germanium it is a 6.7:1 ratio, and for silicon a 2.86:1 ratio.

56. (a) Relative efficiency @ 5 mA ≅ **0.82**
@ 10 mA ≅ **1.02**

$$\frac{1.02 - 0.82}{0.82} \times 100\% = \mathbf{24.4\%} \text{ increase}$$

ratio: $\frac{1.02}{0.82} = 1.24$

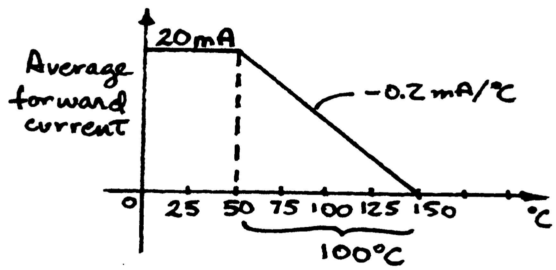
(b) Relative efficiency @ 30 mA ≅ **1.38**
@ 35 mA ≅ **1.42**

$$\frac{1.42 - 1.38}{1.38} \times 100\% = \mathbf{2.9\%} \text{ increase}$$

ratio: $\frac{1.42}{1.38} = \mathbf{1.03}$

(c) For currents greater than about 30 mA the percent increase is significantly less than for increasing currents of lesser magnitude.

58. For the high-efficiency red unit of Fig. 1.53:



$$\frac{0.2\text{ mA}}{°\text{C}} = \frac{20\text{ mA}}{x}$$

$$x = \frac{20\text{ mA}}{0.2\text{ mA}/°\text{C}} = 100°\text{C}$$

Chapter 2 (Odd)

1. The load line will intersect at $I_D = \dfrac{E}{R} = \dfrac{8\text{ V}}{330\ \Omega} = 24.24$ mA and $V_D = 8$ V.

   (a) $V_{D_Q} \cong \mathbf{0.92\ V}$
   $I_{D_Q} \cong \mathbf{21.5\ mA}$
   $V_R = E - V_{D_Q} = 8\text{ V} - 0.92\text{ V} = \mathbf{7.08\ V}$

   (b) $V_{D_Q} \cong \mathbf{0.7\ V}$
   $I_{D_Q} \cong \mathbf{22.2\ mA}$
   $V_R = E - V_{D_Q} = 8\text{ V} - 0.7\text{ V} = \mathbf{7.3\ V}$

   (c) $V_{D_Q} \cong \mathbf{0\ V}$
   $I_{D_Q} \cong \mathbf{24.24\ mA}$
   $V_R = E - V_{D_Q} = 8\text{ V} - 0\text{ V} = \mathbf{8\ V}$

   For (a) and (b), levels of V_{D_Q} and I_{D_Q} are quite close. Levels of part (c) are reasonably close but as expected due to level of applied voltage E.

3. Load line through $I_{D_Q} = 10$ mA of characteristics and $V_D = 7$ V will intersect I_D axis as 11.25 mA.
   $I_D = 11.25\text{ mA} = \dfrac{E}{R} = \dfrac{7\text{ V}}{R}$
   with $R = \dfrac{7\text{ V}}{11.25\text{ mA}} = \mathbf{0.62\ k\Omega}$

5. (a) $I = \mathbf{0\ mA}$; diode reverse-biased.

   (b) $V_{20\Omega} = 20\text{ V} - 0.7\text{ V} = 19.3$ V (Kirchhoff's voltage law)
   $I = \dfrac{19.3\text{ V}}{20\ \Omega} = \mathbf{0.965\ A}$

   (c) $I = \dfrac{10\text{ V}}{10\ \Omega} = \mathbf{1\ A}$; center branch open

7. (a) $V_o = \dfrac{2\text{ k}\Omega(20\text{ V} - 0.7\text{ V} - 0.3\text{ V})}{2\text{ k}\Omega + 2\text{ k}\Omega}$
   $= \dfrac{1}{2}(20\text{ V} - 1\text{ V}) = \dfrac{1}{2}(19\text{ V}) = \mathbf{9.5\ V}$

   (b) $I = \dfrac{10\text{ V} + 2\text{ V} - 0.7\text{ V})}{1.2\text{ k}\Omega + 4.7\text{ k}\Omega} = \dfrac{11.3\text{ V}}{5.9\text{ k}\Omega} = 1.915$ mA
   $V' = IR = (1.915\text{ mA})(4.7\text{ k}\Omega) = 9$ V
   $V_o = V' - 2\text{ V} = 9\text{ V} - 2\text{ V} = \mathbf{7\ V}$

9. (a) $V_{o_1} = 12\text{ V} - 0.7\text{ V} = \mathbf{11.3\ V}$

$V_{o_2} = \mathbf{0.3\ V}$

(b) $V_{o_1} = -10\text{ V} + 0.3\text{ V} + 0.7\text{ V} = \mathbf{-9\ V}$

$$I = \frac{10\text{ V} - 0.7\text{ V} - 0.3\text{ V}}{1.2\text{ k}\Omega + 3.3\text{ k}\Omega} = \frac{9\text{ V}}{4.5\text{ k}\Omega} = 2\text{ mA},\ V_{o_2} = -(2\text{ mA})(3.3\text{ k}\Omega) = \mathbf{-6.6\ V}$$

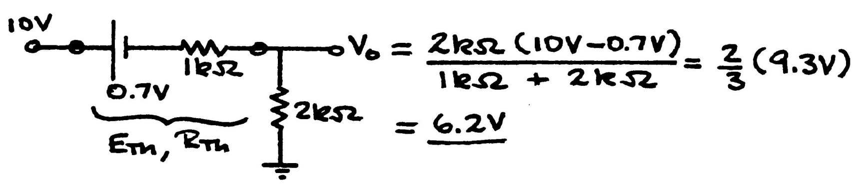
11. (a) Ge diode “on” preventing Si diode from turning “on”:

$$I = \frac{10\text{ V} - 0.3\text{ V}}{1\text{ k}\Omega} = \frac{9.7\text{ V}}{1\text{ k}\Omega} = \mathbf{9.7\ mA}$$

(b) $$I = \frac{16\text{ V} - 0.7\text{ V} - 0.7\text{ V} - 12\text{ V}}{4.7\text{ k}\Omega} = \frac{2.6\text{ V}}{4.7\text{ k}\Omega} = \mathbf{0.553\ mA}$$

$V_o = 12\text{ V} + (0.553\text{ mA})(4.7\text{ k}\Omega) = \mathbf{14.6\ V}$

13. For the parallel Si – 2 kΩ branches a Thevenin equivalent will result (for “on” diodes) in a single series branch of 0.7 V and 1 kΩ resistor as shown below:



$$I_{2\text{ k}\Omega} = \frac{6.2\text{ V}}{2\text{ k}\Omega} = 3.1\text{ mA}$$

$$I_D = \frac{I_{2\text{ k}\Omega}}{2} = \frac{3.1\text{ mA}}{2} = \mathbf{1.55\ mA}$$

15. Both diodes “on”, $V_o = 10\text{ V} - 0.7\text{ V} = \mathbf{9.3\ V}$

17. Both diodes “off”, $V_o = \mathbf{10\ V}$

19. 0 V at one terminal is “more positive” than –5 V at the other input terminal. Therefore assume lower diode “on” and upper diode “off”.
The result:

$V_o = 0\text{ V} - 0.7\text{ V} = \mathbf{-0.7\ V}$

The result supports the above assumptions.

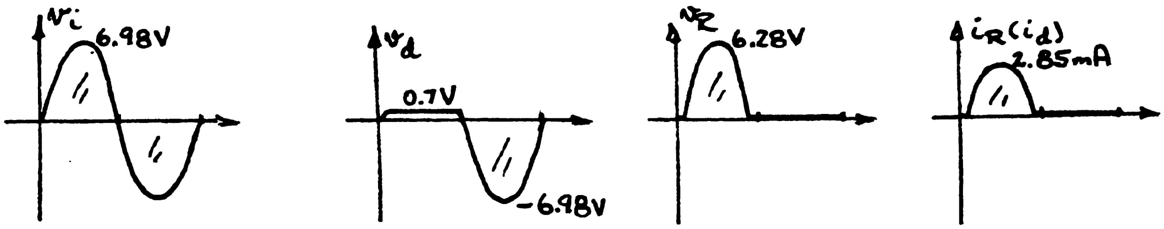
21. The Si diode requires more terminal voltage than the Ge diode to turn “on”. Therefore, with 5 V at both input terminals, assume Si diode “off” and Ge diode “on”.

The result: $V_o = 5\text{ V} - 0.3\text{ V} = \mathbf{4.7\ V}$
The result supports the above assumptions.

23. Using $V_{dc} \cong 0.318(V_m - V_T)$

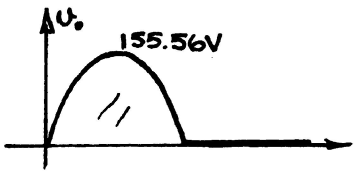
$2\text{ V} = 0.318(V_m - 0.7\text{ V})$

Solving: V_m = **6.98 V** $\cong$ 10:1 for $V_m : V_T$



25. $V_m = \sqrt{2}\,(110\text{ V}) = 155.56\text{ V}$

$V_{dc} = 0.318V_m = 0.318(155.56\text{ V}) =$ **49.47 V**



27. (a) $P_{max} = 14\text{ mW} = (0.7\text{ V})I_D$

$$I_D = \frac{14\text{ mW}}{0.7\text{ V}} = \mathbf{20\text{ mA}}$$

(b) $4.7\text{ k}\Omega \parallel 56\text{ k}\Omega = 4.34\text{ k}\Omega$

$V_R = 160\text{ V} - 0.7\text{ V} = 159.3\text{ V}$

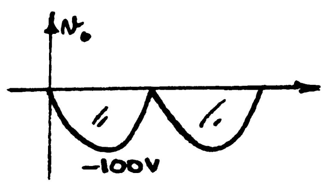
$$I_{max} = \frac{159.3\text{ V}}{4.34\text{ k}\Omega} = \mathbf{36.71\text{ mA}}$$

(c) $$I_{diode} = \frac{I_{max}}{2} = \frac{36.71\text{ mA}}{2} = \mathbf{18.36\text{ mA}}$$

(d) Yes, $I_D = 20\text{ mA} > 18.36\text{ mA}$

(e) $I_{diode} = 36.71\text{ mA} \gg I_{max} = 20\text{ mA}$

29.



PIV = 100V

31. Positive pulse of v_i:

Top left diode "off", bottom left diode "on"

$2.2\text{ k}\Omega \parallel 2.2\text{ k}\Omega = 1.1\text{ k}\Omega$

$$V_{o_{peak}} = \frac{1.1\text{ k}\Omega(170\text{ V})}{1.1\text{ k}\Omega + 2.2\text{ k}\Omega} = 56.67\text{ V}$$

Negative pulse of v_i:

Top left diode "on", bottom left diode "off"

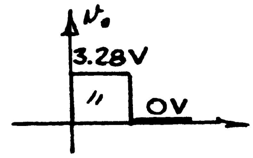
$$V_{o_{\text{peak}}} = \frac{1.1\text{ k}\Omega(170\text{ V})}{1.1\text{ k}\Omega + 2.2\text{ k}\Omega} = 56.67\text{ V}$$

$V_{dc} = 0.636(56.67\text{ V}) = \mathbf{36.04\text{ V}}$

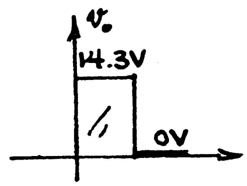
33. (a) Positive pulse of v_i:

$$V_o = \frac{1.2\text{ k}\Omega(10\text{ V} - 0.7\text{ V})}{1.2\text{ k}\Omega + 2.2\text{ k}\Omega} = \mathbf{3.28\text{ V}}$$

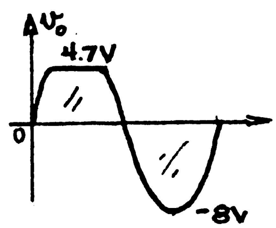
Negative pulse of v_i:
diode "open", $v_o = \mathbf{0\text{ V}}$



(b) Positive pulse of v_i:
$V_o = 10\text{ V} - 0.7\text{ V} + 5\text{ V} = \mathbf{14.3\text{ V}}$
Negative pulse of v_i:
diode "open", $v_o = \mathbf{0\text{ V}}$



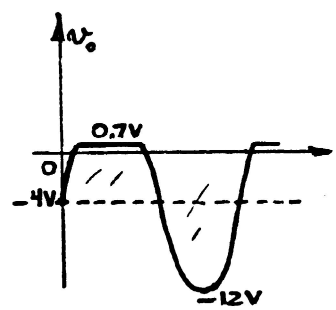
35. (a) Diode "on" for $v_i \geq 4.7$ V
For $v_i > 4.7$ V, $V_o = 4\text{ V} + 0.7\text{ V} = \mathbf{4.7\text{ V}}$
For $v_i < 4.7$ V, diode "off" and $v_o = \boldsymbol{v_i}$



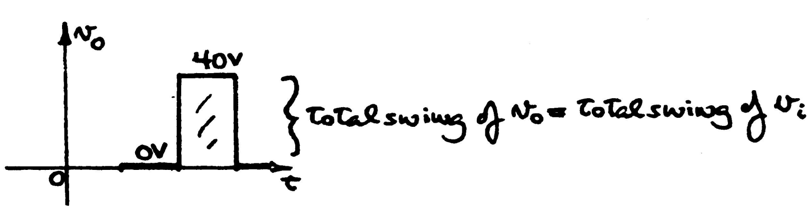
(b) Again, diode "on" for $v_i \geq 4.7$ V but v_o now defined as the voltage across the diode
For $v_i \geq 4.7$ V, $v_o = \mathbf{0.7\text{ V}}$

For $v_i < 4.7$ V, diode "off", $I_D = I_R = 0$ mA and $V_{2.2\text{ k}\Omega} = IR = (0\text{ mA})R = 0$ V

Therefore, $v_o = v_i - 4$ V
At $v_i = 0$ V, $v_o = \mathbf{-4\text{ V}}$
$v_i = -8$ V, $v_o = -8\text{ V} - 4\text{ V} = \mathbf{-12\text{ V}}$

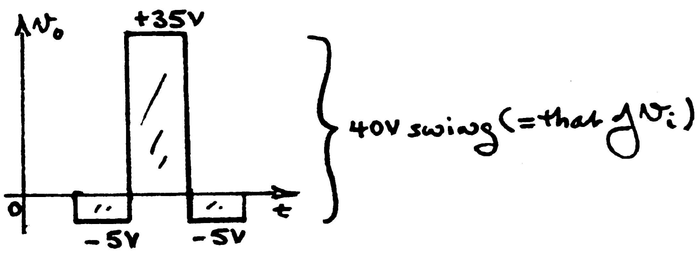


37. (a) Starting with $v_i = -20$ V, the diode is in the "on" state and the capacitor quickly charges to –20 V+. During this interval of time v_o is across the "on" diode (short-current equivalent) and $v_o = 0$ V.
When v_i switches to the +20 V level the diode enters the "off" state (open-circuit equivalent) and $v_o = v_i + v_C = 20\text{ V} + 20\text{ V} = +40$ V



(b) Starting with $v_i = -20$ V, the diode is in the "on" state and the capacitor quickly charges up to -15 V+. Note that $v_i = +20$ V and the 5 V supply are additive across the capacitor. During this time interval v_o is across "on" diode and 5 V supply and $v_o = -5$ V.

When v_i switches to the +20 V level the diode enters the "off" state and $v_o = v_i + v_C =$ 20 V + 15 V = 35 V.

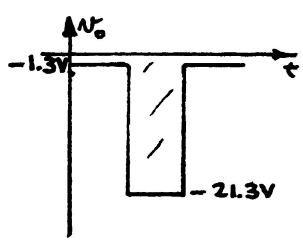


39. (a) $\tau = RC = (56\ \text{k}\Omega)(0.1\ \mu\text{F}) = 5.6$ ms
5τ = **28 ms**

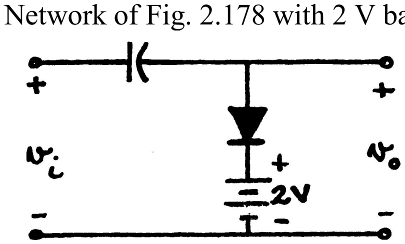
(b) $5\tau = 28\ \text{ms} \gg \dfrac{T}{2} = \dfrac{1\ \text{ms}}{2} =$ **0.5 ms**, 56:1

(c) Positive pulse of v_i:
Diode "on" and $v_o = -2\text{ V} + 0.7\text{ V} = -1.3$ V
Capacitor charges to 10 V + 2 V – 0.7 V = 11.3 V

Negative pulse of v_i:
Diode "off" and $v_o = -10\text{ V} - 11.3\text{ V} = -21.3$ V



41. Network of Fig. 2.178 with 2 V battery reversed.



43. (a) $V_Z = 12$ V, $R_L = \dfrac{V_L}{I_L} = \dfrac{12\text{ V}}{200\text{ mA}} = \mathbf{60\ \Omega}$

$$V_L = V_Z = 12\text{ V} = \frac{R_L V_i}{R_L + R_S} = \frac{60\ \Omega(16\text{ V})}{60\ \Omega + R_s}$$

$$720 + 12R_s = 960$$
$$12R_s = 240$$
$$R_s = \mathbf{20\ \Omega}$$

(b) $P_{Z_{\max}} = V_Z I_{Z_{\max}}$
$= (12\text{ V})(200\text{ mA})$
$= \mathbf{2.4\ W}$

45. At 30 V we have to be sure Zener diode is "on".

$$\therefore\ V_L = 20\text{ V} = \frac{R_L V_i}{R_L + R_s} = \frac{1\text{ k}\Omega(30\text{ V})}{1\text{ k}\Omega + R_s}$$

Solving, $R_s = \mathbf{0.5\ k\Omega}$

At 50 V, $I_{R_S} = \dfrac{50\text{ V} - 20\text{ V}}{0.5\text{ k}\Omega} = 60$ mA, $I_L = \dfrac{20\text{ V}}{1\text{ k}\Omega} = 20$ mA

$I_{ZM} = I_{R_S} - I_L = 60\text{ mA} - 20\text{ mA} = \mathbf{40\ mA}$

47. $V_m = 1.414(120\text{ V}) = 169.68$ V

$2V_m = 2(169.68\text{ V}) = \mathbf{339.36\ V}$

Chapter 2 (Even)

2. (a) $I_D = \dfrac{E}{R} = \dfrac{5\text{ V}}{2.2\text{ k}\Omega} = 2.27\text{ mA}$

The load line extends from $I_D = 2.27$ mA to $V_D = 5$ V.

$V_{D_Q} \cong$ **0.7 V**, $I_{D_Q} \cong$ **2 mA**

(b) $I_D = \dfrac{E}{R} = \dfrac{5\text{ V}}{0.47\text{ k}\Omega} = 10.64\text{ mA}$

The load line extends from $I_D = 10.64$ mA to $V_D = 5$ V.

$V_{D_Q} \cong$ **0.8 V**, $I_{D_Q} \cong$ **9 mA**

(c) $I_D = \dfrac{E}{R} = \dfrac{5\text{ V}}{0.18\text{ k}\Omega} = 27.78\text{ mA}$

The load line extends from $I_D = 27.78$ mA to $V_D = 5$ V.

$V_{D_Q} \cong$ **0.93 V**, $I_{D_Q} \cong$ **22.5 mA**

The resulting values of V_{D_Q} are quite close, while I_{D_Q} extends from 2 mA to 22.5 mA.

4. (a) $I_D = I_R = \dfrac{E - V_D}{R} = \dfrac{30\text{ V} - 0.7\text{ V}}{2.2\text{ k}\Omega} = \mathbf{13.32\text{ mA}}$

$V_D =$ **0.7 V**, $V_R = E - V_D = 30\text{ V} - 0.7\text{ V} =$ **29.3 V**

(b) $I_D = \dfrac{E - V_D}{R} = \dfrac{30\text{ V} - 0\text{ V}}{2.2\text{ k}\Omega} = \mathbf{13.64\text{ mA}}$

$V_D =$ **0 V**, $V_R =$ **30 V**

Yes, since $E \gg V_T$ the levels of I_D and V_R are quite close.

6. (a) Diode forward-biased,

Kirchhoff's voltage law (CW): $-5\text{ V} + 0.7\text{ V} - V_o = 0$

$V_o = \mathbf{-4.3\text{ V}}$

$I_R = I_D = \dfrac{|V_o|}{R} = \dfrac{4.3\text{ V}}{2.2\text{ k}\Omega} = \mathbf{1.955\text{ mA}}$

(b) Diode forward-biased,

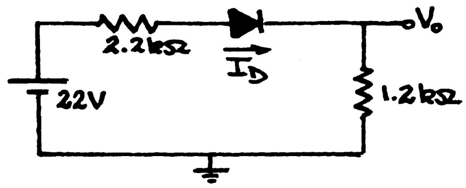
$I_D = \dfrac{8\text{ V} - 0.7\text{ V}}{1.2\text{ k}\Omega + 4.7\text{ k}\Omega} = \mathbf{1.24\text{ mA}}$

$V_o = V_{4.7\text{ k}\Omega} + V_D = (1.24\text{ mA})(4.7\text{ k}\Omega) + 0.7\text{ V}$

$= \mathbf{6.53\text{ V}}$

8. (a) Determine the Thevenin equivalent circuit for the 10 mA source and 2.2 kΩ resistor.

$E_{Th} = IR = (10 \text{ mA})(2.2 \text{ k}\Omega) = 22 \text{ V}$
$R_{Th} = 2.\ 2\text{k}\Omega$



Diode forward-biased

$$I_D = \frac{22 \text{ V} - 0.7 \text{ V}}{2.2 \text{ k}\Omega + 1.2 \text{ k}\Omega} = \mathbf{6.26 \text{ mA}}$$

$$\begin{aligned} V_o &= I_D(1.2 \text{ k}\Omega) \\ &= (6.26 \text{ mA})(1.2 \text{ k}\Omega) \\ &= \mathbf{7.51 \text{ V}} \end{aligned}$$

(b) Diode forward-biased

$$I_D = \frac{20 \text{ V} + 5 \text{ V} \ - 0.7 \text{ V}}{6.8 \text{ k}\Omega} = \mathbf{2.65 \text{ mA}}$$

Kirchhoff's voltage law (CW):
$+V_o - 0.7 \text{ V} + 5 \text{ V} = 0$
$V_o = \mathbf{-4.3 \text{ V}}$

10. (a) Both diodes forward-biased

$$I_R = \frac{20 \text{ V} - 0.7 \text{ V}}{4.7 \text{ k}\Omega} = 4.106 \text{ mA}$$

Assuming identical diodes:

$$I_D = \frac{I_R}{2} = \frac{4.106 \text{ mA}}{2} = \mathbf{2.05 \text{ mA}}$$

$V_o = 20 \text{ V} - 0.7 \text{ V} = \mathbf{19.3 \text{ V}}$

(b) Right diode forward-biased:

$$I_D = \frac{15 \text{ V} + 5 \text{ V} - 0.7 \text{ V}}{2.2 \text{ k}\Omega} = \mathbf{8.77 \text{ mA}}$$

$V_o = 15 \text{ V} - 0.7 \text{ V} = \mathbf{14.3 \text{ V}}$

12. Both diodes forward-biased:
$V_{o_1} = \mathbf{0.7 \text{ V}},\ V_{o_2} = \mathbf{0.3 \text{ V}}$

$$I_{1 \text{ k}\Omega} = \frac{20 \text{ V} - \ 0.7 \text{ V}}{1 \text{ k}\Omega} = \frac{19.3 \text{ V}}{1 \text{ k}\Omega} = 19.3 \text{ mA}$$

$$I_{0.47 \text{ k}\Omega} = \frac{0.7 \text{ V} - 0.3 \text{ V}}{0.47 \text{ k}\Omega} = 0.851 \text{ mA}$$

$$\begin{aligned} I(\text{Si diode}) &= I_{1 \text{ k}\Omega} - I_{0.47 \text{ k}\Omega} \\ &= 19.3 \text{ mA} - 0.851 \text{ mA} \\ &= \mathbf{18.45 \text{ mA}} \end{aligned}$$

14. Both diodes "off". The threshold voltage of 0.7 V is unavailable for either diode.
$V_o = \mathbf{0 \text{ V}}$

16. Both diodes "on".
$V_o = \mathbf{0.7 \text{ V}}$

18. The Si diode with –5 V at the cathode is "on" while the other is "off". The result is

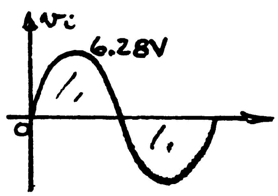
$$V_o = -5\text{ V} + 0.7\text{ V} = \mathbf{-4.3\text{ V}}$$

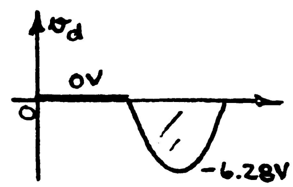
20. Since all the system terminals are at 10 V the required difference of 0.7 V across either diode cannot be established. Therefore, both diodes are "off" and

$$V_o = \mathbf{+10\text{ V}}$$

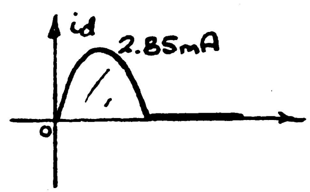
as established by 10 V supply connected to 1 kΩ resistor.

22. $V_{\text{dc}} = 0.318\ V_m \Rightarrow V_m = \dfrac{V_{\text{dc}}}{0.318} = \dfrac{2\text{ V}}{0.318} = \mathbf{6.28\text{ V}}$

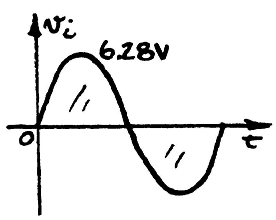


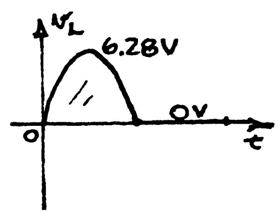


$$I_m = \frac{V_m}{R} = \frac{6.28\text{ V}}{2.2\text{ k}\Omega} = \mathbf{2.85\text{ mA}}$$

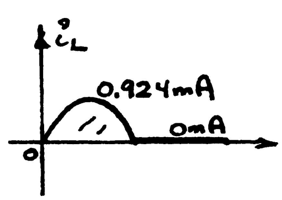


24. $V_m = \dfrac{V_{\text{dc}}}{0.318} = \dfrac{2\text{ V}}{0.318} = \mathbf{6.28\text{ V}}$



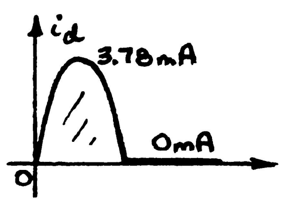


$$I_{L_{\max}} = \frac{6.28\text{ V}}{6.8\text{ k}\Omega} = \mathbf{0.924\text{ mA}}$$



$$I_{\max}(2.2\text{ k}\Omega) = \frac{6.28\text{ V}}{2.2\text{ k}\Omega} = \mathbf{2.855\text{ mA}}$$

$$I_{D_{\max}} = I_{L_{\max}} + I_{\max}(2.2\text{ k}\Omega) = 0.924\text{ mA} + 2.855\text{ mA} = \mathbf{3.78\text{ mA}}$$



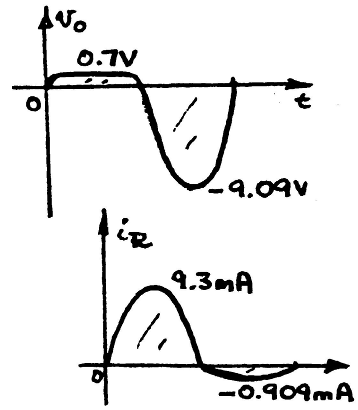
26. Diode will conduct when $v_o = 0.7$ V; that is,

$$v_o = 0.7\text{ V} = \frac{10\text{ k}\Omega(v_i)}{10\text{ k}\Omega + 1\text{ k}\Omega}$$

Solving: v_i = **0.77 V**

For $v_i \geq 0.77$ V Si diode is "on" and v_o = **0.7 V**.
For $v_i < 0.77$ V Si diode is open and level of v_o is determined by voltage divider rule:

$$v_o = \frac{10\text{ k}\Omega(v_i)}{10\text{ k}\Omega + 1\text{ k}\Omega} = 0.909\, v_i$$



For $v_i = -10$ V:

$$v_o = 0.909(-10\text{ V}) = \mathbf{-9.09\text{ V}}$$

When $v_o = 0.7$ V, $v_{R_{max}} = v_{i_{max}} - 0.7\text{ V} = 10\text{ V} - 0.7\text{ V} = 9.3\text{ V}$

$$I_{R_{max}} = \frac{9.3\text{ V}}{1\text{ k}\Omega} = 9.3\text{ mA}$$

$$I_{max}(\text{reverse}) = \frac{10\text{ V}}{1\text{ k}\Omega + 10\text{ k}\Omega} = \mathbf{0.909\text{ mA}}$$

28. (a) $V_m = \sqrt{2}\,(120\text{ V}) = 169.7\text{ V}$

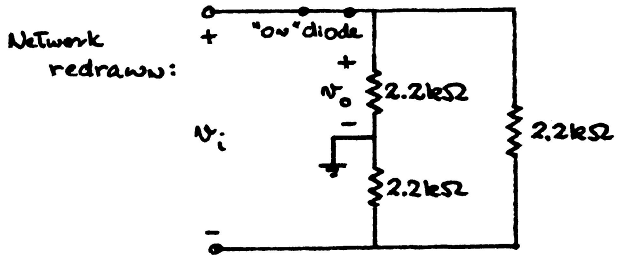
$$V_{L_m} = V_{i_m} - 2V_D$$
$$= 169.7\text{ V} - 2(0.7\text{ V}) = 169.7\text{ V} - 1.4\text{ V}$$
$$= 168.3\text{ V}$$
$$V_{dc} = 0.636(168.3\text{ V}) = \mathbf{107.04\text{ V}}$$

(b) PIV = V_m(load) + V_D = 168.3 V + 0.7 V = **169 V**

(c) $I_D(\text{max}) = \dfrac{V_{L_m}}{R_L} = \dfrac{168.3\text{ V}}{1\text{ k}\Omega} = \mathbf{168.3\text{ mA}}$

(d) $P_{max} = V_D I_D = (0.7\text{ V})I_{max}$
$= (0.7\text{ V})(168.3\text{ mA})$
$= \mathbf{117.81\text{ mW}}$

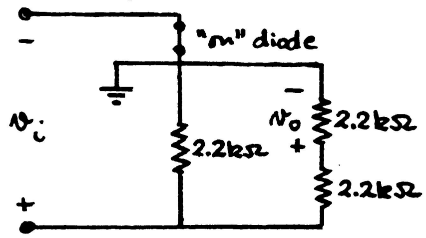
30. Positive half-cycle of v_i:



Voltage-divider rule:

$$V_{o_{\max}} = \frac{2.2\text{ k}\Omega(V_{i_{\max}})}{2.2\text{ k}\Omega + 2.2\text{ k}\Omega}$$
$$= \frac{1}{2}(V_{i_{\max}})$$
$$= \frac{1}{2}(100\text{ V})$$
$$= \mathbf{50\text{ V}}$$

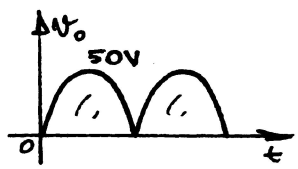
Negative half-cycle of v_i:



Polarity of v_o across the 2.2 kΩ resistor acting as a load is the same.

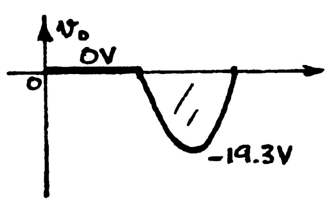
Voltage-divider rule:

$$V_{o_{\max}} = \frac{2.2\text{ k}\Omega(V_{i_{\max}})}{2.2\text{ k}\Omega + 2.2\text{ k}\Omega}$$
$$= \frac{1}{2}(V_{i_{\max}})$$
$$= \frac{1}{2}(100\text{ V})$$
$$= \mathbf{50\text{ V}}$$

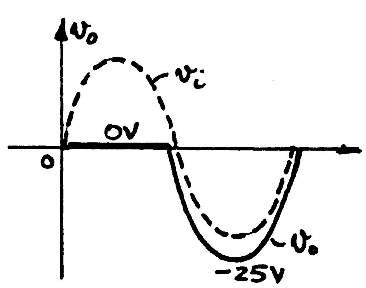


$V_{dc} = 0.636V_m = 0.636\ (50\text{ V})$
$= \mathbf{31.8\text{ V}}$

32. (a) Si diode open for positive pulse of v_i and v_o = **0 V**
For $-20\text{ V} < v_i \le -0.7\text{ V}$ diode "on" and $v_o = v_i + 0.7\text{ V}$.
For $v_i = -20$ V, $v_o = -20\text{ V} + 0.7\text{ V} = \mathbf{-19.3\text{ V}}$
For $v_i = -0.7$ V, $v_o = -0.7\text{ V} + 0.7\text{ V} = \mathbf{0\text{ V}}$



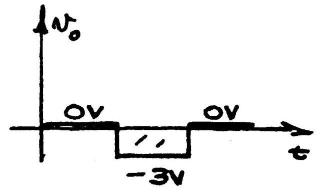
(b) For $v_i \le 5$ V the 5 V battery will ensure the diode is forward-biased and $v_o = v_i - 5$ V.
At $v_i = 5$ V
$v_o = 5\text{ V} - 5\text{ V} = \mathbf{0\text{ V}}$
At $v_i = -20$ V
$v_o = -20\text{ V} - 5\text{ V} = \mathbf{-25\text{ V}}$
For $v_i > 5$ V the diode is reverse-biased and v_o = **0 V**.



34. (a) For $v_i = 20$ V the diode is reverse-biased and $v_o = \mathbf{0\ V}$.
For $v_i = -5$ V, v_i overpowers the 2 V battery and the diode is "on".

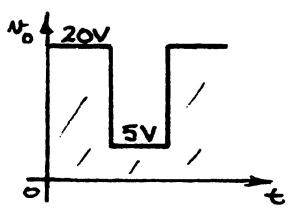
Applying Kirchhoff's voltage law in the clockwise direction:

$$-5\text{ V} + 2\text{ V} - v_o = 0$$
$$v_o = \mathbf{-3\ V}$$



(b) For $v_i = 20$ V the 20 V level overpowers the 5 V supply and the diode is "on". Using the short-circuit equivalent for the diode we find $v_o = v_i = \mathbf{20\ V}$.

For $v_i = -5$ V, both v_i and the 5 V supply reverse-bias the diode and separate v_i from v_o. However, v_o is connected directly through the 2.2 kΩ resistor to the 5 V supply and $v_o = \mathbf{5\ V}$.

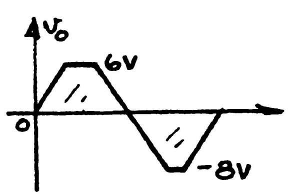


36. For the positive region of v_i:
The right Si diode is reverse-biased.
The left Si diode is "on" for levels of v_i greater than 5.3 V + 0.7 V = 6 V. In fact, $v_o = \mathbf{6\ V}$ for $v_i \geq 6$ V.

For $v_i < 6$ V both diodes are reverse-biased and $v_o = \boldsymbol{v_i}$.

For the negative region of v_i:
The left Si diode is reverse-biased.
The right Si diode is "on" for levels of v_i more negative than 7.3 V + 0.7 V = 8 V. In fact, $v_o = \mathbf{-8\ V}$ for $v_i \leq -8$ V.

For $v_i > -8$ V both diodes are reverse-biased and $v_o = \boldsymbol{v_i}$.



i_R: For -8 V < v_i < 6 V there is no conduction through the 10 kΩ resistor due to the lack of a complete circuit. Therefore, i_R = 0 mA.

For $v_i \geq 6$ V

$$v_R = v_i - v_o = v_i - 6 \text{ V}$$

For v_i = 10 V, v_R = 10 V − 6 V = 4 V

$$\text{and } i_R = \frac{4 \text{ V}}{10 \text{ k}\Omega} = \mathbf{0.4 \text{ mA}}$$

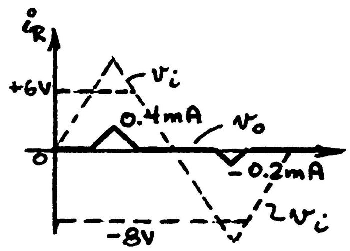
For $v_i \leq -8$ V

$$v_R = v_i - v_o = v_i + 8 \text{ V}$$

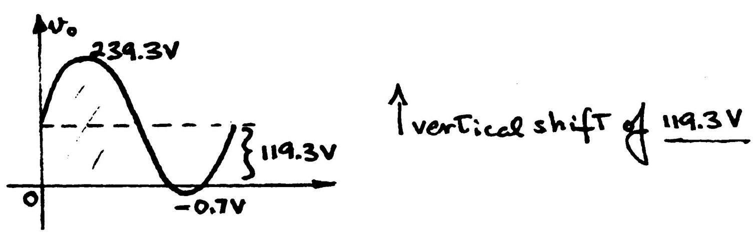
For $v_i = -10$ V

$$v_R = -10 \text{ V} + 8 \text{ V} = -2 \text{ V}$$

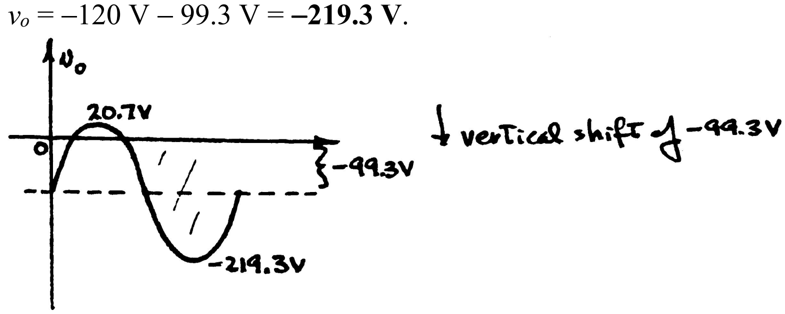
$$\text{and } i_R = \frac{-2 \text{ V}}{10 \text{ k}\Omega} = \mathbf{-0.2 \text{ mA}}$$



38. (a) For negative half cycle capacitor charges to peak value of 120 V − 0.7 V = 119.3 V with polarity (− —|(— +). The output v_o is directly across the "on" diode resulting in v_o = **−0.7 V** as a negative peak value.
For next positive half cycle $v_o = v_i$ + 119.3 V with peak value of v_o = 120 V + 119.3 V = **239.3 V**.



(b) For positive half cycle capacitor charges to peak value of 120 V − 20 V − 0.7 V = 99.3 V with polarity (+ —|(— −). The output v_o = 20 V + 0.7 V = **20.7 V**
For next negative half cycle $v_o = v_i$ − 99.3 V with negative peak value of v_o = −120 V − 99.3 V = **−219.3 V**.



Using the ideal diode approximation the vertical shift of part (a) would be 120 V rather than 119.3 V and −100 V rather than −99.3 V for part (b). Using the ideal diode approximation would certainly be appropriate in this case.

40. Solution is network of Fig. 2.176(b) using a 10 V supply in place of the 5 V source.

42. (a) In the absence of the Zener diode

$$V_L = \frac{180\ \Omega(20\ \text{V})}{180\ \Omega + 220\ \Omega} = 9\ \text{V}$$

$V_L = 9\ \text{V} < V_Z = 10\ \text{V}$ and diode non-conducting

Therefore, $I_L = I_R = \dfrac{20\ \text{V}}{220\ \Omega + 180\ \Omega} = \mathbf{50\ mA}$

with $I_Z = \mathbf{0\ mA}$
and $V_L = \mathbf{9\ V}$

(b) In the absence of the Zener diode

$$V_L = \frac{470\ \Omega(20\ \text{V})}{470\ \Omega + 220\ \Omega} = 13.62\ \text{V}$$

$V_L = 13.62\ \text{V} > V_Z = 10\ \text{V}$ and Zener diode "on"

Therefore, $V_L = \mathbf{10\ V}$ and $V_{R_s} = 10\ \text{V}$

$I_{R_s} = V_{R_s}/R_s = 10\ \text{V}/220\ \Omega = \mathbf{45.45\ mA}$

$I_L = V_L/R_L = 10\ \text{V}/470\ \Omega = \mathbf{21.28\ mA}$

and $I_Z = I_{R_s} - I_L = 45.45\ \text{mA} - 21.28\ \text{mA} = \mathbf{24.17\ mA}$

(c) $P_{Z_{\max}} = 400\ \text{mW} = V_Z I_Z = (10\ \text{V})(I_Z)$

$$I_Z = \frac{400\ \text{mW}}{10\ \text{V}} = 40\ \text{mA}$$

$$I_{L_{\min}} = I_{R_s} - I_{Z_{\max}} = 45.45\ \text{mA} - 40\ \text{mA} = 5.45\ \text{mA}$$

$$R_L = \frac{V_L}{I_{L_{\min}}} = \frac{10\ \text{V}}{5.45\ \text{mA}} = \mathbf{1{,}834.86\ \Omega}$$

Large R_L reduces I_L and forces more of I_{R_s} to pass through Zener diode.

(d) In the absence of the Zener diode

$$V_L = 10\ \text{V} = \frac{R_L(20\ \text{V})}{R_L + 220\ \Omega}$$

$$10R_L + 2200 = 20R_L$$
$$10R_L = 2200$$
$$R_L = \mathbf{220\ \Omega}$$

44. Since $I_L = \dfrac{V_L}{R_L} = \dfrac{V_Z}{R_L}$ is fixed in magnitude the maximum value of I_{R_s} will occur when I_Z is a maximum. The maximum level of I_{R_s} will in turn determine the maximum permissible level of V_i.

$$I_{Z_{\max}} = \frac{P_{Z_{\max}}}{V_Z} = \frac{400\ \text{mW}}{8\ \text{V}} = 50\ \text{mA}$$

$I_L = \frac{V_L}{R_L} = \frac{V_Z}{R_L} = \frac{8\text{ V}}{220\ \Omega} = 36.36\text{ mA}$

$I_{R_s} = I_Z + I_L = 50\text{ mA} + 36.36\text{ mA} = 86.36\text{ mA}$

$I_{R_s} = \frac{V_i - V_Z}{R_s}$

or $V_i = I_{R_s}R_s + V_Z$

$= (86.36\text{ mA})(91\ \Omega) + 8\text{ V} = 7.86\text{ V} + 8\text{ V} = \mathbf{15.86\ V}$

Any value of v_i that exceeds 15.86 V will result in a current I_Z that will exceed the maximum value.

46. For $v_i = +50$ V:

Z_1 forward-biased at 0.7 V

Z_2 reverse-biased at the Zener potential and $V_{Z_2} = 10$ V.

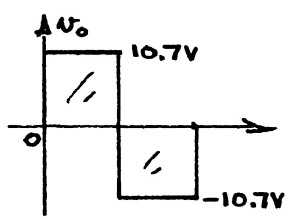
Therefore, $V_o = V_{Z_1} + V_{Z_2} = 0.7\text{ V} + 10\text{ V} = \mathbf{10.7\ V}$

For $v_i = -50$ V:

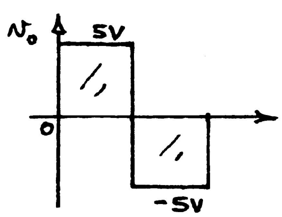
Z_1 reverse-biased at the Zener potential and $V_{Z_1} = -10$ V.

Z_2 forward-biased at -0.7 V.

Therefore, $V_o = V_{Z_1} + V_{Z_2} = \mathbf{-10.7\ V}$



For a 5 V square wave neither Zener diode will reach its Zener potential. In fact, for either polarity of v_i one Zener diode will be in an open-circuit state resulting in $v_o = v_i$.



48. The PIV for each diode is $\mathbf{2}\boldsymbol{V_m}$

$\therefore \text{PIV} = 2(1.414)(V_{\text{rms}})$

Chapter 3 (Odd)

1. –

3. Forward- and reverse-biased.

5. –

7. –

9. $I_B = \frac{1}{100} I_C \Rightarrow I_C = 100 I_B$

   $I_E = I_C + I_B = 100I_B + I_B = 101I_B$

   $I_B = \frac{I_E}{101} = \frac{8 \text{ mA}}{101} = \mathbf{79.21\ \mu A}$

   $I_C = 100I_B = 100(79.21\ \mu\text{A}) = \mathbf{7.921\ mA}$

11. $I_E = 5$ mA, $V_{CB} = 1$ V: $V_{BE} =$ **800 mV**

    $V_{CB} = 10$ V: $V_{BE} =$ **770 mV**

    $V_{CB} = 20$ V: $V_{BE} =$ **750 mV**

    The change in V_{CB} is 20 V:1 V = **20:1**
    The resulting change in V_{BE} is 800 mV:750 mV = **1.07:1** (very slight)

13. (a) $I_C \cong I_E =$ **4.5 mA**

    (b) $I_C \cong I_E =$ **4.5 mA**

    (c) negligible: change cannot be detected on this set of characteristics.

    (d) $I_C \cong I_E$

15. (a) $I_C = \alpha I_E = (0.998)(4 \text{ mA}) = \mathbf{3.992\ mA}$

    (b) $I_E = I_C + I_B \Rightarrow I_C = I_E - I_B = 2.8 \text{ mA} - 0.02 \text{ mA} = \mathbf{2.78\ mA}$

    $\alpha_{dc} = \frac{I_C}{I_E} = \frac{2.78 \text{ mA}}{2.8 \text{ mA}} = \mathbf{0.993}$

    (c) $I_C = \beta I_B = \left(\frac{\alpha}{1-\alpha}\right) I_B = \left(\frac{0.98}{1-0.98}\right)(40\ \mu\text{A}) = 1.96 \text{ mA}$

    $I_E = \frac{I_C}{\alpha} = \frac{1.96 \text{ mA}}{0.993} = \mathbf{2\ mA}$

17. $I_i = V_i/R_i = 500 \text{ mV}/20\ \Omega = 25 \text{ mA}$

    $I_L \cong I_i = 25$ mA

    $V_L = I_L R_L = (25 \text{ mA})(1 \text{ k}\Omega) = 25 \text{ V}$

    $A_v = \frac{V_o}{V_i} = \frac{25 \text{ V}}{0.5 \text{ V}} = \mathbf{50}$

19. –

21. (a) $\beta = \dfrac{I_C}{I_B} = \dfrac{2\text{ mA}}{17\ \mu\text{A}}$ = **117.65**

(b) $\alpha = \dfrac{\beta}{\beta+1} = \dfrac{117.65}{117.65+1}$ = **0.992**

(c) I_{CEO} = **0.3 mA**

(d) $I_{CBO} = (1 - \alpha)I_{CEO}$

$= (1 - 0.992)(0.3\text{ mA}) =$ **2.4 μA**

23. (a) $\beta_{\text{dc}} = \dfrac{I_C}{I_B} = \dfrac{6.7\text{ mA}}{80\ \mu\text{A}}$ = **83.75**

(b) $\beta_{\text{dc}} = \dfrac{I_C}{I_B} = \dfrac{0.85\text{ mA}}{5\ \mu\text{A}}$ = **170**

(c) $\beta_{\text{dc}} = \dfrac{I_C}{I_B} = \dfrac{3.4\text{ mA}}{30\ \mu\text{A}}$ = **113.33**

(d) β_{dc} does change from pt. to pt. on the characteristics.
Low I_B, high $V_{CE} \rightarrow$ higher betas
High I_B, low $V_{CE} \rightarrow$ lower betas

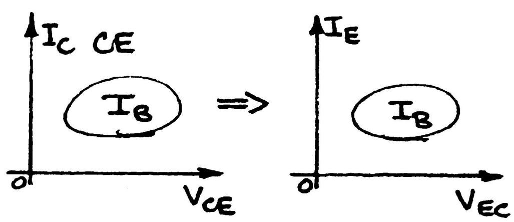
25. $\beta_{\text{dc}} = \dfrac{I_C}{I_B} = \dfrac{2.9\text{ mA}}{25\ \mu\text{A}}$ = **116**

$\alpha = \dfrac{\beta}{\beta+1} = \dfrac{116}{116+1}$ = **0.991**

$I_E = I_C/\alpha = 2.9\text{ mA}/0.991 =$ **2.93 mA**

27. –

29. Output characteristics:



Curves are essentially the same with new scales as shown.

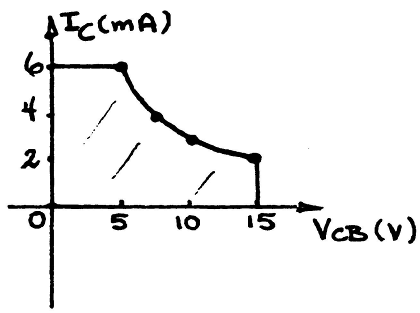
Input characteristics:
Common-emitter input characteristics may be used directly for common-collector calculations.

31. $I_C = I_{C_{\max}}$, $V_{CE} = \dfrac{P_{C_{\max}}}{I_{C_{\max}}} = \dfrac{30\text{ mW}}{6\text{ mA}} = \mathbf{5\ V}$

$V_{CB} = V_{CB_{\max}}$, $I_C = \dfrac{P_{C_{\max}}}{V_{CB_{\max}}} = \dfrac{30\text{ mW}}{15\text{ V}} = \mathbf{2\ mA}$

$I_C = 4\text{ mA}$, $V_{CB} = \dfrac{P_{C_{\max}}}{I_C} = \dfrac{30\text{ mW}}{4\text{ mA}} = \mathbf{7.5\ V}$

$V_{CB} = 10\text{ V}$, $I_C = \dfrac{P_{C_{\max}}}{V_{CB}} = \dfrac{30\text{ mW}}{10\text{ V}} = \mathbf{3\ mA}$



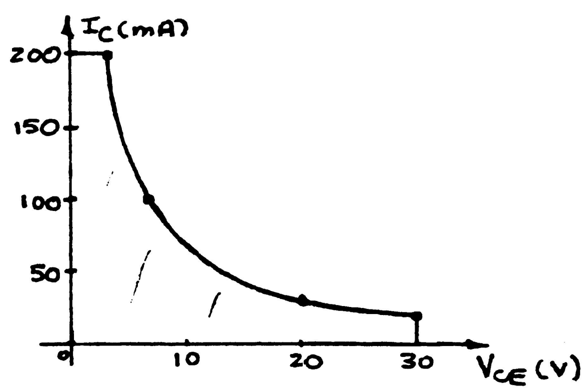
33. $I_{C_{\max}} = 200\text{ mA}$, $V_{CE_{\max}} = 30\text{ V}$, $P_{D_{\max}} = 625\text{ mW}$

$I_C = I_{C_{\max}}$, $V_{CE} = \dfrac{P_{D_{\max}}}{I_{C_{\max}}} = \dfrac{625\text{ mW}}{200\text{ mA}} = 3.125\text{ V}$

$V_{CE} = V_{CE_{\max}}$, $I_C = \dfrac{P_{D_{\max}}}{V_{CE_{\max}}} = \dfrac{625\text{ mW}}{30\text{ V}} = 20.83\text{ mA}$

$I_C = 100\text{ mA}$, $V_{CE} = \dfrac{P_{D_{\max}}}{I_C} = \dfrac{625\text{ mW}}{100\text{ mA}} = 6.25\text{ V}$

$V_{CE} = 20\text{ V}$, $I_C = \dfrac{P_{D_{\max}}}{V_{CE}} = \dfrac{625\text{ mW}}{20\text{ V}} = 31.25\text{ mA}$



35. h_{FE} (β_{dc}) with $V_{CE} = 1$ V, $T = 25°C$

$I_C = 0.1$ mA, $h_{FE} \cong 0.43(100) = 43$

$\downarrow$

$I_C = 10$ mA, $h_{FE} \cong 0.98(100) = 98$

h_{fe}(β_{ac}) with $V_{CE} = 10$ V, $T = 25°C$

$I_C = 0.1$ mA, $h_{fe} \cong 72$

$\downarrow$

$I_C = 10$ mA, $h_{fe} \cong 160$

For both h_{FE} and h_{fe} the same increase in collector current resulted in a similar increase (relatively speaking) in the gain parameter. The levels are higher for h_{fe} but note that V_{CE} is higher also.

37. (a) At $I_C = 1$ mA, $h_{fe} \cong$ **120**
At $I_C = 10$ mA, $h_{fe} \cong$ **160**

(b) The results confirm the conclusions of problems 23 and 24 that beta tends to increase with increasing collector current.

39. (a) $\beta_{ac} = \left.\dfrac{\Delta I_C}{\Delta I_B}\right|_{V_{CE} = 3\text{ V}} = \dfrac{16\text{ mA} - 12.2\text{ mA}}{80\ \mu\text{A} - 60\ \mu\text{A}} = \dfrac{3.8\text{ mA}}{20\ \mu\text{A}} = \mathbf{190}$

(b) $\beta_{dc} = \dfrac{I_C}{I_B} = \dfrac{12\text{ mA}}{59.5\ \mu\text{A}} = \mathbf{201.7}$

(c) $\beta_{ac} = \dfrac{4\text{ mA} - 2\text{ mA}}{18\ \mu\text{A} - 8\ \mu\text{A}} = \dfrac{2\text{ mA}}{10\ \mu\text{A}} = \mathbf{200}$

(d) $\beta_{dc} = \dfrac{I_C}{I_B} = \dfrac{3\text{ mA}}{13\ \mu\text{A}} = \mathbf{230.77}$

(e) In both cases β_{dc} is slightly higher than β_{ac} ($\cong$ 10%)

(f)(g)
In general β_{dc} and β_{ac} increase with increasing I_C for fixed V_{CE} and both decrease for decreasing levels of V_{CE} for a fixed I_E. However, if I_C increases while V_{CE} decreases when moving between two points on the characteristics, chances are the level of β_{dc} or β_{ac} may not change significantly. In other words, the expected increase due to an increase in collector current may be offset by a decrease in V_{CE}. The above data reveals that this is a strong possibility since the levels of β are relatively close.

Chapter 3 (Even)

2. A bipolar transistor utilizes holes and electrons in the injection or charge flow process, while unipolar devices utilize either electrons or holes, but not both, in the charge flow process.

4. The leakage current I_{CO} is the minority carrier current in the collector.

6. –

8. I_E the largest
I_B the smallest
$I_C \cong I_E$

10. –

12. (a) $r_{av} = \dfrac{\Delta V}{\Delta I} = \dfrac{0.9\text{ V} - 0.7\text{ V}}{8\text{ mA} - 0}$ $= \mathbf{25\ \Omega}$
(b) Yes, since 25 Ω is often negligible compared to the other resistance levels of the network.

14. (a) Using Fig. 3.7 first, $I_E \cong 7$ mA
Then Fig. 3.8 results in $I_C \cong$ **7 mA**
(b) Using Fig. 3.8 first, $I_E \cong 5$ mA
Then Fig. 3.7 results in $V_{BE} \cong$ **0.78 V**
(c) Using Fig. 3.10(b) $I_E = 5$ mA results in $V_{BE} \cong$ **0.81 V**
(d) Using Fig. 3.10(c) $I_E = 5$ mA results in $V_{BE} =$ **0.7 V**
(e) Yes, the difference in levels of V_{BE} can be ignored for most applications if voltages of several volts are present in the network.

16. –

18. $I_i = \dfrac{V_i}{R_i + R_s} = \dfrac{200\text{ mV}}{20\ \Omega + 100\ \Omega} = \dfrac{200\text{ mV}}{120\ \Omega}$ $= 1.67$ mA
$I_L = I_i = 1.67$ mA
$V_L = I_L R = (1.67\text{ mA})(5\text{ k}\Omega) = 8.35$ V
$A_v = \dfrac{V_o}{V_i} = \dfrac{8.35\text{ V}}{0.2\text{ V}}$ $=$ **41.75**

20. (a) Fig. 3.14(b): $I_B \cong 35\mu$A
Fig. 3.14(a): $I_C \cong$ **3.6 mA**

(b) Fig. 3.14(a): $V_{CE} \cong 2.5$ V
Fig. 3.14(b): $V_{BE} \cong$ **0.72 V**

22. (a) Fig. 3.14(a): $I_{CEO} \cong$ **0.3 mA**

(b) Fig. 3.14(a): $I_C \cong 1.35$ mA

$$\beta_{\text{dc}} = \frac{I_C}{I_B} = \frac{1.35\text{ mA}}{10\ \mu\text{A}} = \mathbf{135}$$

(c) $\alpha = \dfrac{\beta}{\beta+1} = \dfrac{135}{136} = \mathbf{0.9926}$

$I_{CBO} \cong (1 - \alpha)I_{CEO}$
$= (1 - 0.9926)(0.3\text{ mA})$
$= \mathbf{2.2\ \mu A}$

24. (a) $\beta_{\text{ac}} = \left.\dfrac{\Delta I_C}{\Delta I_B}\right|_{V_{CE}=5\text{ V}} = \dfrac{7.3\text{ mA} - 6\text{ mA}}{90\ \mu\text{A} - 70\ \mu\text{A}} = \dfrac{1.3\text{ mA}}{20\ \mu\text{A}} = \mathbf{65}$

(b) $\beta_{\text{ac}} = \left.\dfrac{\Delta I_C}{\Delta I_B}\right|_{V_{CE}=15\text{ V}} = \dfrac{1.4\text{ mA} - 0.3\text{ mA}}{10\ \mu\text{A} - 0\ \mu\text{A}} = \dfrac{1.1\text{ mA}}{10\ \mu\text{A}} = \mathbf{110}$

(c) $\beta_{\text{ac}} = \left.\dfrac{\Delta I_C}{\Delta I_B}\right|_{V_{CE}=10\text{ V}} = \dfrac{4.25\text{ mA} - 2.35\text{ mA}}{40\ \mu\text{A} - 20\ \mu\text{A}} = \dfrac{1.9\text{ mA}}{20\ \mu\text{A}} = \mathbf{95}$

(d) β_{ac} does change from point to point on the characteristics. The highest value was obtained at a higher level of V_{CE} and lower level of I_C. The separation between I_B curves is the greatest in this region.

(e)

V_{CE}	I_B	β_{dc}	β_{ac}	I_C	$\beta_{\text{dc}}/\beta_{\text{ac}}$
5 V	80 μA	83.75	65	6.7 mA	1.29
10 V	30 μA	113.33	95	3.4 mA	1.19
15 V	5 μA	170	110	0.85 mA	1.55

As I_C decreased, the level of β_{dc} and β_{ac} increased. Note that the level of β_{dc} and β_{ac} in the center of the active region is close to the average value of the levels obtained. In each case β_{dc} is larger than β_{ac}, with the least difference occurring in the center of the active region.

26. (a) $\beta = \dfrac{\alpha}{1-\alpha} = \dfrac{0.987}{1-0.987} = \dfrac{0.987}{0.013} = \mathbf{75.92}$

(b) $\alpha = \dfrac{\beta}{\beta+1} = \dfrac{120}{120+1} = \dfrac{120}{121} = \mathbf{0.992}$

(c) $I_B = \dfrac{I_C}{\beta} = \dfrac{2\text{ mA}}{180} = \mathbf{11.11\ \mu A}$

$I_E = I_C + I_B = 2\text{ mA} + 11.11\ \mu\text{A}$
$= \mathbf{2.011\text{ mA}}$

28. $V_e = V_i - V_{be} = 2\text{ V} - 0.1\text{ V} = 1.9\text{ V}$

$$A_v = \frac{V_o}{V_i} = \frac{1.9\text{ V}}{2\text{ V}} = \mathbf{0.95} \cong 1$$

$$I_e = \frac{V_E}{R_E} = \frac{1.9\text{ V}}{1\text{ k}\Omega} = \mathbf{1.9\text{ mA}}\text{ (rms)}$$

30. $P_{C_{\max}} = 30\text{ mW} = V_{CE}I_C$

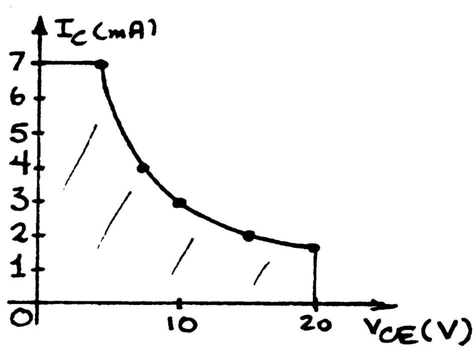
$$I_C = I_{C_{\max}},\ V_{CE} = \frac{P_{C_{\max}}}{I_{C_{\max}}} = \frac{30\text{ mW}}{7\text{ mA}} = 4.29\text{ V}$$

$$V_{CE} = V_{CE_{\max}},\ I_C = \frac{P_{C_{\max}}}{V_{CE_{\max}}} = \frac{30\text{ mW}}{20\text{ V}} = 1.5\text{ mA}$$

$$V_{CE} = 10\text{ V},\ I_C = \frac{P_{C_{\max}}}{V_{CE}} = \frac{30\text{ mW}}{10\text{ V}} = 3\text{ mA}$$

$$I_C = 4\text{ mA},\ V_{CE} = \frac{P_{C_{\max}}}{I_C} = \frac{30\text{ mW}}{4\text{ mA}} = 7.5\text{ V}$$

$$V_{CE} = 15\text{ V},\ I_C = \frac{P_{C_{\max}}}{V_{CE}} = \frac{30\text{ mW}}{15\text{ V}} = 2\text{ mA}$$



32. The operating temperature range is $-55°\text{C} \le T_J \le 150°\text{C}$

$$°\text{F} = \frac{9}{5}°\text{C} + 32°$$

$$= \frac{9}{5}(-55°\text{C}) + 32° = \mathbf{-67°F}$$

$$°\text{F} = \frac{9}{5}(150°\text{C}) + 32° = \mathbf{302°F}$$

$$\therefore\ \mathbf{-67°F \le T_J \le 302°F}$$

34. From Fig. 3.23 (a) I_{CBO} = 50 nA max

$$\beta_{avg} = \frac{\beta_{min} + \beta_{max}}{2} = \frac{50 + 150}{2} = \frac{200}{2} = 100$$

$\therefore I_{CEO} \cong \beta I_{CBO} = (100)(50 \text{ nA}) = \mathbf{5\ \mu A}$

36. As the reverse-bias potential increases in magnitude the input capacitance C_{ibo} decreases (Fig. 3.23(b)). Increasing reverse-bias potentials causes the width of the depletion region to increase, thereby reducing the capacitance $\left(C = \varepsilon \frac{A}{d}\right)$.

38. At I_C = 10 mA, $h_{FE} \cong 0.98$ (normalized) @ 25°C
$h_{FE} \cong 1.45$ (normalized) @ 125°C
$h_{FE} \cong 0.51$ (normalized) @ –55°C

Assuming β = 100 at 25°C will result in a beta of about 145 at 125°C and 51 at –55°C—a significant change—one that must be considered in the design phase.

Chapter 4 (Odd)

1. (a) $I_{B_Q} = \dfrac{V_{CC} - V_{BE}}{R_B} = \dfrac{16\text{ V} - 0.7\text{ V}}{470\text{ k}\Omega} = \dfrac{15.3\text{ V}}{470\text{ k}\Omega}$ = **32.55 μA**

(b) $I_{C_Q} = \beta I_{B_Q}$ = (90)(32.55 μA) = **2.93 mA**

(c) $V_{CE_Q} = V_{CC} - I_{C_Q}R_C$ = 16 V − (2.93 mA)(2.7 kΩ) = **8.09 V**

(d) $V_C = V_{CE_Q}$ = **8.09 V**

(e) $V_B = V_{BE}$ = **0.7 V**

(f) V_E = **0 V**

3. (a) $I_C = I_E - I_B$ = 4 mA − 20 μA = **3.98 mA** ≅ 4 mA

(b) $V_{CC} = V_{CE} + I_C R_C$ = 7.2 V + (3.98 mA)(2.2 kΩ)

= **15.96 V** ≅ 16 V

(c) $\beta = \dfrac{I_C}{I_B} = \dfrac{3.98\text{ mA}}{20\ \mu\text{A}}$ = **199** ≅ 200

(d) $R_B = \dfrac{V_{R_B}}{I_B} = \dfrac{V_{CC} - V_{BE}}{I_B} = \dfrac{15.96\text{ V} - 0.7\text{ V}}{20\ \mu\text{A}}$ = **763 kΩ**

5. (a) Load line intersects vertical axis at $I_C = \dfrac{21\text{ V}}{3\text{ k}\Omega}$ = 7 mA

and horizontal axis at V_{CE} = 21 V.

(b) I_B = 25 μA: $R_B = \dfrac{V_{CC} - V_{BE}}{I_B} = \dfrac{21\text{ V} - 0.7\text{ V}}{25\ \mu\text{A}}$ = **812 kΩ**

(c) I_{C_Q} ≅ **3.4 mA**, V_{CE_Q} ≅ **10.75 V**

(d) $\beta = \dfrac{I_C}{I_B} = \dfrac{3.4\text{ mA}}{25\ \mu\text{A}}$ = **136**

(e) $\alpha = \dfrac{\beta}{\beta + 1} = \dfrac{136}{136 + 1} = \dfrac{136}{137}$ = **0.992**

(f) $I_{C_{\text{sat}}} = \dfrac{V_{CC}}{R_C} = \dfrac{21\text{ V}}{3\text{ k}\Omega}$ = **7 mA**

(g) −

(h) $P_D = V_{CE_Q} I_{C_Q}$ = (10.75 V)(3.4 mA) = **36.55 mW**

(i) $P_s = V_{CC}(I_C + I_B)$ = 21 V(3.4 mA + 25 μA) = **71.92 mW**

(j) $P_R = P_s - P_D$ = 71.92 mW − 36.55 mW = **35.37 mW**

7. (a) $R_C = \dfrac{V_{CC} - V_C}{I_C} = \dfrac{12\text{ V} - 7.6\text{ V}}{2\text{ mA}} = \dfrac{4.4\text{ V}}{2\text{ mA}}$ = **2.2 kΩ**

(b) $I_E \cong I_C$: $R_E = \dfrac{V_E}{I_E} = \dfrac{2.4\text{ V}}{2\text{ mA}}$ = **1.2 kΩ**

(c) $R_B = \dfrac{V_{R_B}}{I_B} = \dfrac{V_{CC} - V_{BE} - V_E}{I_B} = \dfrac{12\text{ V} - 0.7\text{ V} - 2.4\text{ V}}{2\text{ mA}/80} = \dfrac{8.9\text{ V}}{25\ \mu\text{A}}$ = **356 kΩ**

(d) $V_{CE} = V_C - V_E = 7.6\text{ V} - 2.4\text{ V} =$ **5.2 V**

(e) $V_B = V_{BE} + V_E = 0.7\text{ V} + 2.4\text{ V} =$ **3.1 V**

9. $I_{C_{\text{sat}}} = \dfrac{V_{CC}}{R_C + R_E} = \dfrac{20\text{ V}}{2.4\text{ k}\Omega + 1.5\text{ k}\Omega} = \dfrac{20\text{ V}}{3.9\text{ k}\Omega}$ = **5.13 mA**

11. (a) Problem 1: I_{C_Q} = **2.93 mA**, V_{CE_Q} = **8.09 V**

(b) $I_{B_Q} = 32.55\ \mu\text{A}$ (the same)

$I_{C_Q} = \beta I_{B_Q} = (135)(32.55\ \mu\text{A}) = 4.39\text{ mA}$

$V_{CE_Q} = V_{CC} - I_{C_Q}R_C = 16\text{ V} - (4.39\text{ mA})(2.7\text{ k}\Omega) =$ **4.15 V**

(c) $\%\Delta I_C = \left|\dfrac{4.39\text{ mA} - 2.93\text{ mA}}{2.93\text{ mA}}\right| \times 100\% =$ **49.83%**

$\%\Delta V_{CE} = \left|\dfrac{4.15\text{ V} - 8.09\text{ V}}{8.09\text{ V}}\right| \times 100\% =$ **48.70%**

Less than 50% due to level of accuracy carried through calculations.

(d) Problem 6: I_{C_Q} = **2.92 mA**, V_{CE_Q} = **8.61 V** ($I_{B_Q} = 29.18\ \mu\text{A}$)

(e) $I_{B_Q} = \dfrac{V_{CC} - V_{BE}}{R_B + (\beta + 1)R_E} = \dfrac{20\text{ V} - 0.7\text{ V}}{510\text{ k}\Omega + (150 + 1)(1.5\text{ k}\Omega)} = 26.21\ \mu\text{A}$

$I_{C_Q} = \beta I_{B_Q} = (150)(26.21\ \mu\text{A}) =$ **3.93 mA**

$V_{CE_Q} = V_{CC} - I_C(R_C + R_E)$

$= 20\text{ V} - (3.93\text{ mA})(2.4\text{ k}\Omega + 1.5\text{ k}\Omega) =$ **4.67 V**

(f) $\%\Delta I_C = \left|\dfrac{3.93\text{ mA} - 2.92\text{ mA}}{2.92\text{ mA}}\right| \times 100\% =$ **34.59%**

$\%\Delta V_{CE} = \left|\dfrac{4.67\text{ V} - 8.61\text{ V}}{8.61\text{ V}}\right| \times 100\% =$ **46.76%**

(g) For both I_C and V_{CE} the % change is less for the emitter-stabilized.

13. (a) $I_C = \dfrac{V_{CC} - V_C}{R_C} = \dfrac{18\text{ V} - 12\text{ V}}{4.7\text{ k}\Omega}$ = **1.28 mA**

(b) $V_E = I_ER_E \cong I_CR_E = (1.28\text{ mA})(1.2\text{ k}\Omega) =$ **1.54 V**

(c) $V_B = V_{BE} + V_E = 0.7\text{ V} + 1.54\text{ V} = \mathbf{2.24\text{ V}}$

(d) $R_1 = \dfrac{V_{R_1}}{I_{R_1}}$: $V_{R_1} = V_{CC} - V_B = 18\text{ V} - 2.24\text{ V} = \mathbf{15.76\text{ V}}$

$$I_{R_1} \cong I_{R_2} = \frac{V_B}{R_2} = \frac{2.24\text{ V}}{5.6\text{ k}\Omega} = 0.4\text{ mA}$$

$$R_1 = \frac{V_{R_1}}{I_{R_1}} = \frac{15.76\text{ V}}{0.4\text{ mA}} = \mathbf{39.4\text{ k}\Omega}$$

15. $$I_{C_{sat}} = \frac{V_{CC}}{R_C + R_E} = \frac{16\text{ V}}{3.9\text{ k}\Omega + 0.68\text{ k}\Omega} = \frac{16\text{ V}}{4.58\text{ k}\Omega} = \mathbf{3.49\text{ mA}}$$

17. (a) $R_{Th} = R_1 \parallel R_2 = 39\text{ k}\Omega \parallel 8.2\text{ k}\Omega = 6.78\text{ k}\Omega$

$$E_{Th} = \frac{R_C V_{CC}}{R_1 + R_2} = \frac{8.2\text{ k}\Omega(18\text{ V})}{39\text{ k}\Omega + 8.2\text{ k}\Omega} = 3.13\text{ V}$$

$$I_B = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta + 1)R_E} = \frac{3.13\text{ V} - 0.7\text{ V}}{6.78\text{ k}\Omega + (121)(1\text{ k}\Omega)}$$

$$= \frac{2.43\text{ V}}{127.78\text{ k}\Omega} = 19.02\ \mu\text{A}$$

$I_C = \beta I_B = (120)(19.02\ \mu\text{A}) = \mathbf{2.28\text{ mA}}$ (vs. 2.43 mA #16)

(b) $V_{CE} = V_{CC} - I_C(R_C + R_E) = 18\text{ V} - (2.28\text{ mA})(3.3\text{ k}\Omega + 1\text{ k}\Omega)$
$= 18\text{ V} - 9.8\text{ V} = \mathbf{8.2\text{ V}}$ (vs. 7.55 V #16)

(c) **19.02 μA** (vs. 20.25 μA #16)

(d) $V_E = I_E R_E \cong I_C R_E = (2.28\text{ mA})(1\text{ k}\Omega) = \mathbf{2.28\text{ V}}$ (vs. 2.43 V #16)

(e) $V_B = V_{BE} + V_E = 0.7\text{ V} + 2.28\text{ V} = \mathbf{2.98\text{ V}}$ (vs. 3.13 V #16)
The results suggest that the approximate approach is valid if Eq. 4.33 is satisfied.

19. (a) $$I_{C_{sat}} = 7.5\text{ mA} = \frac{V_{CC}}{R_C + R_E} = \frac{24\text{ V}}{3R_E + R_E} = \frac{24\text{ V}}{4R_E}$$

$$R_E = \frac{24\text{ V}}{4(7.5\text{ mA})} = \frac{24\text{ V}}{30\text{ mA}} = \mathbf{0.8\text{ k}\Omega}$$

$R_C = 3R_E = 3(0.8\text{ k}\Omega) = 2.4\text{ k}\Omega$

(b) $V_E = I_E R_E \cong I_C R_E = (5\text{ mA})(0.8\text{ k}\Omega) = \mathbf{4\text{ V}}$

(c) $V_B = V_E + V_{BE} = 4\text{ V} + 0.7\text{ V} = \mathbf{4.7\text{ V}}$

(d) $V_B = \dfrac{R_2 V_{CC}}{R_2 + R_1}$, $4.7\text{ V} = \dfrac{R_2(24\text{ V})}{R_2 + 24\text{ k}\Omega}$

$R_2 = \mathbf{5.84\text{ k}\Omega}$

(e) $\beta_{\text{dc}} = \dfrac{I_C}{I_B} = \dfrac{5 \text{ mA}}{38.5\ \mu\text{A}} = \mathbf{129.8}$

(f) $\beta R_E \geq 10R_2$
$(129.8)(0.8 \text{ k}\Omega) \geq 10(5.84 \text{ k}\Omega)$
$103.84 \text{ k}\Omega \geq 58.4 \text{ k}\Omega$ (checks)

21. I.(a) Problem 16: Approximation approach: $I_{C_Q} = \mathbf{2.43\ mA}$, $V_{CE_Q} = \mathbf{7.55\ V}$

Problem 17: Exact analysis: $I_{C_Q} = \mathbf{2.28\ mA}$, $V_{CE_Q} = \mathbf{8.2\ V}$

The exact solution will be employed to demonstrate the effect of the change of β. Using the approximate approach would result in $\%\Delta I_C = 0\%$ and $\%\Delta V_{CE} = 0\%$.

(b) Problem 17: $E_{Th} = 3.13$ V, $R_{Th} = 6.78$ kΩ

$$I_B = \frac{E_{TH} - V_{BE}}{R_{Th} + (\beta+1)R_E} = \frac{3.13 \text{ V} - 0.7 \text{ V}}{6.78 \text{ k}\Omega + (180+1)1 \text{ k}\Omega} = \frac{2.43 \text{ V}}{187.78 \text{ k}\Omega}$$
$$= 12.94\ \mu\text{A}$$
$I_C = \beta I_B = (180)(12.94\ \mu\text{A}) = \mathbf{2.33\ mA}$
$V_{CE} = V_{CC} - I_C(R_C + R_E) = 18 \text{ V} - (2.33 \text{ mA})(3.3 \text{ k}\Omega + 1 \text{ k}\Omega)$
$= \mathbf{7.98\ V}$

(c) $$\%\Delta I_C = \left|\frac{2.33 \text{ mA} - 2.28 \text{ mA}}{2.28 \text{ mA}}\right| \times 100\% = \mathbf{2.19\%}$$

$$\%\Delta V_{CE} = \left|\frac{7.98 \text{ V} - 8.2 \text{ V}}{8.2 \text{ V}}\right| \times 100\% = \mathbf{2.68\%}$$

For situations where $\beta R_E > 10R_2$ the change in I_C and/or V_{CE} due to significant change in β will be relatively small.

(d) $\%\Delta I_C = 2.19\%$ vs. 49.83% for problem 11.
$\%\Delta V_{CE} = 2.68\%$ vs. 48.70% for problem 11.

(e) Voltage-divider configuration considerably less sensitive.

II. The resulting $\%\Delta I_C$ and $\%\Delta V_{CE}$ will be quite small.

23. (a) $$I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta(R_C + R_E)} = \frac{30 \text{ V} - 0.7 \text{ V}}{6.90 \text{ k}\Omega + 100(6.2 \text{ k}\Omega + 1.5 \text{ k}\Omega)} = 20.07\ \mu\text{A}$$

$I_C = \beta I_B = (100)(20.07\ \mu\text{A}) = \mathbf{2.01\ mA}$

(b) $V_C = V_{CC} - I_C R_C$
$= 30 \text{ V} - (2.01 \text{ mA})(6.2 \text{ k}\Omega) = 30 \text{ V} - 12.462 \text{ V} = \mathbf{17.54\ V}$

(c) $V_E = I_E R_E \cong I_C R_E = (2.01 \text{ mA})(1.5 \text{ k}\Omega) = \mathbf{3.02\ V}$

(d) $V_{CE} = V_{CC} - I_C(R_C + R_E) = 30 \text{ V} - (2.01 \text{ mA})(6.2 \text{ k}\Omega + 1.5 \text{ k}\Omega)$
$= \mathbf{14.52\ V}$

25. 1 MΩ = 0 Ω, R_B = 150 kΩ

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta(R_C + R_E)} = \frac{12\text{ V} - 0.7\text{ V}}{150\text{ k}\Omega + (180)(4.7\text{ k}\Omega + 3.3\text{ k}\Omega)}$$

$= 7.11\ \mu\text{A}$

$I_C = \beta I_B = (180)(7.11\ \mu\text{A}) = 1.28$ mA

$V_C = V_{CC} - I_C R_C = 12\text{ V} - (1.28\text{ mA})(4.7\text{ k}\Omega)$

$=$ **5.98 V**

Full 1 MΩ: R_B = 1,000 kΩ + 150 kΩ = 1,150 kΩ = 1.15 MΩ

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta(R_C + R_E)} = \frac{12\text{ V} - 0.7\text{ V}}{1.15\text{ M}\Omega + (180)(4.7\text{ k}\Omega + 3.3\text{ k}\Omega)}$$

$= 4.36\ \mu\text{A}$

$I_C = \beta I_B = (180)(4.36\ \mu\text{A}) = 0.785$ mA

$V_C = V_{CC} - I_C R_C = 12\text{ V} - (0.785\text{ mA})(4.7\text{ k}\Omega)$

$=$ **8.31 V**

V_C ranges from **5.98 V to 8.31 V**

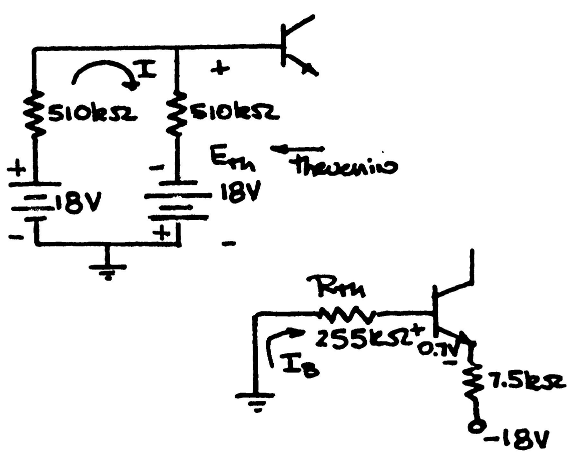
27. (a) $I_B = \dfrac{V_{R_B}}{R_B} = \dfrac{V_C - V_{BE}}{R_B} = \dfrac{8\text{ V} - 0.7\text{ V}}{560\text{ k}\Omega}$ = **13.04 μA**

(b) $I_C = \dfrac{V_{CC} - V_C}{R_C} = \dfrac{18\text{ V} - 8\text{ V}}{3.9\text{ k}\Omega} = \dfrac{10\text{ V}}{3.9\text{ k}\Omega}$ = **2.56 mA**

(c) $\beta = \dfrac{I_C}{I_B} = \dfrac{2.56\text{ mA}}{13.04\ \mu\text{A}}$ = **196.32**

(d) $V_{CE} = V_C =$ **8 V**

29. (a) $\beta R_E > 10R_2$ not satisfied ∴ Use exact approach:
Network redrawn to determine the Thevenin equivalent:



$$R_{Th} = \frac{510\text{ k}\Omega}{2} = \mathbf{255\text{ k}\Omega}$$

$$I = \frac{18\text{ V} + 18\text{ V}}{510\text{ k}\Omega + 510\text{ k}\Omega} = 35.29\ \mu\text{A}$$

$E_{Th} = -18\text{ V} + (35.29\ \mu\text{A})(510\text{ k}\Omega)$

$=$ **0 V**

$$I_B = \frac{18\text{ V} - 0.7\text{ V}}{255\text{ k}\Omega + (130 + 1)(7.5\text{ k}\Omega)}$$

$=$ **13.95 μA**

(b) $I_C = \beta I_B = (130)(13.95\ \mu\text{A})$ = **1.81 mA**

(c) $V_E = -18\text{ V} + (1.81\text{ mA})(7.5\text{ k}\Omega)$

$= -18\text{ V} + 13.58\text{ V}$

$=$ **–4.42 V**

(d) $V_{CE} = 18\text{ V} + 18\text{ V} - (1.81\text{ mA})(9.1\text{ k}\Omega + 7.5\text{ k}\Omega)$
$= 36\text{ V} - 30.05\text{ V} = \mathbf{5.95\ V}$

31. (a) $I_E = \dfrac{8\text{ V} - 0.7\text{ V}}{2.2\text{ k}\Omega} = \dfrac{7.3\text{ V}}{2.2\text{ k}\Omega} = \mathbf{3.32\ mA}$

(b) $V_C = 10\text{ V} - (3.32\text{ mA})(1.8\text{ k}\Omega) = 10\text{ V} - 5.976$
$= \mathbf{4.02\ V}$

(c) $V_{CE} = 10\text{ V} + 8\text{ V} - (3.32\text{ mA})(2.2\text{ k}\Omega + 1.8\text{ k}\Omega)$
$= 18\text{ V} - 13.28\text{ V}$
$= \mathbf{4.72\ V}$

33. $I_{C_{\text{sat}}} = \dfrac{V_{CC}}{R_C + R_E} = 10\text{ mA}$

$\dfrac{20\text{ V}}{4R_E + R_E} = 10\text{ mA} \Rightarrow \dfrac{20\text{ V}}{5R_E} = 10\text{ mA} \Rightarrow 5R_E = \dfrac{20\text{ V}}{10\text{ mA}} = 2\text{ k}\Omega$

$R_E = \dfrac{2\text{ k}\Omega}{5} = \mathbf{400\ \Omega}$

$R_C = 4R_E = \mathbf{1.6\ k\Omega}$

$I_B = \dfrac{I_C}{\beta} = \dfrac{5\text{ mA}}{120} = 41.67\ \mu\text{A}$

$R_B = V_{RB}/I_B = \dfrac{20\text{ V} - 0.7\text{ V} - 5\text{ mA}(0.4\text{ k}\Omega)}{41.67\ \mu\text{A}} = \dfrac{19.3 - 2\text{ V}}{41.67\ \mu\text{A}}$

$= \mathbf{415.17\ k\Omega}$

Standard values: $R_E = \mathbf{390\ \Omega}$, $R_C = \mathbf{1.6\ k\Omega}$, $R_B = \mathbf{430\ k\Omega}$

35. $V_E = \dfrac{1}{5}V_{CC} = \dfrac{1}{5}(28\text{ V}) = 5.6\text{ V}$

$R_E = \dfrac{V_E}{I_E} = \dfrac{5.6\text{ V}}{5\text{ mA}} = \mathbf{1.12\ k\Omega}$ (use $\mathbf{1.1\ k\Omega}$)

$V_C = \dfrac{V_{CC}}{2} + V_E = \dfrac{28\text{ V}}{2} + 5.6\text{ V} = 14\text{ V} + 5.6\text{ V} = 19.6\text{ V}$

$V_{R_C} = V_{CC} - V_C = 28\text{ V} - 19.6\text{ V} = 8.4\text{ V}$

$R_C = \dfrac{V_{R_C}}{I_C} = \dfrac{8.4\text{ V}}{5\text{ mA}} = \mathbf{1.68\ k\Omega}$ (use $1.6\text{ k}\Omega$)

$V_B = V_{BE} + V_E = 0.7\text{ V} + 5.6\text{ V} = 6.3\text{ V}$

$V_B = \dfrac{R_2 V_{CC}}{R_2 + R_1} \Rightarrow 6.3\text{ V} = \dfrac{R_2(28\text{ V})}{R_2 + R_1}$ (2 unknowns)

$\beta = \dfrac{I_C}{I_B} = \dfrac{5\text{ mA}}{37\ \mu\text{A}} = 135.14$

$\beta R_E = 10R_2$

$(135.14)(1.12\text{ k}\Omega) = 10(R_2)$

$R_2 = 15.14\text{ k}\Omega$ (use $15\text{ k}\Omega$)

Substituting: $6.3\text{ V} = \dfrac{(15.14\text{ k}\Omega)(28\text{ V})}{15.14\text{ k}\Omega + R_1}$

Solving, $R_1 = 52.15\text{ k}\Omega$ (use $51\text{ k}\Omega$)

Standard values:

R_E = **1.1 kΩ**
R_C = **1.6 kΩ**
R_1 = **51 kΩ**
R_2 = **15 kΩ**

37. $I_{C_{sat}} = 8\text{ mA} = \dfrac{5\text{ V}}{R_C}$

$R_C = \dfrac{5\text{ V}}{8\text{ mA}}$ = **0.625 kΩ**

$I_{B_{max}} = \dfrac{I_{C_{sat}}}{\beta} = \dfrac{8\text{ mA}}{100} = 80\ \mu\text{A}$

Use $1.2\,(80\ \mu\text{A}) = 96\ \mu\text{A}$

$R_B = \dfrac{5\text{ V} - 0.7\text{ V}}{96\ \mu\text{A}}$ = **44.79 kΩ**

Standard values:

R_B = **43 kΩ**
R_C = **0.62 kΩ**

39. (a) Open-circuit in the base circuit
Bad connection of emitter terminal
Damaged transistor

(b) Shorted base-emitter junction
Open at collector terminal

(c) Open-circuit in base circuit
Open transistor

41. (a) $R_B\uparrow$, $I_B\downarrow$, $I_C\downarrow$, $V_C\uparrow$
(b) $\beta\downarrow$, $I_C\downarrow$
(c) Unchanged, $I_{C_{sat}}$ not a function of β
(d) $V_{CC}\downarrow$, $I_B\downarrow$, $I_C\downarrow$
(e) $\beta\downarrow$, $I_C\downarrow$, $V_{R_C}\downarrow$, $V_{R_E}\downarrow$, $V_{CE}\uparrow$

43. (a) R_B open, $I_B = 0\ \mu\text{A}$, $I_C = I_{CEO} \cong 0$ mA
and $V_C \cong V_{CC} =$ **18 V**

(b) $\beta\uparrow, I_C\uparrow, V_{R_C}\uparrow, V_{R_E}\uparrow, V_{CE}\downarrow$

(c) $R_C\downarrow, I_B\uparrow, I_C\uparrow, V_E\uparrow$

(d) Drop to a relatively low voltage $\cong 0.06$ V

(e) Open in the base circuit

45. $\beta R_E \geq 10R_2$
$(220)(0.75\ \text{k}\Omega) \geq 10(16\ \text{k}\Omega)$
$165\ \text{k}\Omega \geq 160\ \text{k}\Omega$ (checks)
Use approximate approach:

$$V_B \cong \frac{16\ \text{k}\Omega(-22\ \text{V})}{16\ \text{k}\Omega + 82\ \text{k}\Omega} = -3.59\ \text{V}$$

$V_E = V_B + 0.7\ \text{V} = -3.59\ \text{V} + 0.7\ \text{V} = -2.89\ \text{V}$
$I_C \cong I_E = V_E/R_E = 2.89/0.75\ \text{k}\Omega = 3.85\ \text{mA}$

$$I_B = \frac{I_C}{\beta} = \frac{3.85\ \text{mA}}{220} = \mathbf{17.5\ \mu A}$$

$V_C = -V_{CC} + I_C R_C$
$= -22\ \text{V} + (3.85\ \text{mA})(2.2\ \text{k}\Omega)$
$= \mathbf{-13.53\ V}$

47. (a) $S(I_{CO}) = \beta + 1 =$ **91**

(b) $$S(V_{BE}) = \frac{-\beta}{R_B} = \frac{-90}{470\ \text{k}\Omega} = \mathbf{-1.92 \times 10^{-4}\ S}$$

(c) $$S(\beta) = \frac{I_{C_1}}{\beta_1} = \frac{2.93\ \text{mA}}{90} = \mathbf{32.56 \times 10^{-6}\ A}$$

(d) $\Delta I_C = S(I_{CO})\Delta I_{CO} + S(V_{BE})\Delta V_{BE} + S(\beta)\Delta\beta$
$= (91)(10\ \mu\text{A} - 0.2\ \mu\text{A}) + (-1.92 \times 10^{-4}\text{S})(0.5\ \text{V} - 0.7\ \text{V}) + (32.56 \times 10^{-6}\text{A})(112.5 - 90)$
$= (91)(9.8\ \mu\text{A}) + (1.92 \times 10^{-4}\text{S})(0.2\ \text{V}) + (32.56 \times 10^{-6}\text{A})(22.5)$
$= 8.92 \times 10^{-4}\text{A} + 0.384 \times 10^{-4}\text{A} + 7.326 \times 10^{-4}\text{A}$
$= 16.63 \times 10^{-4}\text{A}$
$\cong$ **1.66 mA**

49. (a) $R_{Th} = 62\text{ k}\Omega \parallel 9.1\text{ k}\Omega = 7.94\text{ k}\Omega$

$$S(I_{CO}) = (\beta + 1)\frac{1 + R_{Th}/R_E}{(\beta+1) + R_{Th}/R_E} = (80+1)\frac{(1+7.94\text{ k}\Omega/0.68\text{ k}\Omega)}{(80+1)+7.94\text{ k}\Omega/0.68\text{ k}\Omega}$$

$$= \frac{(81)(1+11.68)}{81+11.68} = \mathbf{11.08}$$

(b) $$S(V_{BE}) = \frac{-\beta}{R_{Th}+(\beta+1)R_E} = \frac{-80}{7.94\text{ k}\Omega + (81)(0.68\text{ k}\Omega)}$$

$$= \frac{-80}{7.94\text{ k}\Omega + 55.08\text{ k}\Omega} = \mathbf{-1.27 \times 10^{-3} S}$$

(c) $$S(\beta) = \frac{I_{C_1}(1+R_{Th}/R_E)}{\beta_1(1+\beta_2+R_{Th}/R_E)} = \frac{1.71\text{ mA}(1+7.94\text{ k}\Omega/0.68\text{ k}\Omega)}{80(1+100+7.94\text{ k}\Omega/0.68\text{ k}\Omega)}$$

$$= \frac{1.71\text{ mA}(12.68)}{80(112.68)} = \mathbf{2.41 \times 10^{-6}\ A}$$

(d) $\Delta I_C = S(I_{CO})\Delta I_{CO} + S(V_{BE})\,\Delta V_{BE} + S(\beta)\Delta\beta$

$= (11.08)(10\ \mu\text{A} - 0.2\ \mu\text{A}) + (-1.27 \times 10^{-3}\text{S})(0.5\text{ V} - 0.7\text{ V}) + (2.41 \times 10^{-6}\text{A})(100 - 80)$

$= (11.08)(9.8\ \mu\text{A}) + (-1.27 \times 10^{-3}\text{S})(-0.2\text{ V}) + (2.41 \times 10^{-6}\text{A})(20)$

$= 1.09 \times 10^{-4}\text{A} + 2.54 \times 10^{-4}\text{A} + 0.482 \times 10^{-4}\text{A}$

$= 4.11 \times 10^{-4}\text{A} =$ **0.411 mA**

51.

Type	$S(I_{CO})$	$S(V_{BE})$	$S(\beta)$
Collector ~~F~~feedback	83.69	-1.477×10^{-4}S	4.83×10^{-6} A
Emitter-bias	78.1	-1.512×10^{-4}S	21.37×10^{-6} A
Voltage-divider	11.08	-12.7×10^{-4}S	2.41×10^{-6}A
Fixed-bias	91	-1.92×10^{-4}S	32.56×10^{-6} A

$S(I_{CO})$: Considerably less for the voltage-divider configuration compared to the other three.

$S(V_{BE})$: The voltage-divider configuration is more sensitive than the other three (which have similar levels of sensitivity~~.~~).

$S(\beta)$~~J~~: The voltage-divider configuration is the least sensitive with the fixed-bias configuration very sensitive.

In general, the voltage-divider configuration is the least sensitive with the fixed-bias the most sensitive.

Chapter 4 (Even)

2. (a) $I_C = \beta I_B = 80(40\ \mu\text{A}) = \mathbf{3.2\ mA}$

(b) $R_C = \dfrac{V_{R_C}}{I_C} = \dfrac{V_{CC} - V_C}{I_C} = \dfrac{12\text{ V} - 6\text{ V}}{3.2\text{ mA}} = \dfrac{6\text{ V}}{3.2\text{ mA}} = \mathbf{1.875\ k\Omega}$

(c) $R_B = \dfrac{V_{R_B}}{I_B} = \dfrac{12\text{ V} - 0.7\text{ V}}{40\ \mu\text{A}} = \dfrac{11.3\text{ V}}{40\ \mu\text{A}} = \mathbf{282.5\ k\Omega}$

(d) $V_{CE} = V_C = \mathbf{6\ V}$

4. $I_{C_{\text{sat}}} = \dfrac{V_{CC}}{R_C} = \dfrac{16\text{ V}}{2.7\text{ k}\Omega} = \mathbf{5.93\ mA}$

6. (a) $I_{B_Q} = \dfrac{V_{CC} - V_{BE}}{R_B + (\beta + 1)R_E} = \dfrac{20\text{ V} - 0.7\text{ V}}{510\text{ k}\Omega + (101)1.5\text{ k}\Omega} = \dfrac{19.3\text{ V}}{661.5\text{ k}\Omega}$
$= \mathbf{29.18\ \mu A}$

(b) $I_{C_Q} = \beta I_{B_Q} = (100)(29.18\ \mu\text{A}) = \mathbf{2.92\ mA}$

(c) $V_{CE_Q} = V_{CC} - I_C(R_C + R_E) = 20\text{ V} - (2.92\text{ mA})(2.4\text{ k}\Omega + 1.5\text{ k}\Omega)$
$= 20\text{ V} - 11.388\text{ V}$
$= \mathbf{8.61\ V}$

(d) $V_C = V_{CC} - I_C R_C = 20\text{ V} - (2.92\text{ mA})(2.4\text{ k}\Omega) = 20\text{ V} - 7.008\text{ V}$
$= \mathbf{13\ V}$

(e) $V_B = V_{CC} - I_B R_B = 20\text{ V} - (29.18\ \mu\text{A})(510\text{ k}\Omega)$
$= 20\text{ V} - 14.882\text{ V} = \mathbf{5.12\ V}$

(f) $V_E = V_C - V_{CE} = 13\text{ V} - 8.61\text{ V} = \mathbf{4.39\ V}$

8. (a) $I_C \cong I_E = \dfrac{V_E}{R_E} = \dfrac{2.1\text{ V}}{0.68\text{ k}\Omega} = 3.09\text{ mA}$

$\beta = \dfrac{I_C}{I_B} = \dfrac{3.09\text{ mA}}{20\ \mu\text{A}} = \mathbf{154.5}$

(b) $V_{CC} = V_{R_C} + V_{CE} + V_E$
$= (3.09\text{ mA})(2.7\text{ k}\Omega) + 7.3\text{ V} + 2.1\text{ V} = 8.34\text{ V} + 7.3\text{ V} + 2.1\text{ V}$
$= \mathbf{17.74\ V}$

(c) $R_B = \dfrac{V_{R_B}}{I_B} = \dfrac{V_{CC} - V_{BE} - V_E}{I_B} = \dfrac{17.74\text{ V} - 0.7\text{ V} - 2.1\text{ V}}{20\ \mu\text{A}}$
$= \dfrac{14.94\text{ V}}{20\ \mu\text{A}} = \mathbf{747\ k\Omega}$

10. (a) $I_{C_{sat}} = 6.8\text{ mA} = \dfrac{V_{CC}}{R_C + R_E} = \dfrac{24\text{ V}}{R_C + 1.2\text{ k}\Omega}$

$$R_C + \cancel{=} 1.2\text{ k}\Omega = \frac{24\text{ V}}{6.8\text{ mA}} = 3.529\text{ k}\Omega$$

$$R_C = \mathbf{2.33\text{ k}\Omega}$$

(b) $\beta = \dfrac{I_C}{I_B} = \dfrac{4\text{ mA}}{30\ \mu\text{A}} = \mathbf{133.33}$

(c) $R_B = \dfrac{V_{R_B}}{I_B} = \dfrac{V_{CC} - V_{BE} - V_E}{I_B} = \dfrac{24\text{ V} - 0.7\text{ V} - (4\text{ mA})(1.2\text{ k}\Omega)}{30\ \mu\text{A}}$

$$= \frac{18.5\text{ V}}{30\ \mu\text{A}} = \mathbf{616.67\text{ k}\Omega}$$

(d) $P_D = V_{CE_Q} I_{C_Q}$

$$= (10\text{ V})(4\text{ mA}) = \mathbf{40\text{ mW}}$$

(e) $P = I_C^2 R_C = (4\text{ mA})^2(2.33\text{ k}\Omega)$

$$= \mathbf{37.28\text{ mW}}$$

12. $\beta R_E \overset{?}{\geq} 10R_2$

$(80)(0.68\text{ k}\Omega) \geq 10(9.1\text{ k}\Omega)$

$54.4\text{ k}\Omega \ngeq 91\text{ k}\Omega$ (No!)

(a) Use e~~E~~xact approach:

$$R_{Th} = R_1 \parallel R_2 = 62\text{ k}\Omega \parallel 9.1\text{ k}\Omega = 7.94\text{ k}\Omega$$

$$E_{Th} = \frac{R_2 V_{CC}}{R_2 + R_1} = \frac{(9.1\text{ k}\Omega)(16\text{ V})}{9.1\text{ k}\Omega + 62\text{ k}\Omega} = 2.05\text{ V}$$

$$I_{B_Q} = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta + 1)R_E} = \frac{2.05\text{ V} - 0.7\text{ V}}{7.94\text{ k}\Omega + (81)(0.68\text{ k}\Omega)}$$

$$= \mathbf{21.42\ \mu A}$$

(b) $I_{C_Q} = \beta I_{B_Q} = (80)(21.42\ \mu\text{A}) = \mathbf{1.71\text{ mA}}$

(c) $V_{CE_Q} = V_{CC} - I_{C_Q}(R_C + R_E)$

$$= 16\text{ V} - (1.71\text{ mA})(3.9\text{ k}\Omega + 0.68\text{ k}\Omega)$$

$$= \mathbf{8.17\text{ V}}$$

(d) $V_C = V_{CC} - I_C R_C$

$$= 16\text{ V} - (1.71\text{ mA})(3.9\text{ k}\Omega)$$

$$= \mathbf{9.33\text{ V}}$$

(e) $V_E = I_E R_E \cong I_C R_E = (1.71\text{ mA})(0.68\text{ k}\Omega)$

$$= \mathbf{1.16\text{ V}}$$

(f) $V_B = V_E + V_{BE} = 1.16\text{ V} + 0.7\text{ V}$
$= \mathbf{1.86\ V}$

14. (a) $I_C = \beta I_B = (100)(20\ \mu\text{A}) = \mathbf{2\ mA}$

(b) $I_E = I_C + I_B = 2\text{ mA} + 20\ \mu\text{A}$
$= 2.02\text{ mA}$
$V_E = I_E R_E = (2.02\text{ mA})(1.2\text{ k}\Omega)$
$= \mathbf{2.42\ V}$

(c) $V_{CC} = V_C + I_C R_C = 10.6\text{ V} + (2\text{ mA})(2.7\text{ k}\Omega)$
$= 10.6\text{ V} + 5.4\text{ V}$
$= \mathbf{16\ V}$

(d) $V_{CE} = V_C - V_E = 10.6\text{ V} - 2.42\text{ V}$
$= \mathbf{8.18\ V}$

(e) $V_B = V_E + V_{BE} = 2.42\text{ V} + 0.7\text{ V} = \mathbf{3.12\ V}$

(f) $I_{R_1} = I_{R_2} + I_B$

$$= \frac{3.12\text{ V}}{8.2\text{ k}\Omega} + 20\ \mu\text{A} = 380.5\ \mu\text{A} + 20\ \mu\text{A} = 400.5\ \mu\text{A}$$

$$R_1 = \frac{V_{CC} - V_B}{I_{R_1}} = \frac{16\text{ V} - 3.12\text{ V}}{400.5\ \mu\text{A}} = \mathbf{32.16\ k\Omega}$$

16. (a) $\beta R_E \geq 10R_2$
$(120)(1\text{ k}\Omega) \geq 10(8.2\text{ k}\Omega)$
$120\text{ k}\Omega \geq 82\text{ k}\Omega$ (checks)

$$\therefore V_B = \frac{R_2 V_{CC}}{R_1 + R_2} = \frac{(8.2\text{ k}\Omega)(18\text{ V})}{39\text{ k}\Omega + 8.2\text{ k}\Omega} = 3.13\text{ V}$$

$V_E = V_B - V_{BE} = 3.13\text{ V} - 0.7\text{ V} = 2.43\text{ V}$

$$I_C \cong I_E = \frac{V_E}{R_E} = \frac{2.43\text{ V}}{1\text{ k}\Omega} = \mathbf{2.43\ mA}$$

(b) $V_{CE} = V_{CC} - I_C(R_C + R_E)$
$= 18\text{ V} - (2.43\text{ mA})(3.3\text{ k}\Omega + 1\text{ k}\Omega)$
$= \mathbf{7.55\ V}$

(c) $$I_B = \frac{I_C}{\beta} = \frac{2.43\text{ mA}}{120} = \mathbf{20.25\ \mu A}$$

(d) $V_E = I_E R_E \cong I_C R_E = (2.43\text{ mA})(1\text{ k}\Omega) = \mathbf{2.43\ V}$

(e) $V_B = \mathbf{3.13\ V}$

18. (a) $V_B = \dfrac{R_2}{R_1 + R_2} V_{CC} = \dfrac{9.1\text{ k}\Omega(16\text{ V})}{62\text{ k}\Omega + 9.1\text{ k}\Omega} = 2.05\text{ V}$

$V_E = V_B - V_{BE} = 2.05\text{ V} - 0.7\text{ V} = 1.35\text{ V}$

$I_E = \dfrac{V_E}{R_E} = \dfrac{1.35\text{ V}}{0.68\text{ k}\Omega} = 1.99\text{ mA}$

$I_{C_Q} \cong I_E = \mathbf{1.99\text{ mA}}$

$V_{CE_Q} = V_{CC} - I_C(R_C + R_E)$

$= 16\text{ V} - (1.99\text{ mA})(3.9\text{ k}\Omega + 0.68\text{ k}\Omega)$

$= 16\text{ V} - 9.11\text{ V}$

$= \mathbf{6.89\text{ V}}$

$I_{B_Q} = \dfrac{I_{C_Q}}{\beta} = \dfrac{1.99\text{ mA}}{80} = \mathbf{24.88\ \mu A}$

(b) From Problem 12:

$I_{C_Q} = \mathbf{1.71\text{ mA}}$, $V_{CE_Q} = \mathbf{8.17\text{ V}}$, $I_{B_Q} = \mathbf{21.42\ \mu A}$

(c) The differences of about 14% suggest that the exact approach should be employed when appropriate.

20. (a) From problem~~s~~ 12b, $I_C = \mathbf{1.71\text{ mA}}$

From problem 12c, $V_{CE} = \mathbf{8.17\text{ V}}$

(b) β changed to 120:

From problem 12a, $E_{Th} = 2.05\text{ V}$, $R_{Th} = 7.94\text{ k}\Omega$

$I_B = \dfrac{E_{Th} - V_{BE}}{R_{Th} + (\beta + 1)R_E} = \dfrac{2.05\text{ V} - 0.7\text{ V}}{7.94\text{ k}\Omega + (121)(0.68\text{ k}\Omega)}$

$= 14.96\ \mu A$

$I_C = \beta I_B = (120)(14.96\ \mu A) = \mathbf{1.8\text{ mA}}$

$V_{CE} = V_{CC} - I_C(R_C + R_E)$

$= 16\text{ V} - (1.8\text{ mA})(3.9\text{ k}\Omega + 0.68\text{ k}\Omega)$

$= \mathbf{7.76\text{ V}}$

(c) $\%\Delta I_C = \left|\dfrac{1.8\text{ mA} - 1.71\text{ mA}}{1.71\text{ mA}}\right| \times 100\% = \mathbf{5.26\%}$

$\%\Delta V_{CE} = \left|\dfrac{7.76\text{ V} - 8.17\text{ V}}{8.17\text{ V}}\right| \times 100\% = \mathbf{5.02\%}$

(d)

	11c	11f	20c
$\%\Delta I_C$	49.83%	34.59%	5.26%
$\%\Delta V_{CE}$	48.70%	46.76%	5.02%
	Fixed-bias	Emitter f~~F~~eedback	Voltage-divider

(e) Quitse obviously, the voltage-divider configuration is the least sensitive to changes in β.

22. (a) $I_B = \dfrac{V_{CC} - V_{BE}}{R_B + \beta(R_C + R_E)} = \dfrac{16\text{ V} - 0.7\text{ V}}{470\text{ k}\Omega + (120)(3.6\text{ k}\Omega + 0.51\text{ k}\Omega)}$

$= \mathbf{15.88\ \mu A}$

(b) $I_C = \beta I_B = (120)(15.88\ \mu\text{A})$

$= \mathbf{1.91\ mA}$

(c) $V_C = V_{CC} - I_C R_C$

$= 16\text{ V} - (1.91\text{ mA})(3.6\text{ k}\Omega)$

$= \mathbf{9.12\ V}$

24. (a) $I_B = \dfrac{V_{CC} - V_{BE}}{R_B + \beta(R_C + R_E)} = \dfrac{22\text{ V} - 0.7\text{ V}}{470\text{ k}\Omega + (90)(9.1\text{ k}\Omega + 9.1\text{ k}\Omega)}$

$= 10.09\ \mu\text{A}$

$I_C = \beta I_B = (90)(10.09\ \mu\text{A}) = \mathbf{0.91\ mA}$

$V_{CE} = V_{CC} - I_C(R_C + R_E) = 22\text{ V} - (0.91\text{ mA})(9.1\text{ k}\Omega + 9.1\text{ k}\Omega)$

$= \mathbf{5.44\ V}$

(b) $\beta = 135$, $I_B = \dfrac{V_{CC} - V_{BE}}{R_B + \beta(R_C + R_E)} = \dfrac{22\text{ V} - 0.7\text{ V}}{470\text{ k}\Omega + (135)(9.1\text{ k}\Omega + 9.1\text{ k}\Omega)}$

$= 7.28\ \mu\text{A}$

$I_C = \beta I_B = (135)(7.28\ \mu\text{A}) = \mathbf{0.983\ mA}$

$V_{CE} = V_{CC} - I_C(R_C + R_E) = 22\text{ V} - (0.983\text{ mA})(9.1\text{ k}\Omega + 9.1\text{ k}\Omega)$

$= \mathbf{4.11\ V}$

(c) $\%\Delta I_C = \left|\dfrac{0.983\text{ mA} - 0.91\text{ mA}}{0.91\text{ mA}}\right| \times 100\% = \mathbf{8.02\%}$

$\%\Delta V_{CE} = \left|\dfrac{4.11\text{ V} - 5.44\text{ V}}{5.44\text{ V}}\right| \times 100\% = \mathbf{24.45\%}$

(d) The results for the collector feedback configuration are closer to the voltage-divider configuration than to the other two. However, the voltage-divider configuration continues to have the least sensitivities to change in β.

26. (a) $V_E = V_B - V_{BE} = 4\text{ V} - 0.7\text{ V} = \mathbf{3.3\ V}$

(b) $I_C \cong I_E = \dfrac{V_E}{R_E} = \dfrac{3.3\text{ V}}{1.2\text{ k}\Omega} = \mathbf{2.75\ mA}$

(c) $V_C = V_{CC} - I_C R_C = 18\text{ V} - (2.75\text{ mA})(2.2\text{ k}\Omega)$

$= \mathbf{11.95\ V}$

(d) $V_{CE} = V_C - V_E = 11.95\text{ V} - 3.3\text{ V} = \mathbf{8.65\ V}$

(e) $I_B = \dfrac{V_{R_B}}{R_B} = \dfrac{V_C - V_B}{R_B} = \dfrac{11.95\text{ V} - 4\text{ V}}{330\text{ k}\Omega} = \mathbf{24.09\ \mu A}$

(f) $\beta = \dfrac{I_C}{I_B} = \dfrac{2.75\text{ mA}}{24.09\ \mu\text{A}} = \mathbf{114.16}$

28. (a) $I_B = \dfrac{V_{EE} - V_{BE}}{R_B + (\beta + 1)R_E} = \dfrac{12\text{ V} - 0.7\text{ V}}{9.1\text{ k}\Omega + (120+1)15\text{ k}\Omega}$

$= \mathbf{6.2\ \mu A}$

(b) $I_C = \beta I_B = (120)(6.2\ \mu\text{A}) = \mathbf{0.744\ mA}$

(c) $V_{CE} = V_{CC} + V_{EE} - I_C(R_C + R_E)$

$= 16\text{ V} + 12\text{ V} - (0.744\text{ mA})(27\text{ k}\Omega)$

$= \mathbf{7.91\ V}$

(d) $V_C = V_{CC} - I_C R_C = 16\text{ V} - (0.744\text{ mA})(12\text{ k}\Omega) = \mathbf{7.07\ V}$

30. (a) $I_B = \dfrac{V_{CC} + V_{EE} - V_{BE}}{R_B + (\beta + 1)R_E} = \dfrac{6\text{ V} + 6\text{ V} - 0.7\text{ V}}{330\text{ k}\Omega + (121)(1.2\text{ k}\Omega)}$

$= 23.78\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (121)(23.78\ \mu\text{A})$

$= \mathbf{2.88\ mA}$

$-V_{EE} + I_E R_E - V_E = 0$

$V_E = -V_{EE} + I_E R_E = -6\text{ V} + (2.88\text{ mA})(1.2\text{ k}\Omega)$

$= \mathbf{-2.54\ V}$

32. $I_B = \dfrac{I_C}{\beta} = \dfrac{2.5\text{ mA}}{80} = 31.25\ \mu\text{A}$

$R_B = \dfrac{V_{R_B}}{I_B} = \dfrac{V_{CC} - V_{BE}}{I_B} = \dfrac{12\text{ V} - 0.7\text{ V}}{31.25\ \mu\text{A}} = \mathbf{361.6\ k\Omega}$

$R_C = \dfrac{V_{R_C}}{I_C} = \dfrac{V_{CC} - V_C}{I_C} = \dfrac{V_{CC} - V_{CE_Q}}{I_{C_Q}} = \dfrac{12\text{ V} - 6\text{ V}}{2.5\text{ mA}} = \dfrac{6\text{ V}}{2.5\text{ mA}}$

$= \mathbf{2.4\ k\Omega}$

Standard values:

$R_B = \mathbf{360\ k\Omega}$

$R_C = \mathbf{2.4\ k\Omega}$

34. $R_E = \dfrac{V_E}{I_E} \cong \dfrac{V_E}{I_C} = \dfrac{3\text{ V}}{4\text{ mA}} = \mathbf{0.75\ k\Omega}$

$R_C = \dfrac{V_{R_C}}{I_C} = \dfrac{V_{CC} - V_C}{I_C} = \dfrac{V_{CC} - (V_{CE_Q} + V_E)}{I_C}$

$= \dfrac{24\text{ V} - (8\text{ V} + 3\text{ V})}{4\text{ mA}} = \dfrac{24\text{ V} - 11\text{ V}}{4\text{ mA}} = \dfrac{13\text{ V}}{4\text{ mA}} = \mathbf{3.25\ k\Omega}$

$V_B = V_E + V_{BE} = 3\text{ V} + 0.7\text{ V} = 3.7\text{ V}$

$V_B = \dfrac{R_2 V_{CC}}{R_2 + R_1} \Rightarrow 3.7\text{ V} = \left.\dfrac{R_2(24\text{ V})}{R_2 + R_1}\right\}$ 2 unknowns!

$\therefore$ use $\beta R_E \geq 10R_2$ for increased stability

$(110)(0.75\text{ k}\Omega) = 10R_2$

$R_2 = 8.25\text{ k}\Omega$

Choose $R_2 = \mathbf{7.5\text{ k}\Omega}$

Substituting in the above equation:

$$3.7\text{ V} = \frac{7.5\text{ k}\Omega(24\text{ V})}{7.5\text{ k}\Omega + R_1}$$

$R_1 = \mathbf{41.15\text{ k}\Omega}$

Standard values:

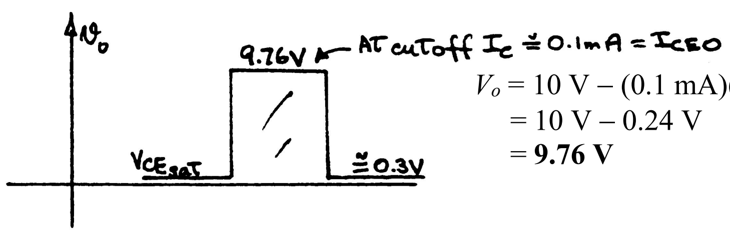
$R_E = \mathbf{0.75\text{ k}\Omega}$, $R_C = \mathbf{3.3\text{ k}\Omega}$, $R_2 = \mathbf{7.5\text{ k}\Omega}$, $R_1 = \mathbf{43\text{ k}\Omega}$

36. $$I_{C_{\text{sat}}} = \frac{V_{CC}}{R_C} = \frac{10\text{ V}}{2.4\text{ k}\Omega} = \mathbf{4.167\text{ mA}}$$

From characteristics $I_{B_{\max}} \cong 31\ \mu\text{A}$

$$I_B = \frac{V_i - V_{BE}}{R_B} = \frac{10\text{ V} - 0.7\text{ V}}{180\text{ k}\Omega} = 51.67\ \mu\text{A}$$

$51.67\ \mu\text{A} \gg 31\ \mu\text{A}$, well saturated



$V_o = 10\text{ V} - (0.1\text{ mA})(2.4\text{ k}\Omega)$

$= 10\text{ V} - 0.24\text{ V}$

$= \mathbf{9.76\text{ V}}$

38. (a) From Fig. 3.23c:

$I_C = 2\text{ mA}$: $t_f = 38\text{ ns}$, $t_r = 48\text{ ns}$, $t_d = 120\text{ ns}$, $t_s = 110\text{ ns}$

$t_{\text{on}} = t_r + t_d = 48\text{ ns} + 120\text{ ns} = \mathbf{168\text{ ns}}$

$t_{\text{off}} = t_s + t_f = 110\text{ ns} + 38\text{ ns} = \mathbf{148\text{ ns}}$

(b) $I_C = 10\text{ mA}$: $t_f = 12\text{ ns}$, $t_r = 15\text{ ns}$, $t_d = 22\text{ ns}$, $t_s = 120\text{ ns}$

$t_{\text{on}} = t_r + t_d = 15\text{ ns} + 22\text{ ns} = \mathbf{37\text{ ns}}$

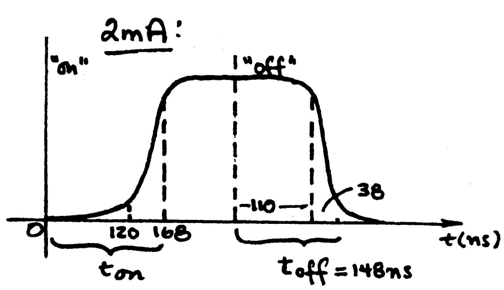
$t_{\text{off}} = t_s + t_f = 120\text{ ns} + 12\text{ ns} = \mathbf{132\text{ ns}}$

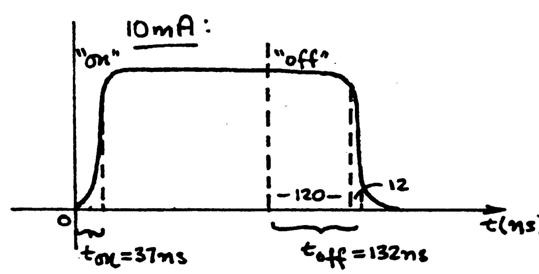
The turn-on time has dropped dramatically

168 ns:37 ns = **4.54:1**

while the turn-off time is only slightly smaller

148 ns:132 ns = **1.12:1**





40. (a) The base voltage of 9.4 V reveals that the 18 kΩ resistor is not making contact with the base terminal of the transistor ~~is operating properly:~~.

If operating properly:

$$V_B \cong \frac{18\text{ k}\Omega(16\text{ V})}{18\text{ k}\Omega + 91\text{ k}\Omega} = \mathbf{2.64\ V}\text{ vs. }9.4\text{ V}$$

As an emitter feedback bias circuit:

$$I_B = \frac{V_{CC} - V_{BE}}{R_1 + (\beta+1)R_E} = \frac{16\text{ V} - 0.7\text{ V}}{91\text{ k}\Omega + (100+1)1.2\text{ k}\Omega}$$
$$= 7\cancel{.}2.1\ \mu\text{A}$$
$$V_B = V_{CC} - I_B(R_1) = 16\text{ V} - (72.1\ \mu\text{A})(91\text{ k}\Omega)$$
$$= \mathbf{9.4\ V}$$

(b) Since $V_E > V_B$ the transistor should be "off~~OFF~~"

With $I_B = 0\ \mu\text{A}$, $V_B = \dfrac{18\text{ k}\Omega(16\text{ V})}{18\text{ k}\Omega + 91\text{ k}\Omega} = 2.64\text{ V}$

$\therefore$ Assume base circuit "open"

The 4 V at the emitter is the voltage that would exist i~~o~~f the transistor were shorted collector to emitter.

$$V_E = \frac{1.2\text{ k}\Omega(16\text{ V})}{1.2\text{ k}\Omega + 3.6\text{ k}\Omega} = \mathbf{4\ V}$$

42. (a) $I_B = \dfrac{E_{Th} - V_{BE}}{R_{Th} + (\beta+1)R_E} \cong \dfrac{E_{Th} - V_{BE}}{R_{Th} + \beta R_E}$

$$I_C = \beta I_B = \beta\left[\frac{E_{Th} - V_{BE}}{R_{Th} + \beta R_E}\right] = \frac{E_{Th} - V_{BE}}{\dfrac{R_{Th}}{\beta} + R_E}$$

As $\beta\uparrow$, $\dfrac{R_{Th}}{\beta}\downarrow$,~~;~~ $I_C\uparrow$, $V_{R_C}\uparrow$

$V_C = V_{CC} - V_{R_C}$

and $\boldsymbol{V_C}\downarrow$

(b) $R_2 = \text{open}$, $I_B\uparrow$, $I_C\uparrow$

$V_{CE} = V_{CC} - I_C(R_C + R_E)$

and $\boldsymbol{V_{CE}}\downarrow$

(c) $V_{CC}\downarrow$, $V_B\downarrow$, $V_E\downarrow$, $I_E\downarrow$, $\boldsymbol{I_C}\downarrow$

(d) $I_B = 0\ \mu\text{A}$, $I_C = I_{CEO}$ and $I_C(R_C + R_E)$ negligible with $V_{CE} \cong V_{CC} = \mathbf{20\ V}$

(e) Base-emitter junction = short $I_B\uparrow$ but transistor action lost and $I_C = 0$ mA with $V_{CE} = V_{CC} = \mathbf{20\ V}$

44. $I_B = \dfrac{V_{CC} - V_{BE}}{R_B} = \dfrac{12\text{ V} - 0.7\text{ V}}{510\text{ k}\Omega} = \dfrac{11.3\text{ V}}{510\text{ k}\Omega} = 22.16\ \mu\text{A}$

$I_C = \beta I_B = (100)(22.16\ \mu\text{A}) = \mathbf{2.216\ mA}$

$V_C = -V_{CC} + I_C R_C = -12\text{ V} + (2.216\text{ mA})(3.3\text{ k}\Omega)$

$= \mathbf{-4.69\ V}$

$V_{CE} = V_C = \mathbf{-4.69\ V}$

46. $I_E = \dfrac{V - V_{BE}}{R_E} = \dfrac{8\text{ V} - 0.7\text{ V}}{3.3\text{ k}\Omega} = \dfrac{7.3\text{ V}}{3.3\text{ k}\Omega} = \mathbf{2.212\ mA}$

$V_C = -V_{CC} + I_C R_C = -12\text{ V} + (2.212\text{ mA})(3.9\text{ k}\Omega)$

$= \mathbf{-3.37\ V}$

48. For the emitter-bias:

(a) $S(I_{CO}) = (\beta + 1)\dfrac{(1 + R_B/R_E)}{(\beta+1) + R_B/R_E} = (100+1)\dfrac{(1 + 510\text{ k}\Omega/1.5\text{ k}\Omega)}{(100+1) + 510\text{ k}\Omega/1.5\text{ k}\Omega}$

$= \mathbf{78.1}$

(b) $S(V_{BE}) = \dfrac{-\beta}{R_B + (\beta+1)R_E} = \dfrac{-100}{510\text{ k}\Omega + (100+1)1.5\text{ k}\Omega}$

$= \mathbf{-1.512 \times 10^{-4}S}$

(c) $S(\beta) = \dfrac{I_{C_1}(1 + R_B/R_E)}{\beta_1(1 + \beta_2 + R_B/R_E)} = \dfrac{2.92\text{ mA}(1 + 340)}{100(1 + 125 + 340)}$

$= \mathbf{21.37 \times 10^{-6}A}$

(d) $\Delta I_C = S(I_{CO})\Delta I_{CO} + S(V_{BE})\Delta V_{BE} + S(\beta)\Delta\beta$

$= (78.1)(9.8\ \mu\text{A}) + (-1.512 \times 10^{-14}\underline{\text{S}})(-0.2\text{ V}) + (21.37 \times 10^{-6}\text{ A})(25)$

$= 0.7654\text{ mA} + 0.0302\text{ mA} + 0.5343\text{ mA}$

$= \mathbf{1.33\ mA}$

50. For collector-feedback bias:

(a) $S(I_{CO}) = (\beta + 1)\dfrac{(1 + R_B/R_C)}{(\beta+1) + R_B/R_C} = (196.32+1)\dfrac{(1 + 560\text{ k}\Omega/3.9\text{ k}\Omega)}{(196.32+1) + 560\text{ k}\Omega/3.9\text{ k}\Omega}$

$= (197.32)\dfrac{1 + 143.59}{(197.32 + 143.59)}$

$= \mathbf{83.69}$

(b) $S(V_{BE}) = \dfrac{-\beta}{R_B + (\beta+1)R_C} = \dfrac{-196.32}{560\text{ k}\Omega + (196.32+1)3.9\text{ k}\Omega}$

$= \mathbf{-1.477 \times 10^{-4}}\underline{\mathbf{S}}\cancel{\mathbf{S}}$

(c) $S(\beta) = \dfrac{I_{C_1}(R_B + R_C)}{\beta_1(R_B + R_C(\beta_2 + 1))} = \dfrac{2.56\text{ mA}(560\text{ k}\Omega + 3.9\text{ k}\Omega)}{196.32(560\text{ k}\Omega + 3.9\text{ k}\Omega(245.4 + 1))}$

$= \mathbf{4.83 \times 10^{-6}A}$

(d) $\Delta I_C = S(I_{CO})\Delta I_{CO} + S(V_{BE})\,\Delta V_{BE} + S(\beta)\Delta\beta$
$= (83.69)(9.8\ \mu\text{A}) + (-1.477 \times 10^{-4}\text{S})(-0.2\text{ V}) + (4.83 \times 10^{-6}\text{A})(49.1)$
$= 8.20 \times 10^{-4}\text{A} + 0.295 \times 10^{-4}\text{A} + 2.372 \times 10^{-4}\text{A}$
$= 10.867 \times 10^{-4}\text{A} =$ **1.087 mA**

52. (a) Fixed-bias:
$S(I_{CO}) = 91$, $\Delta I_C = 0.892$ mA
$S(V_{BE}) = -1.92 \times 10^{-4}\text{S}$, $\Delta I_C = 0.0384$ mA
$S(\beta) = 32.56 \times 10^{-6}\text{A}$, $\Delta I_C = 0.7326$ mA

(b) Voltage-divider bias:
$S(I_{CO}) = 11.08$, $\Delta I_C = 0.1090$ mA
$S(V_{BE}) = -1.27 \times 10^{-3}\text{S}$, $\Delta I_C = 0.2540$ mA
$S(\beta) = 2.41 \times 10^{-6}\text{A}$, $\Delta I_C = 0.0482$ mA

(c) For the fixed-bias configuration there is a strong sensitivity to changes in I_{CO} and β and less to changes in V_{BE}.

For the voltage-divider configuration the opposite occurs with a high sensitivity to changes in V_{BE} and less to changes in I_{CO} and β.

In total the voltage-divider configuration is considerably more stable than the fixed-bias configuration.