Instructor's Resource Manual
to accompany

Electronic Devices and Circuit Theory

Tenth Edition

Robert L. Boylestad
Louis Nashelsky

PEARSON
Prentice Hall

Upper Saddle River, New Jersey
Columbus, Ohio

10 9 8 7 6 5 4 3 2 1

PEARSON
Prentice
Hall

ISBN-13: 978-0-13-503865-9
ISBN-10: 0-13-503865-0

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Chapter 1

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.

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.

3. –

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

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

   $$Q = \frac{W}{V} = \frac{76.8\times10^{-19}\text{ J}}{12\text{ V}} = \mathbf{6.40 \times 10^{-19}\ C}$$

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

6. | | | |
   |---|---|---|
   | GaP | Gallium Phosphide | E_g = **2.24 eV** |
   | ZnS | Zinc Sulfide | E_g = **3.67 eV** |

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.

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

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.

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

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

12. –

13. –

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

15. $T_K = 20 + 273 = 293$
$k = 11{,}600/n = 11{,}600/2$ (low value of V_D) $= 5800$
$$I_D = I_s\left(e^{\frac{kV_D}{T_K}} - 1\right) = 50 \times 10^{-9}\left(e^{\frac{(5800)(0.6)}{293}} - 1\right)$$
$$= 50 \times 10^{-9}\,(e^{11.877} - 1) = \mathbf{7.197\ mA}$$

16. $k = 11{,}600/n = 11{,}600/2 = 5800$ ($n = 2$ for $V_D = 0.6$ V)
$T_K = T_C + 273 = 100 + 273 = 373$
$$e^{kV/T_K} = e^{\frac{(5800)(0.6\text{ V})}{373}} = e^{9.33} = 11.27 \times 10^3$$
$$I = I_s(e^{kV/T_K} - 1) = 5\ \mu\text{A}(11.27 \times 10^3 - 1) = \mathbf{56.35\ mA}$$

17. (a) $T_K = 20 + 273 = 293$
$k = 11{,}600/n = 11{,}600/2 = 5800$
$$I_D = I_s\left(e^{\frac{kV_D}{T_K}} - 1\right) = 0.1\mu\text{A}\left(e^{\frac{(5800)(-10\text{ V})}{293}} - 1\right)$$
$$= 0.1 \times 10^{-6}(e^{-197.95} - 1) = 0.1 \times 10^{-6}(1.07 \times 10^{-86} - 1)$$
$$\cong 0.1 \times 10^{-6}\ 0.1\mu\text{A}$$
$$I_D = I_s = \mathbf{0.1\ \mu A}$$

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

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 $I = I_s(1 - 1) = \mathbf{0\ mA}$

19. $T = 20°C$: $I_s = 0.1\ \mu A$
$T = 30°C$: $I_s = 2(0.1\ \mu A) = 0.2\ \mu A$ (Doubles every 10°C rise in temperature)
$T = 40°C$: $I_s = 2(0.2\ \mu A) = 0.4\ \mu A$
$T = 50°C$: $I_s = 2(0.4\ \mu A) = 0.8\ \mu A$
$T = 60°C$: $I_s = 2(0.8\ \mu A) = \mathbf{1.6\ \mu A}$

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

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.

21. From 1.19:

	−75°C	25°C	125°C
V_F @ 10 mA	1.1 V	0.85 V	0.6 V
I_s	0.01 pA	1 pA	1.05 μA

V_F decreased with increase in temperature
1.1 V: 0.6 V $\cong$ **1.83:1**
I_s increased with increase in temperature
1.05 μA: 0.01 pA = $\mathbf{105 \times 10^3{:}1}$

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.

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.

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).

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

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

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

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

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

27. $V_D = -10$ V, $I_D = I_s = \mathbf{-0.1\ \mu A}$

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

$V_D = -30$ V, $I_D = I_s = \mathbf{-0.1\ \mu A}$

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

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

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

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

(c) quite close

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

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

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

$R_{DC} >> r_d$

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

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

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)

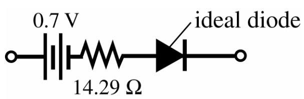
$I_D = 15$ mA, $r_d = \dfrac{26 \text{ mV}}{I_D} = \dfrac{26 \text{ mV}}{15 \text{ mA}} = \mathbf{1.73\ \Omega}$ vs 2 Ω (#30)

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

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

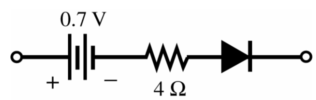
(relatively close to average value of 24.4 Ω (#32))

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



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

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



36. (a) $V_R = -25$ V: $C_T \cong$ **0.75 pF**
$V_R = -10$ 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) $V_R = -10$ V: $C_T \cong$ **1.25 pF**
$V_R = -1$ 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 ≅ **6:1**
Increased sensitivity near $V_D = 0$ V

37. From Fig. 1.33
$V_D = 0$ V, $C_D =$ **3.3 pF**
$V_D = 0.25$ V, $C_D =$ **9 pF**

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.

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

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

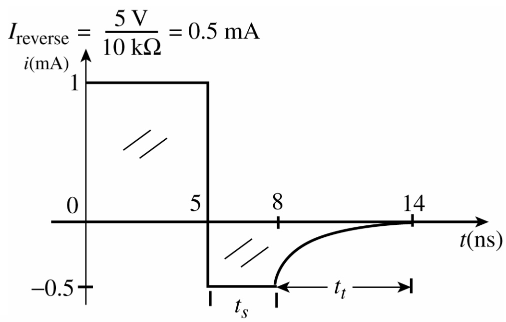
40. $I_f = \dfrac{10\text{ V}}{10\text{ k}\Omega} = 1$ mA

$t_s + t_t = t_{rr} = 9$ ns

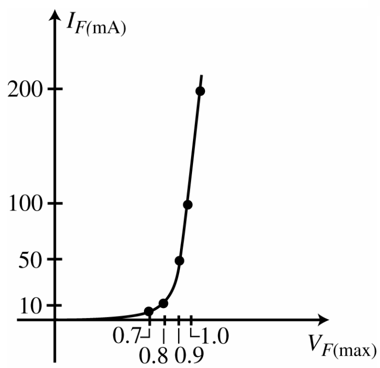
$t_s + 2t_s = 9$ ns

$t_s =$ **3 ns**

$t_t = 2t_s =$ **6 ns**



41.



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.

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.

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).

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.

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

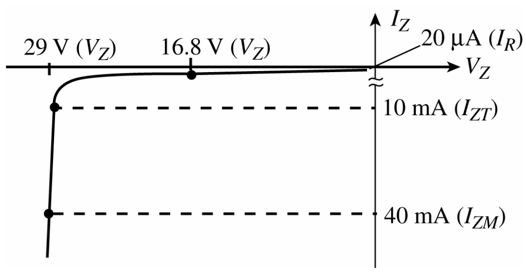
$$I_F = \frac{P_{\max}}{V_F} = \frac{500\text{ mW}}{0.7\text{ V}} = \mathbf{714.29\text{ mA}}$$

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

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

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

48.



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

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

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

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

$$T_1 = 104.17° + 25° = \mathbf{129.17°}$$

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

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

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.

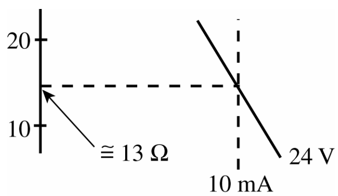
At $I_Z = 0.1$ mA, $T_C \cong 0.06\%/°\text{C}$

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

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**

52.



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.

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.

55. Fig. 1.53 (f) $I_F \cong$ **13 mA**

Fig. 1.53 (e) $V_F \cong$ **2.3 V**

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

@ 10 mA ≅ **1.02**

$\dfrac{1.02 - 0.82}{0.82} \times 100\% =$ **24.4%** increase

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

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

@ 35 mA ≅ **1.42**

$\dfrac{1.42 - 1.38}{1.38} \times 100\% =$ **2.9%** increase

ratio: $\dfrac{1.42}{1.38} =$ **1.03**

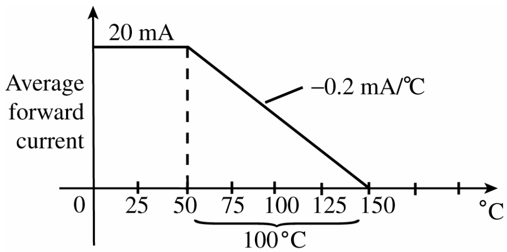
(c) For currents greater than about 30 mA the percent increase is significantly less than for increasing currents of lesser magnitude.

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

From Fig. 1.53 (i) $\measuredangle \cong \mathbf{75°}$

(b) $0.5 \Rightarrow \measuredangle = \mathbf{40\ °}$

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



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

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

Chapter 2

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 V – 0.92 V = **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 V – 0.7 V = **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 V – 0 V = **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.

2. (a) $I_D = \dfrac{E}{R} = \dfrac{5\text{ V}}{2.2\text{ k}\Omega}$ = 2.27 mA
The load line extends from I_D = 2.27 mA to V_D = 5 V.
$V_{D_Q} \cong \mathbf{0.7\ V}$, $I_{D_Q} \cong \mathbf{2\ mA}$

(b) $I_D = \dfrac{E}{R} = \dfrac{5\text{ V}}{0.47\text{ k}\Omega}$ = 10.64 mA
The load line extends from I_D = 10.64 mA to V_D = 5 V.
$V_{D_Q} \cong \mathbf{0.8\ V}$, $I_{D_Q} \cong \mathbf{9\ mA}$

(c) $I_D = \dfrac{E}{R} = \dfrac{5\text{ V}}{0.18\text{ k}\Omega}$ = 27.78 mA
The load line extends from I_D = 27.78 mA to V_D = 5 V.
$V_{D_Q} \cong \mathbf{0.93\ V}$, $I_{D_Q} \cong \mathbf{22.5\ mA}$

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

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 $R = \dfrac{7\text{ V}}{11.25\text{ mA}} = \mathbf{0.62\ k\Omega}$

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

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

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

$V_D = \mathbf{0\ V}$, $V_R = \mathbf{30\ V}$

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

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

(b) $V_{20\Omega} = 20\text{ V} - 0.7\text{ V} = 19.3\text{ V}$ (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

6. (a) Diode forward-biased,

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

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

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

(b) Diode forward-biased,

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

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

$= \mathbf{6.53\ V}$

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

$= \dfrac{1}{2}(20\text{ V} - 1\text{ V}) = \dfrac{1}{2}(19\text{ V}) = \mathbf{9.5\ V}$

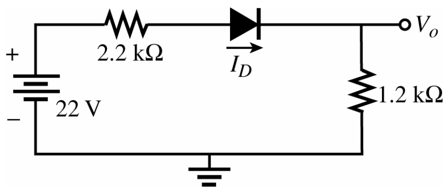
(b) $I = \dfrac{10\text{ V} + 2\text{ V} - 0.7\text{ V})}{1.2\text{ k}\Omega + 4.7\text{ k}\Omega} = \dfrac{11.3\text{ V}}{5.9\text{ k}\Omega} = 1.915\text{ mA}$

$V' = IR = (1.915\text{ mA})(4.7\text{ k}\Omega) = 9\text{ V}$

$V_o = V' - 2\text{ V} = 9\text{ V} - 2\text{ V} = \mathbf{7\ V}$

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):

$+V_o - 0.7\text{ V} + 5\text{ V} = 0$

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

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

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

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

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

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:

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

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

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

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

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

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

12. Both diodes forward-biased:

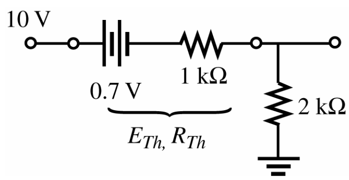
V_{o_1} = **0.7 V**, V_{o_2} = **0.3 V**

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

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

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

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:



$$V_o = \frac{2\text{ k}\Omega\,(10\text{ V} - 0.7\text{ V})}{1\text{ k}\Omega + 2\text{ k}\Omega} = \frac{2}{3}(9.3\text{ V}) = 6.2\text{ V}$$

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

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

14. Both diodes "off". The threshold voltage of 0.7 V is unavailable for either diode.

V_o = **0 V**

15. Both diodes "on", V_o = 10 V – 0.7 V = **9.3 V**

16. Both diodes "on".

V_o = **0.7 V**

17. Both diodes "off", V_o = **10 V**

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

V_o = –5 V + 0.7 V = **–4.3 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 V – 0.7 V = **–0.7 V**

The result supports the above assumptions.

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

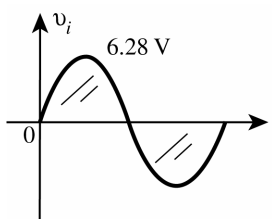
V_o = **+10 V**

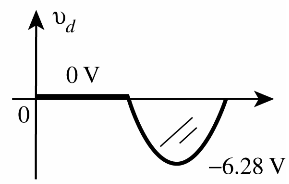
as established by 10 V supply connected to 1 kΩ resistor.

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”.

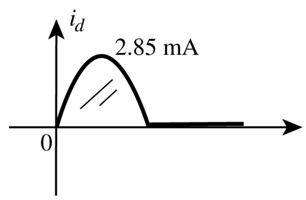
The result: $V_o = 5\text{ V} - 0.3\text{ V} = \mathbf{4.7\text{ V}}$
The result supports the above assumptions.

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

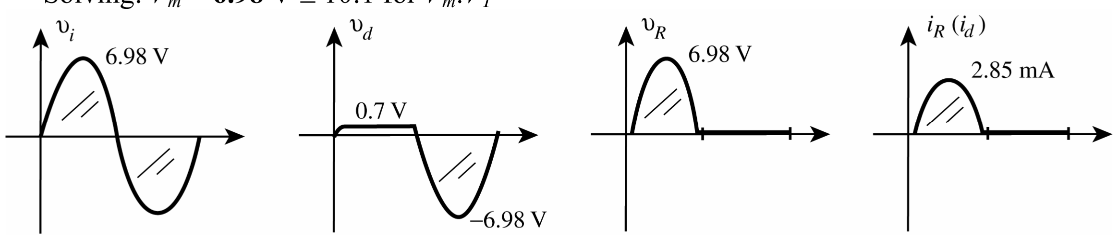




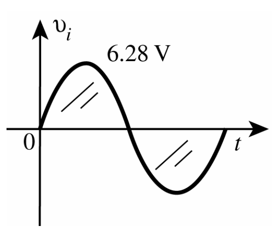
$I_m = \dfrac{V_m}{R} = \dfrac{6.28\text{ V}}{2.2\text{ k}\Omega} = \mathbf{2.85\text{ mA}}$

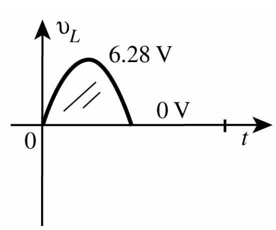


23. Using $V_{dc} \cong 0.318(V_m - V_T)$
$2\text{ V} = 0.318(V_m - 0.7\text{ V})$
Solving: $V_m = \mathbf{6.98\text{ V}} \cong 10{:}1$ for $V_m{:}V_T$

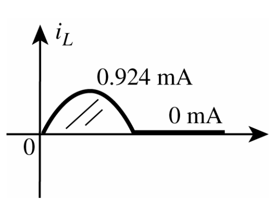


24. $V_m = \dfrac{V_{dc}}{0.318} = \dfrac{2\text{ V}}{0.318} = \mathbf{6.28\text{ V}}$



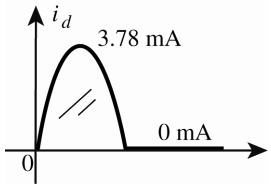


$I_{L_{max}} = \dfrac{6.28\text{ V}}{6.8\text{ k}\Omega} = \mathbf{0.924\text{ mA}}$

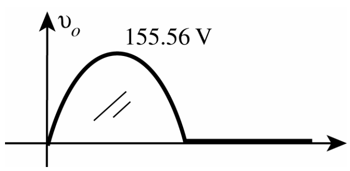


$I_{max}(2.2\text{ k}\Omega) = \dfrac{6.28\text{ V}}{2.2\text{ k}\Omega}$ = **2.855 mA**

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



25. $V_m = \sqrt{2}$ (110 V) = 155.56 V
$V_{dc} = 0.318V_m$ = 0.318(155.56 V) = **49.47 V**



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

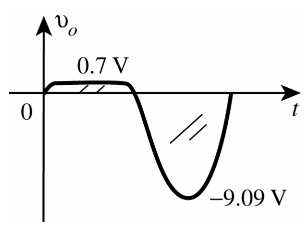
$$v_o = 0.7\text{ V} = \frac{10\text{ k}\Omega(v_i)}{10\text{ k}\Omega + 1\text{ k}\Omega}$$

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:

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

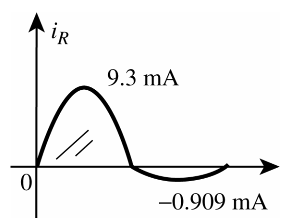
For $v_i = -10$ V:
$v_o = 0.909(-10\text{ V})$
= **–9.09 V**



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

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

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



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) $4.7 \text{ k}\Omega \,\|\, 56 \text{ k}\Omega = 4.34 \text{ k}\Omega$

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

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

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

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

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

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

$$\begin{aligned} V_{L_m} &= V_{i_m} - 2V_D \\ &= 169.7 \text{ V} - 2(0.7 \text{ V}) = 169.7 \text{ V} - 1.4 \text{ V} \\ &= 168.3 \text{ V} \end{aligned}$$

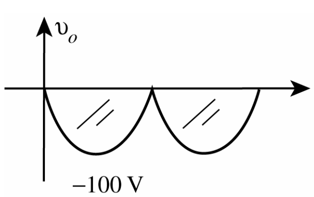
$V_{\text{dc}} = 0.636(168.3 \text{ V}) = \mathbf{107.04 \text{ V}}$

(b) $\text{PIV} = V_m(\text{load}) + V_D = 168.3 \text{ V} + 0.7 \text{ V} = \mathbf{169 \text{ V}}$

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

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

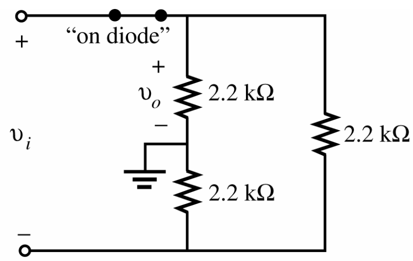
29.



PIV = **100 V**

30. Positive half-cycle of v_i:

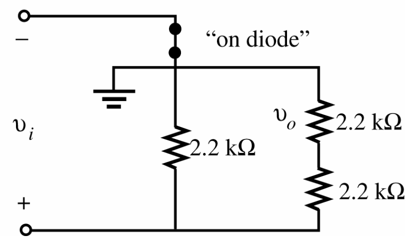
Network redrawn:



Voltage-divider rule:

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

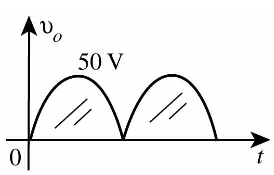
Negative half-cycle of υ_i:



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

Voltage-divider rule:

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



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

31. Positive pulse of v_i:

Top left diode "off", bottom left diode "on"
2.2 kΩ || 2.2 kΩ = 1.1 kΩ

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

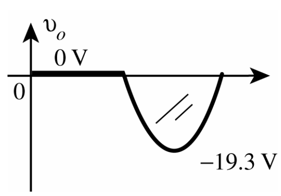
Negative pulse of v_i:

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

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

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

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



(b) For $v_i \leq 5$ V the 5 V battery will ensure the diode is forward-biased and $v_o = v_i - 5$ V.

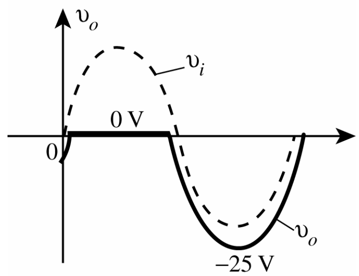
At $v_i = 5$ V

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

At $v_i = -20$ V

$v_o = -20\text{ V} - 5\text{ V} = \mathbf{-25\ V}$

For $v_i > 5$ V the diode is reverse-biased and $v_o = \mathbf{0\ V}$.

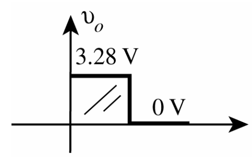


33. (a) Positive pulse of v_i:

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

Negative pulse of v_i:

diode "open", $v_o = \mathbf{0\ V}$

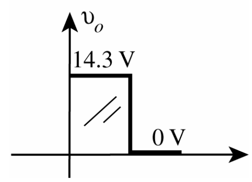


(b) Positive pulse of v_i:

$V_o = 10\text{ V} - 0.7\text{ V} + 5\text{ V} = \mathbf{14.3\ V}$

Negative pulse of v_i:

diode "open", $v_o = \mathbf{0\ V}$

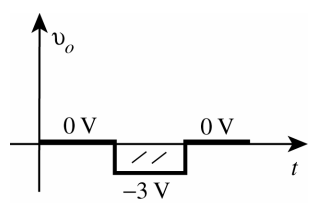


34. (a) For $v_i = 20$ V the diode is reverse-biased and $v_o = \mathbf{0\ V}$.

For $v_i = -5$ V, v_i overpowers the 2 V battery and the diode is "on".

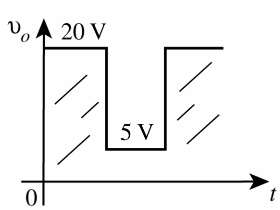
Applying Kirchhoff's voltage law in the clockwise direction:

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

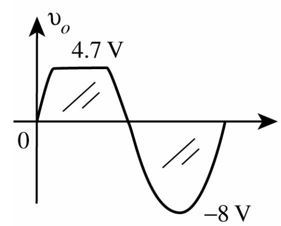


(b) For $v_i = 20$ V the 20 V level overpowers the 5 V supply and the diode is "on". Using the short-circuit equivalent for the diode we find $v_o = v_i = \mathbf{20\ V}$.

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 $v_o = \mathbf{5\ V}$.



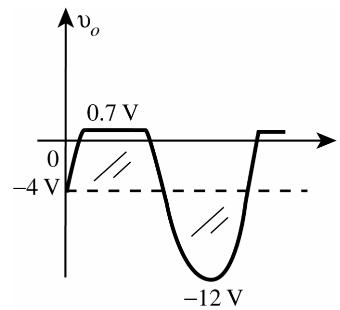
35. (a) Diode "on" for $v_i \geq 4.7$ V
For $v_i > 4.7$ V, $V_o = 4$ V + 0.7 V = **4.7 V**
For $v_i < 4.7$ V, diode "off" and $v_o = \boldsymbol{v_i}$



(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 = **0.7 V**

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

Therefore, $v_o = v_i - 4$ V
At $v_i = 0$ V, v_o = **−4 V**
$v_i = -8$ V, $v_o = -8$ V − 4 V = **−12 V**

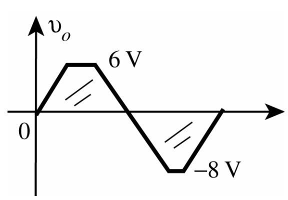


36. For the positive region of v_i:
The right Si diode is reverse-biased.
The left Si diode is "on" for levels of v_i greater than 5.3 V + 0.7 V = 6 V. In fact, v_o = **6 V** for $v_i \geq 6$ V.

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 = **−8 V** for $v_i \leq -8$ V.

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

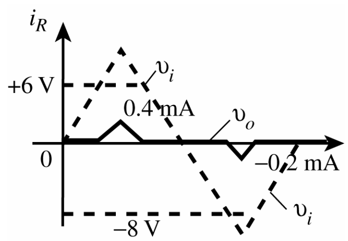


i_R: For $-8\text{ V} < v_i < 6$ V there is no conduction through the 10 kΩ resistor due to the lack of a complete circuit. Therefore, $i_R = 0$ mA.
For $v_i \geq 6$ V
$v_R = v_i - v_o = v_i - 6$ V
For $v_i = 10$ V, $v_R = 10$ V − 6 V = 4 V
and $i_R = \dfrac{4\text{ V}}{10\text{ k}\Omega} = \mathbf{0.4\ mA}$
For $v_i \leq -8$ V
$v_R = v_i - v_o = v_i + 8$ V

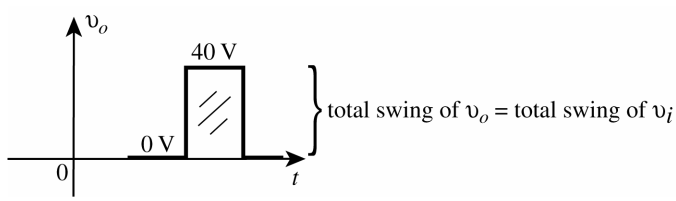
For $v_i = -10$ V

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

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

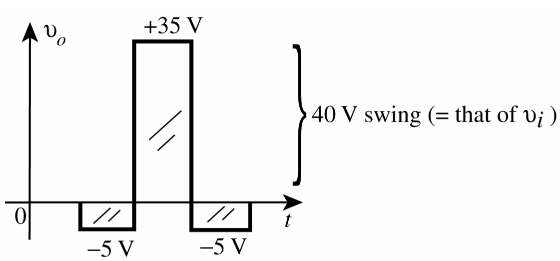


37. (a) Starting with $v_i = -20$ V, the diode is in the "on" state and the capacitor quickly charges to −20 V+. During this interval of time v_o is across the "on" diode (short-current equivalent) and $v_o = 0$ V.
When v_i switches to the +20 V level the diode enters the "off" state (open-circuit equivalent)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

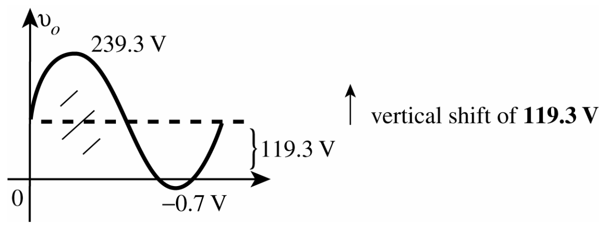


(b) Starting with $v_i = -20$ V, the diode is in the "on" state and the capacitor quickly charges up to −15 V+. Note that $v_i = +20$ V and the 5 V supply are additive across the capacitor. During this time interval v_o is across "on" diode and 5 V supply and $v_o = -5$ V.

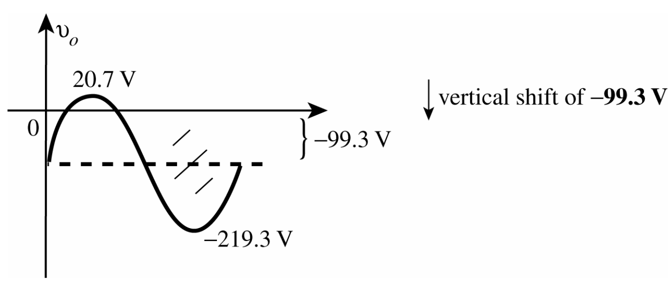
When v_i switches to the +20 V level the diode enters the "off" state and $v_o = v_i + v_C = 20 \text{ V} + 15 \text{ V} = 35 \text{ V}$.



38. (a) For negative half cycle capacitor charges to peak value of 120 V – 0.7 V = 119.3 V with polarity $(- \;\dashv\vdash\; +)$. 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 $(+ \;\dashv\vdash\; -)$. 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**.



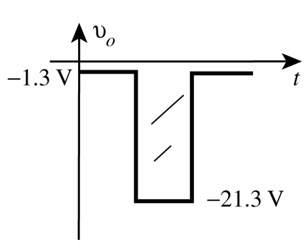
Using the ideal diode approximation the vertical shift of part (a) would be 120 V rather than 119.3 V and –100 V rather than –99.3 V for part (b). Using the ideal diode approximation would certainly be appropriate in this case.

39. (a) $\tau = RC$ = (56 kΩ)(0.1 μF) = 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

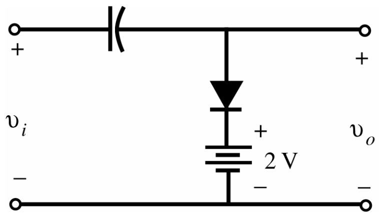
(c) Positive pulse of v_i:
Diode “on” and v_o = –2 V + 0.7 V = –1.3 V
Capacitor charges to 10 V + 2 V – 0.7 V = 11.3 V

Negative pulse of v_i:
Diode “off” and v_o = –10 V – 11.3 V = –21.3 V



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

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



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

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

$V_L = 9$ V < $V_Z = 10$ 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

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

$V_L = 13.62$ V > $V_Z = 10$ V and Zener diode "on"

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

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

$10R_L + 2200 = 20R_L$

$10R_L = 2200$

$R_L = \mathbf{220\ \Omega}$

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

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

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

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

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 mA)(91 Ω) + 8 V = 7.86 V + 8 V = **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.

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 = **0.5 kΩ**

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 mA − 20 mA = **40 mA**

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.

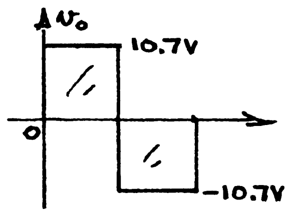
Therefore, $V_o = V_{Z_1} + V_{Z_2}$ = 0.7 V + 10 V = **10.7 V**

For $v_i = -50$ V:

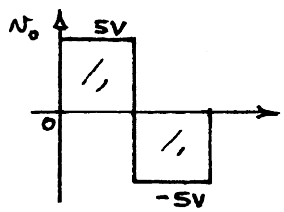
Z_1 reverse-biased at the Zener potential and $V_{Z_1} = -10$ V.

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 $v_o = v_i$.



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

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

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

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

Chapter 3

1. –

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.

3. Forward- and reverse-biased.

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

5. –

6. –

7. –

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

9. $I_B = \dfrac{1}{100} I_C \Rightarrow I_C = 100 I_B$
$I_E = I_C + I_B = 100I_B + I_B = 101I_B$
$I_B = \dfrac{I_E}{101} = \dfrac{8\text{ mA}}{101} = \mathbf{79.21\ \mu A}$
$I_C = 100I_B = 100(79.21\ \mu\text{A}) = \mathbf{7.921\ mA}$

10. –

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)

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.

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) $I_C \cong I_E$

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.

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

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

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

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

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

16. –

17. $I_i = V_i/R_i = 500\text{ mV}/20\ \Omega = 25\text{ mA}$
$I_L \cong I_i = 25\text{ mA}$
$V_L = I_L R_L = (25\text{ mA})(1\text{ k}\Omega) = 25\text{ V}$

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

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

$$A_v = \frac{V_o}{V_i} = \frac{8.35\text{ V}}{0.2\text{ V}} = \mathbf{41.75}$$

19. –

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**

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

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

(c) $I_{CEO} = \mathbf{0.3\ mA}$

(d) $I_{CBO} = (1 - \alpha)I_{CEO}$
$= (1 - 0.992)(0.3 \text{ mA}) = \mathbf{2.4\ \mu A}$

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

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

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

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

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

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

(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

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	β_{dc}/β_{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.

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

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

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

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

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

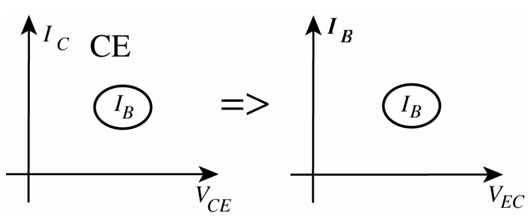
27. –

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

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

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

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.

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

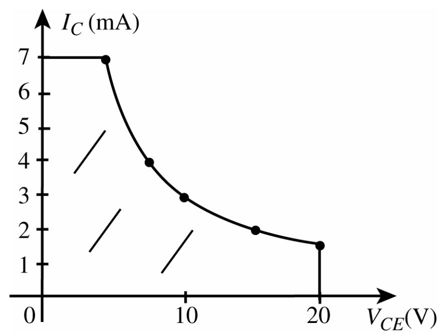
$$I_C = I_{C_{max}},\ V_{CE} = \frac{P_{C_{max}}}{I_{C_{max}}} = \frac{30 \text{ mW}}{7 \text{ mA}} = 4.29 \text{ V}$$

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

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

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

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

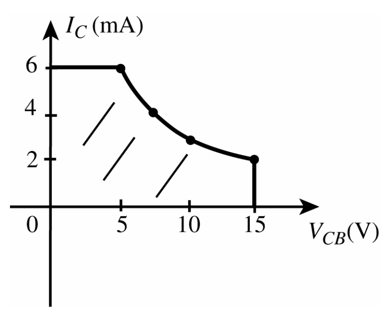


31. $$I_C = I_{C_{max}},\ V_{CE} = \frac{P_{C_{max}}}{I_{C_{max}}} = \frac{30 \text{ mW}}{6 \text{ mA}} = \mathbf{5\ V}$$

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

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

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



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

$$°\text{F} = \frac{9}{5}°\text{C} + 32°$$
$$= \frac{9}{5}(-55°\text{C}) + 32° = \mathbf{-67°F}$$
$$°\text{F} = \frac{9}{5}(150°\text{C}) + 32° = \mathbf{302°F}$$
$$\therefore\ \mathbf{-67°F \le \boldsymbol{T_J} \le 302°F}$$

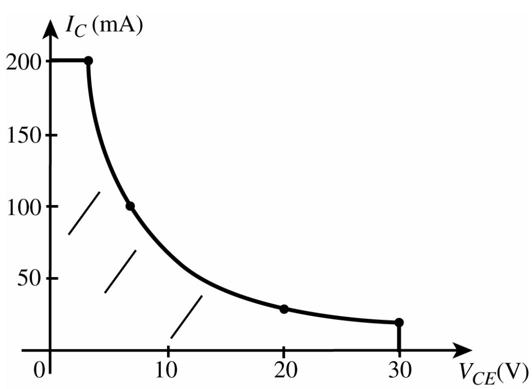
33. $I_{C_{\max}} = 200\text{ mA},\ V_{CE_{\max}} = 30\text{ V},\ P_{D_{\max}} = 625\text{ mW}$

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

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

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

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



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

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

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

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.

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 $\left(C = \in \frac{A}{d}\right)$.

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

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

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

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

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

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

(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 4

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**

2. (a) $I_C = \beta I_B$ = 80(40 μA) = **3.2 mA**

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

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

(d) $V_{CE} = V_C$ = **6 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**

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

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**

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

(b) $I_{C_Q} = \beta I_{B_Q}$ = (100)(29.18 μA) = **2.92 mA**

(c) $V_{CE_Q} = V_{CC} - I_C(R_C + R_E)$ = 20 V – (2.92 mA)(2.4 kΩ + 1.5 kΩ)
= 20 V – 11.388 V
= **8.61 V**

(d) $V_C = V_{CC} - I_C R_C$ = 20 V – (2.92 mA)(2.4 kΩ) = 20 V – 7.008 V
= **13 V**

(e) $V_B = V_{CC} - I_B R_B$ = 20 V – (29.18 μA)(510 kΩ)
= 20 V – 14.882 V = **5.12 V**

(f) $V_E = V_C - V_{CE}$ = 13 V – 8.61 V = **4.39 V**

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 V – 2.4 V = **5.2 V**

(e) $V_B = V_{BE} + V_E$ = 0.7 V + 2.4 V = **3.1 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) $R_B = \dfrac{V_{R_B}}{I_B} = \dfrac{V_{CC} - V_{BE} - V_E}{I_B} = \dfrac{17.74\text{ V} - 0.7\text{ V} - 2.1\text{ V}}{20\ \mu\text{A}}$

$= \dfrac{14.94\text{ V}}{20\ \mu\text{A}} = \mathbf{747\ k\Omega}$

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

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

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

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

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

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

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

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

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

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

$= \mathbf{37.28\ mW}$

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

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

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

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

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

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

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 μA)

(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 μA) = **3.93 mA**

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

= 20 V − (3.93 mA)(2.4 kΩ + 1.5 kΩ) = **4.67 V**

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

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

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

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

(80)(0.68 kΩ) ≥ 10(9.1 kΩ)

54.4 kΩ $\not\geq$ 91 kΩ (No!)

(a) Use exact approach:

$R_{Th} = R_1 \| R_2$ = 62 kΩ ‖ 9.1 kΩ = 7.94 kΩ

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

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

= **21.42 μA**

(b) $I_{C_Q} = \beta I_{B_Q}$ = (80)(21.42 μA) = **1.71 mA**

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

= 16 V − (1.71 mA)(3.9 kΩ + 0.68 kΩ)

= **8.17 V**

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

= 16 V − (1.71 mA)(3.9 kΩ)

= **9.33 V**

(e) $V_E = I_E R_E \cong I_C R_E$ = (1.71 mA)(0.68 kΩ)

= **1.16 V**

(f) $V_B = V_E + V_{BE}$ = 1.16 V + 0.7 V

= **1.86 V**

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) $V_E = I_E R_E \cong I_C R_E$ = (1.28 mA)(1.2 kΩ) = **1.54 V**

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

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

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

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

14. (a) $I_C = \beta I_B$ = (100)(20 μA) = **2 mA**

(b) $I_E = I_C + I_B$ = 2 mA + 20 μA
= 2.02 mA
$V_E = I_E R_E$ = (2.02 mA)(1.2 kΩ)
= **2.42 V**

(c) $V_{CC} = V_C + I_C R_C$ = 10.6 V + (2 mA)(2.7 kΩ)
= 10.6 V + 5.4 V
= **16 V**

(d) $V_{CE} = V_C - V_E$ = 10.6 V − 2.42 V
= **8.18 V**

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

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

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

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

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

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)

$$\therefore V_B = \frac{R_2V_{CC}}{R_1 + R_2} = \frac{(8.2\text{ k}\Omega)(18\text{ V})}{39\text{ k}\Omega + 8.2\text{ k}\Omega} = 3.13\text{ V}$$

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

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

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

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

(d) $V_E = I_ER_E \cong I_CR_E = (2.43\text{ mA})(1\text{ k}\Omega) = \mathbf{2.43\text{ V}}$

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

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

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

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

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

$I_C = \beta I_B = (120)(19.02\ \mu\text{A}) = \mathbf{2.28\text{ mA}}$ (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) $\mathbf{19.02\ \mu A}$ (vs. 20.25 μA #16)

(d) $V_E = I_ER_E \cong I_CR_E = (2.28\text{ mA})(1\text{ k}\Omega) = \mathbf{2.28\text{ V}}$ (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.

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

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

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

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

$V_{CE_Q} = V_{CC} - I_C\,(R_C + R_E)$
$= 16\text{ V} - (1.99\text{ mA})(3.9\text{ k}\Omega + 0.68\text{ k}\Omega)$
$= 16\text{ V} - 9.11\text{ V}$
$= \mathbf{6.89\ V}$

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

(b) From Problem 12:
$I_{C_Q} = \mathbf{1.71\ mA}$, $V_{CE_Q} = \mathbf{8.17\ V}$, $I_{B_Q} = \mathbf{21.42\ \mu A}$

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

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

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

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

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

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

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

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

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

(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)

20. (a) From problem 12b, $I_C = \mathbf{1.71\ mA}$
From problem 12c, $V_{CE} = \mathbf{8.17\ V}$

(b) β changed to 120:
From problem 12a, $E_{Th} = 2.05\text{ V}$, $R_{Th} = 7.94\text{ k}\Omega$

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

$= 14.96\ \mu\text{A}$
$I_C = \beta I_B = (120)(14.96\ \mu\text{A}) = \mathbf{1.8\ mA}$
$V_{CE} = V_{CC} - I_C(R_C + R_E)$
$= 16\text{ V} - (1.8\text{ mA})(3.9\text{ k}\Omega + 0.68\text{ k}\Omega)$
$= \mathbf{7.76\ V}$

(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 feedback	Voltage-divider

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

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

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

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.

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) $V_C = V_{CC} - I_C R_C$
$= 16\text{ V} - (1.91\text{ mA})(3.6\text{ k}\Omega)$
$= \mathbf{9.12\ V}$

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

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

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

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.

25. $1\text{ M}\Omega = 0\ \Omega$, $R_B = 150\text{ k}\Omega$

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta(R_C + R_E)} = \frac{12\text{ V} - 0.7\text{ V}}{150\text{ k}\Omega + (180)(4.7\text{ k}\Omega + 3.3\text{ k}\Omega)}$$
$= 7.11\ \mu\text{A}$

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

$V_C = V_{CC} - I_C R_C = 12\text{ V} - (1.28\text{ mA})(4.7\text{ k}\Omega)$
$= \mathbf{5.98\ V}$

Full $1\text{ M}\Omega$: $R_B = 1{,}000\text{ k}\Omega + 150\text{ k}\Omega = 1{,}150\text{ k}\Omega = 1.15\text{ M}\Omega$

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta(R_C + R_E)} = \frac{12\text{ V} - 0.7\text{ V}}{1.15\text{ M}\Omega + (180)(4.7\text{ k}\Omega + 3.3\text{ k}\Omega)}$$
$= 4.36\ \mu\text{A}$

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

$V_C = V_{CC} - I_C R_C = 12\text{ V} - (0.785\text{ mA})(4.7\text{ k}\Omega)$
$= \mathbf{8.31\ V}$

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

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

27. (a) $I_B = \dfrac{V_{CC} + V_{EE} - V_{BE}}{R_B + (\beta + 1)R_E} = \dfrac{6\text{ V} + 6\text{ V} - 0.7\text{ V}}{330\text{ k}\Omega + (121)(1.2\text{ k}\Omega)}$
$= 23.78\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (121)(23.78\ \mu\text{A})$
$= \mathbf{2.88\ mA}$

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

$V_E = -V_{EE} + I_E R_E = -6\text{ V} + (2.88\text{ mA})(1.2\text{ k}\Omega)$
$= \mathbf{-2.54\ V}$

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) $V_{CE} = V_{CC} + V_{EE} - I_C(R_C + R_E)$
$= 16\text{ V} + 12\text{ V} - (0.744\text{ mA})(27\text{ k}\Omega)$
$= \mathbf{7.91\ V}$

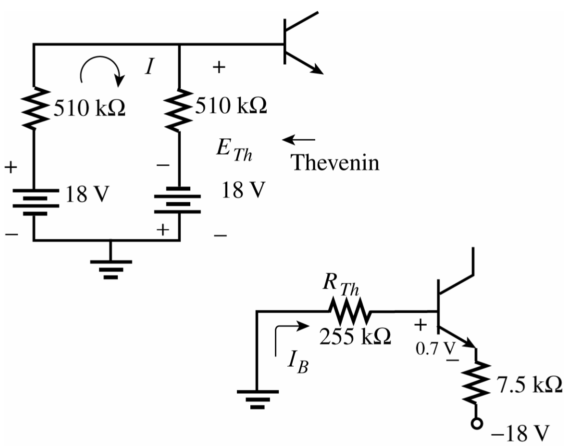
(d) $V_C = V_{CC} - I_C R_C = 16\text{ V} - (0.744\text{ mA})(12\text{ k}\Omega) = \mathbf{7.07\ V}$

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

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

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

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



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

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

$E_{Th} = -18\text{ V} + (35.29\ \mu\text{A})(510\text{ k}\Omega)$
$= \mathbf{0\text{ V}}$

$I_B = \dfrac{18\text{ V} - 0.7\text{ V}}{255\text{ k}\Omega + (130+1)(7.5\text{ k}\Omega)}$
$= \mathbf{13.95\ \mu A}$

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

(c) $V_E = -18\text{ V} + (1.81\text{ mA})(7.5\text{ k}\Omega)$
$= -18\text{ V} + 13.58\text{ V}$
$= \mathbf{-4.42\text{ V}}$

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

31. (a) $I_B = \dfrac{V_{R_B}}{R_B} = \dfrac{V_C - V_{BE}}{R_B} = \dfrac{8\text{ V} - 0.7\text{ V}}{560\text{ k}\Omega} = \mathbf{13.04\ \mu A}$

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

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

(d) $V_{CE} = V_C = \mathbf{8\text{ V}}$

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 = **360 kΩ**

R_C = **2.4 kΩ**

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

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

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

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

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

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

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

Standard values: R_E = **390 Ω**, R_C = **1.6 kΩ**, R_B = **430 kΩ**

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

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

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

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

$\left.V_B = \dfrac{R_2 V_{CC}}{R_2 + R_1} \Rightarrow 3.7 \text{ V} = \dfrac{R_2(24 \text{ V})}{R_2 + R_1}\right\}$ 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 = **7.5 kΩ**

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 = **41.15 kΩ**

Standard values:

R_E = **0.75 kΩ**, R_C = **3.3 kΩ**, R_2 = **7.5 kΩ**, R_1 = **43 kΩ**

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

$R_E = \frac{V_E}{I_E} = \frac{5.6 \text{ V}}{5 \text{ mA}}$ = **1.12 kΩ** (use **1.1 kΩ**)

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

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

$R_C = \frac{V_{R_C}}{I_C} = \frac{8.4 \text{ V}}{5 \text{ mA}}$ = **1.68 kΩ** (use 1.6 kΩ)

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

$V_B = \frac{R_2V_{CC}}{R_2 + R_1} \Rightarrow 6.3 \text{ V} = \frac{R_2(28 \text{ V})}{R_2 + R_1}$ (2 unknowns)

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

$\beta R_E = 10R_2$

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

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

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

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

Standard values:

R_E = **1.1 kΩ**

R_C = **1.6 kΩ**

R_1 = **51 kΩ**

R_2 = **15 kΩ**

36. $I_{2\text{ k}\Omega} = \frac{18 \text{ V} - 0.7 \text{ V}}{2 \text{ k}\Omega}$ = **8.65 mA** $\cong I$

37. For current mirror:

$I(3 \text{ k}\Omega) = I(2.4 \text{ k}\Omega) = I$ = **2 mA**

38. $I_{D_Q} = I_{DSS}$ = **6 mA**

39. $V_B \cong \dfrac{4.3\text{ k}\Omega}{4.3\text{ k}\Omega + 4.3\text{ k}\Omega}(-18\text{ V}) = -9\text{ V}$

$V_E = -9\text{ V} - 0.7\text{ V} = -9.7\text{ V}$

$I_E = \dfrac{-18\text{ V} - (-9.7\text{ V})}{1.8\text{ k}\Omega} = \mathbf{4.6\text{ mA}} = I$

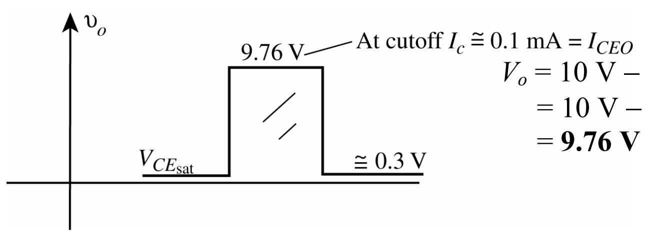
40. $I_E = \dfrac{V_Z - V_{BE}}{R_E} = \dfrac{5.1\text{ V} - 0.7\text{ V}}{1.2\text{ k}\Omega} = \mathbf{3.67\text{ mA}}$

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

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

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

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



$V_o = 10\text{ V} - (0.1\text{ mA})(2.4\text{ k}\Omega)$
$= 10\text{ V} - 0.24\text{ V}$
$= \mathbf{9.76\text{ V}}$

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

$R_C = \dfrac{5\text{ V}}{8\text{ mA}} = \mathbf{0.625\text{ k}\Omega}$

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

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

$R_B = \dfrac{5\text{ V} - 0.7\text{ V}}{96\ \mu\text{A}} = \mathbf{44.79\text{ k}\Omega}$

Standard values:

$R_B = \mathbf{43\text{ k}\Omega}$

$R_C = \mathbf{0.62\text{ k}\Omega}$

43. (a) From Fig. 3.23c:

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

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

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

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

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

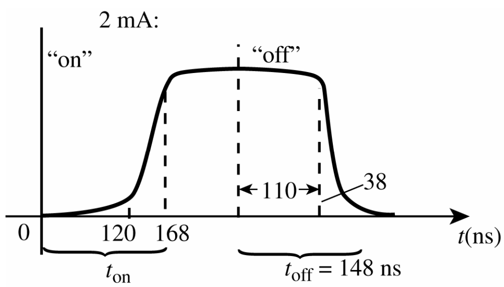
$t_{\text{off}} = t_s + t_f = 120\text{ ns} + 12\text{ ns} = \mathbf{132\ ns}$

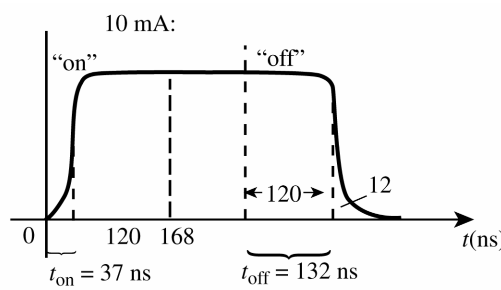
The turn-on time has dropped dramatically

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

while the turn-off time is only slightly smaller

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





44. (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

45. (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.

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:

$$I_B = \frac{V_{CC} - V_{BE}}{R_1 + (\beta + 1)R_E} = \frac{16\text{ V} - 0.7\text{ V}}{91\text{ k}\Omega + (100+1)1.2\text{ k}\Omega}$$

$= 72.1\ \mu\text{A}$

$V_B = V_{CC} - I_B(R_1) = 16\text{ V} - (72.1\ \mu\text{A})(91\text{ k}\Omega)$

$= \mathbf{9.4\ V}$

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

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

$\therefore$ Assume base circuit "open"

The 4 V at the emitter is the voltage that would exist if the transistor were shorted collector to emitter.

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

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

47. (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 = 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) $I_B = 0\ \mu A$, $I_C = I_{CEO}$ 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 $V_{CE} = V_{CC} = \mathbf{20\ V}$

48. (a) R_B open, $I_B = 0\ \mu A$, $I_C = I_{CEO} \cong 0$ mA

and $V_C \cong V_{CC} = \mathbf{18\ V}$

(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

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

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

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

$= \mathbf{-4.69\ V}$

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

50. $\beta R_E \geq 10R_2$

$(220)(0.75\text{ k}\Omega) \geq 10(16\text{ k}\Omega)$

$165\text{ k}\Omega \geq 160\text{ k}\Omega$ (checks)

Use approximate approach:

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

$V_E = V_B + 0.7\text{ V} = -3.59\text{ V} + 0.7\text{ V} = -2.89\text{ V}$

$I_C \cong I_E = V_E/R_E = 2.89/0.75\text{ k}\Omega = 3.85\text{ mA}$

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

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

$= -22\text{ V} + (3.85\text{ mA})(2.2\text{ k}\Omega)$

$= \mathbf{-13.53\ V}$

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

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

$= \mathbf{-3.37\ V}$

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

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

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

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

$= (91)(10\ \mu\text{A} - 0.2\ \mu\text{A}) + (-1.92 \times 10^{-4}\text{S})(0.5\text{ V} - 0.7\text{ V}) + (32.56 \times 10^{-6}\text{A})(112.5 - 90)$

$= (91)(9.8\ \mu\text{A}) + (1.92 \times 10^{-4}\text{S})(0.2\text{ V}) + (32.56 \times 10^{-6}\text{A})(22.5)$

$= 8.92 \times 10^{-4}\text{A} + 0.384 \times 10^{-4}\text{A} + 7.326 \times 10^{-4}\text{A}$

$= 16.63 \times 10^{-4}\text{A}$

$\cong \mathbf{1.66\ mA}$

53. For the emitter-bias:

(a) $$S(I_{CO}) = (\beta + 1)\frac{(1 + R_B/R_E)}{(\beta + 1) + R_B/R_E} = (100+1)\frac{(1 + 510\text{ k}\Omega/1.5\text{ k}\Omega)}{(100+1) + 510\text{ k}\Omega/1.5\text{ k}\Omega}$$
$= \mathbf{78.1}$

(b) $$S(V_{BE}) = \frac{-\beta}{R_B + (\beta+1)R_E} = \frac{-100}{510\text{ k}\Omega + (100+1)1.5\text{ k}\Omega}$$
$= \mathbf{-1.512 \times 10^{-4}S}$

(c) $$S(\beta) = \frac{I_{C_1}(1 + R_B/R_E)}{\beta_1(1 + \beta_2 + R_B/R_E)} = \frac{2.92\text{ mA}(1 + 340)}{100(1 + 125 + 340)}$$
$= \mathbf{21.37 \times 10^{-6}A}$

(d) $\Delta I_C = S(I_{CO})\Delta I_{CO} + S(V_{BE})\Delta V_{BE} + S(\beta)\Delta\beta$
$= (78.1)(9.8\ \mu\text{A}) + (-1.512 \times 10^{-14}\text{S})(-0.2\text{ V}) + (21.37 \times 10^{-6}\text{ A})(25)$
$= 0.7654\text{ mA} + 0.0302\text{ mA} + 0.5343\text{ mA}$
$= \mathbf{1.33\ mA}$

54. (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) $\Delta I_C = S(I_{CO})\Delta I_{CO} + S(V_{BE})\ \Delta V_{BE} + S(\beta)\Delta\beta$
$= (11.08)(10\ \mu\text{A} - 0.2\ \mu\text{A}) + (-1.27 \times 10^{-3}\text{S})(0.5\text{ V} - 0.7\text{ V}) + (2.41 \times 10^{-6}\text{A})(100 - 80)$
$= (11.08)(9.8\ \mu\text{A}) + (-1.27 \times 10^{-3}\text{S})(-0.2\text{ V}) + (2.41 \times 10^{-6}\text{A})(20)$
$= 1.09 \times 10^{-4}\text{A} + 2.54 \times 10^{-4}\text{A} + 0.482 \times 10^{-4}\text{A}$
$= 4.11 \times 10^{-4}\text{A} = \mathbf{0.411\ mA}$

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

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

(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**

56.

Type	$S(I_{CO})$	$S(V_{BE})$	$S(\beta)$
Collector 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).
$S(\beta)$: 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.

57. (a) Fixed-bias:

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

(b) Voltage-divider bias:

$S(I_{CO}) = 11.08$, $\Delta I_C = 0.1090$ mA
$S(V_{BE}) = -1.27 \times 10^{-3}$S, $\Delta I_C = 0.2540$ mA
$S(\beta) = 2.41 \times 10^{-6}$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.

Chapter 5

1. (a) If the dc power supply is set to zero volts, the amplification will be zero.

   (b) Too low a dc level will result in a clipped output waveform.

   (c) $P_o = I^2R = (5\text{ mA})^2 2.2\text{ k}\Omega = 55\text{ mW}$
   $P_i = V_{CC}I = (18\text{ V})(3.8\text{ mA}) = 68.4\text{ mW}$
   $$\eta = \frac{P_o(\text{ac})}{P_i(\text{dc})} = \frac{55\text{ mW}}{68.4\text{ mW}} = 0.804 \Rightarrow \mathbf{80.4\%}$$

2. –

3. $$x_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(1\text{ kHz})(10\ \mu\text{F})} = \mathbf{15.92\ \Omega}$$
   $f = 100$ kHz: $x_C = \mathbf{0.159\ \Omega}$
   Yes, better at 100 kHz

4. –

5. (a) $Z_i = \dfrac{V_i}{I_i} = \dfrac{10\text{ mV}}{0.5\text{ mA}}$
   $= \mathbf{20\ \Omega}$ ($=r_e$)

   (b) $V_o = I_cR_L$
   $= \alpha I_cR_L$
   $= (0.98)(0.5\text{ mA})(1.2\text{ k}\Omega)$
   $= \mathbf{0.588\ V}$

   (c) $A_v = \dfrac{V_o}{V_i} = \dfrac{0.588\text{ V}}{10\text{ mV}}$
   $= \mathbf{58.8}$

   (d) $Z_o = \infty\ \Omega$

   (e) $A_i = \dfrac{I_o}{I_i} = \dfrac{\alpha I_e}{I_e} = \alpha = \mathbf{0.98}$

   (f) $I_b = I_e - I_c$
   $= 0.5\text{ mA} - 0.49\text{ mA}$
   $= \mathbf{10\ \mu A}$

6. (a) $r_e = \dfrac{V_i}{I_i} = \dfrac{48 \text{ mV}}{3.2 \text{ mA}} = \mathbf{15\ \Omega}$

(b) $Z_i = r_e = \mathbf{15\ \Omega}$

(c) $I_C = \alpha I_e = (0.99)(3.2 \text{ mA}) = \mathbf{3.168 \text{ mA}}$

(d) $V_o = I_C R_L = (3.168 \text{ mA})(2.2 \text{ k}\Omega) = \mathbf{6.97 \text{ V}}$

(e) $A_v = \dfrac{V_o}{V_i} = \dfrac{6.97 \text{ V}}{48 \text{ mV}} = \mathbf{145.21}$

(f) $I_b = (1 - \alpha)I_e = (1 - 0.99)I_e = (0.01)(3.2 \text{ mA})$
$= \mathbf{32\ \mu A}$

7. (a) $r_e = \dfrac{26 \text{ mV}}{I_E(\text{dc})} = \dfrac{26 \text{ mV}}{2 \text{ mA}} = 13\ \Omega$

$Z_i = \beta r_e = (80)(13\ \Omega)$
$= \mathbf{1.04 \text{ k}\Omega}$

(b) $I_b = \dfrac{I_C}{\beta} = \dfrac{\alpha I_e}{\beta} = \dfrac{\cancel{\beta}}{\beta+1} \cdot \dfrac{I_e}{\cancel{\beta}} = \dfrac{I_e}{\beta+1}$

$= \dfrac{2 \text{ mA}}{81} = \mathbf{24.69\ \mu A}$

(c) $A_i = \dfrac{I_o}{I_i} = \dfrac{I_L}{I_b}$

$I_L = \dfrac{r_o(\beta I_b)}{r_o + R_L}$

$A_i = \dfrac{\dfrac{r_o}{r_o + R_L} \cdot \beta \cancel{I_b}}{\cancel{I_b}} = \dfrac{r_o}{r_o + R_L} \cdot \beta$

$= \dfrac{40 \text{ k}\Omega}{40 \text{ k}\Omega + 1.2 \text{ k}\Omega}(80)$
$= \mathbf{77.67}$

(d) $A_v = -\dfrac{R_L \| r_o}{r_e} = -\dfrac{1.2 \text{ k}\Omega \| 40 \text{ k}\Omega}{13\ \Omega}$

$= -\dfrac{1.165 \text{ k}\Omega}{13\ \Omega}$
$= \mathbf{-89.6}$

8. (a) $Z_i = \beta r_e = (140)r_e = 1200$

$$r_e = \frac{1200}{140} = \mathbf{8.571\ \Omega}$$

(b) $I_b = \dfrac{V_i}{Z_i} = \dfrac{30\text{ mV}}{1.2\text{ k}\Omega} = \mathbf{25\ \mu A}$

(c) $I_c = \beta I_b = (140)(25\ \mu\text{A}) = \mathbf{3.5\ mA}$

(d) $I_L = \dfrac{r_o I_c}{r_o + R_L} = \dfrac{(50\text{ k}\Omega)(3.5\text{ mA})}{50\text{ k}\Omega + 2.7\text{ k}\Omega} = 3.321\text{ mA}$

$A_i = \dfrac{I_L}{I_i} = \dfrac{3.321\text{ mA}}{25\ \mu\text{A}} = \mathbf{132.84}$

(e) $A_v = \dfrac{V_o}{V_i} = \dfrac{-A_i R_L}{Z_i} = -(132.84)\dfrac{(2.7\text{ k}\Omega)}{1.2\text{ k}\Omega}$

$= \mathbf{-298.89}$

9. (a) r_e: $I_B = \dfrac{V_{CC} - V_{BE}}{R_B} = \dfrac{12\text{ V} - 0.7\text{ V}}{220\text{ k}\Omega} = 51.36\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (60 + 1)(51.36\ \mu\text{A})$

$= 3.13\text{ mA}$

$r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{3.13\text{ mA}} = 8.31\ \Omega$

$Z_i = R_B \parallel \beta r_e = 220\text{ k}\Omega \parallel (60)(8.31\ \Omega) = 220\text{ k}\Omega \parallel 498.6\ \Omega$

$= \mathbf{497.47\ \Omega}$

$r_o \geq 10R_C \therefore Z_o = R_C = \mathbf{2.2\ k\Omega}$

(b) $A_v = -\dfrac{R_C}{r_e} = \dfrac{-2.2\text{ k}\Omega}{8.31\ \Omega} = \mathbf{-264.74}$

(c) $Z_i = \mathbf{497.47\ \Omega}$ (the same)

$Z_o = r_o \parallel R_C = 20\text{ k}\Omega \parallel 2.2\text{ k}\Omega$

$= \mathbf{1.98\ k\Omega}$

(d) $A_v = \dfrac{-R_C \parallel r_o}{r_e} = \dfrac{-1.98\text{ k}\Omega}{8.31\ \Omega} = \mathbf{-238.27}$

$A_i = -A_v Z_i / R_C$

$= -(-238.27)(497.47\ \Omega)/2.2\text{ k}\Omega$

$= \mathbf{53.88}$

10. $A_v = -\dfrac{R_C}{r_e} \Rightarrow r_e = -\dfrac{R_C}{A_v} = -\dfrac{4.7\text{ k}\Omega}{(-200)} = 23.5\ \Omega$

$$r_e = \frac{26\text{ mV}}{I_E} \Rightarrow I_E = \frac{26\text{ mV}}{r_e} = \frac{26\text{ mV}}{23.5\ \Omega} = 1.106\text{ mA}$$

$$I_B = \frac{I_E}{\beta+1} = \frac{1.106\text{ mA}}{91} = 12.15\ \mu\text{A}$$

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} \Rightarrow V_{CC} = I_B R_B + V_{BE}$$

$$= (12.15\ \mu\text{A})(1\text{ M}\Omega) + 0.7\text{ V}$$
$$= 12.15\text{ V} + 0.7\text{ V}$$
$$= \mathbf{12.85\text{ V}}$$

11. (a) $I_B = \dfrac{V_{CC} - V_{BE}}{R_B} = \dfrac{10\text{ V} - 0.7\text{ V}}{390\text{ k}\Omega} = \mathbf{23.85\ \mu A}$

$I_E = (\beta + 1)I_B = (101)(23.85\ \mu\text{A}) = 2.41\text{ mA}$

$$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{2.41\text{ mA}} = \mathbf{10.79\ \Omega}$$

$I_C = \beta I_B = (100)(23.85\ \mu\text{A}) = \mathbf{2.38\text{ mA}}$

(b) $Z_i = R_B \parallel \beta r_e = 390\text{ k}\Omega \parallel (100)(10.79\ \Omega) = 390\text{ k}\Omega \parallel 1.08\text{ k}\Omega$
$= \mathbf{1.08\text{ k}\Omega}$

$r_o \geq 10R_C \therefore Z_o = R_C = \mathbf{4.3\text{ k}\Omega}$

(c) $A_v = -\dfrac{R_C}{r_e} = \dfrac{-4.3\text{ k}\Omega}{10.79\ \Omega} = \mathbf{-398.52}$

(d) $A_v = -\dfrac{R_C \| r_o}{r_e} = -\dfrac{(4.3\text{ k}\Omega)\|(30\text{ k}\Omega)}{10.79\ \Omega} = -\dfrac{3.76\text{ k}\Omega}{10.79\ \Omega} = \mathbf{-348.47}$

12. (a) Test $\beta R_E \geq 10R_2$

$(100)(1.2\text{ k}\Omega) \overset{?}{\geq} 10(4.7\text{ k}\Omega)$

$120\text{ k}\Omega > 47\text{ k}\Omega$ (satisfied)

Use approximate approach:

$$V_B = \frac{R_2 V_{CC}}{R_1 + R_2} = \frac{4.7\text{ k}\Omega(16\text{ V})}{39\text{ k}\Omega + 4.7\text{ k}\Omega} = 1.721\text{ V}$$

$V_E = V_B - V_{BE} = 1.721\text{ V} - 0.7\text{ V} = 1.021\text{ V}$

$$I_E = \frac{V_E}{R_E} = \frac{1.021\text{ V}}{1.2\text{ k}\Omega} = 0.8507\text{ mA}$$

$$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{0.8507\text{ mA}} = \mathbf{30.56\ \Omega}$$

(b) $Z_i = R_1 \| R_2 \| \beta r_e$
$= 4.7\text{ k}\Omega \| 39\text{ k}\Omega \| (100)(30.56\ \Omega)$
$= \mathbf{1.768\ k\Omega}$
$r_o \geq 10R_C \therefore Z_o \cong R_C = \mathbf{3.9\ k\Omega}$

(c) $A_v = -\dfrac{R_C}{r_e} = -\dfrac{3.9\text{ k}\Omega}{30.56\ \Omega} = \mathbf{-127.6}$

(d) $r_o = 25\text{ k}\Omega$

(b) $Z_i(\text{unchanged}) = \mathbf{1.768\ k\Omega}$
$Z_o = R_C \| r_o = 3.9\text{ k}\Omega \| 25\text{ k}\Omega = \mathbf{3.37\ k\Omega}$

(c) $A_v = -\dfrac{(R_C \| r_o)}{r_e} = -\dfrac{(3.9\text{ k}\Omega)\|(25\text{ k}\Omega)}{30.56\ \Omega} = -\dfrac{3.37\text{ k}\Omega}{30.56\ \Omega}$
$= \mathbf{-110.28}$ (vs. -127.6)

13. $\beta R_E \overset{?}{\geq} 10R_2$
$(100)(1\text{ k}\Omega) \geq 10(5.6\text{ k}\Omega)$
$100\text{ k}\Omega > 56\text{ k}\Omega$ (checks!) & $r_o \geq 10R_C$
Use approximate approach:

$$A_v = -\frac{R_C}{r_e} \Rightarrow r_e = -\frac{R_C}{A_v} = -\frac{3.3\text{ k}\Omega}{-160} = \mathbf{20.625\ \Omega}$$

$$r_e = \frac{26\text{ mV}}{I_E} \Rightarrow I_E = \frac{26\text{ mV}}{r_e} = \frac{26\text{ mV}}{20.625\ \Omega} = 1.261\text{ mA}$$

$$I_E = \frac{V_E}{R_E} \Rightarrow V_E = I_E R_E = (1.261\text{ mA})(1\text{ k}\Omega) = 1.261\text{ V}$$

$$V_B = V_{BE} + V_E = 0.7\text{ V} + 1.261\text{ V} = 1.961\text{ V}$$

$$V_B = \frac{5.6\text{ k}\Omega\, V_{CC}}{5.6\text{ k}\Omega + 82\text{ k}\Omega} = 1.961\text{ V}$$

$$5.6\text{ k}\Omega\ V_{CC} = (1.961\text{ V})(87.6\text{ k}\Omega)$$

$$V_{CC} = \mathbf{30.68\ V}$$

14. Test $\beta R_E \geq 10R_2$
$(180)(2.2\text{ k}\Omega) \overset{?}{\geq} 10(56\text{ k}\Omega)$
$396\text{ k}\Omega < 560\text{ k}\Omega$ (not satisfied)

Use exact analysis:

(a) $R_{Th} = 56\text{ k}\Omega \| 220\text{ k}\Omega = 44.64\text{ k}\Omega$

$$E_{Th} = \frac{56\text{ k}\Omega(20\text{ V})}{220\text{ k}\Omega + 56\text{ k}\Omega} = 4.058\text{ V}$$

$$I_B = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta + 1)R_E} = \frac{4.058\text{ V} - 0.7\text{ V}}{44.64\text{ k}\Omega + (181)(2.2\text{ k}\Omega)}$$

$= 7.58\ \mu\text{A}$
$I_E = (\beta + 1)I_B = (181)(7.58\ \mu\text{A})$
$= 1.372\text{ mA}$

$$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{1.372\text{ mA}} = \mathbf{18.95\ \Omega}$$

(b) $V_E = I_E R_E = (1.372\text{ mA})(2.2\text{ k}\Omega) = 3.02\text{ V}$
$V_B = V_E + V_{BE} = 3.02\text{ V} + 0.7\text{ V}$
$= \mathbf{3.72\ V}$
$V_C = V_{CC} - I_C R_C$
$= 20\text{ V} - \beta I_B R_C = 20\text{ V} - (180)(7.58\ \mu\text{A})(6.8\text{ k}\Omega)$
$= \mathbf{10.72\ V}$

(c) $Z_i = R_1 \,\|\, R_2 \,\|\, \beta r_e$
$= 56\text{ k}\Omega \,\|\, 220\text{ k}\Omega \,\|\, (180)(18.95\text{ k}\Omega)$
$= 44.64\text{ k}\Omega \,\|\, 3.41\text{ k}\Omega$
$= \mathbf{3.17\ k\Omega}$

$$r_o < 10R_C \therefore A_v = -\frac{R_C \| r_o}{r_e}$$
$$= -\frac{(6.8\text{ k}\Omega)\|(50\text{ k}\Omega)}{18.95\ \Omega}$$
$$= \mathbf{-315.88}$$

15. (a) $$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta+1)R_E} = \frac{20\text{ V} - 0.7\text{ V}}{390\text{ k}\Omega + (141)(1.2\text{ k}\Omega)}$$
$$= \frac{19.3\text{ V}}{559.2\text{ k}\Omega} = 34.51\ \mu\text{A}$$
$I_E = (\beta + 1)I_B = (140 + 1)(34.51\ \mu\text{A}) = 4.866\text{ mA}$
$$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{4.866\text{ mA}} = \mathbf{5.34\ \Omega}$$

(b) $Z_b = \beta r_e + (\beta + 1)R_E$
$= (140)(5.34\text{ k}\Omega) + (140 + 1)(1.2\text{ k}\Omega) = 747.6\ \Omega + 169.9\text{ k}\Omega$
$= \mathbf{169.95\ k\Omega}$
$Z_i = R_B \,\|\, Z_b = 390\text{ k}\Omega \,\|\, 169.95\text{ k}\Omega = \mathbf{118.37\ k\Omega}$
$Z_o = R_C = \mathbf{2.2\ k\Omega}$

(c) $$A_v = -\frac{\beta R_C}{Z_b} = -\frac{(140)(2.2\text{ k}\Omega)}{169.95\text{ k}\Omega} = \mathbf{-1.81}$$

(d) $$Z_b = \beta r_e + \left[\frac{(\beta+1) + R_C / r_o}{1 + (R_C + R_E)/r_o}\right] R_E$$
$$= 747.6\ \Omega \left[\frac{(141) + 2.2\text{ k}\Omega / 20\text{ k}\Omega}{1 + (3.4\text{ k}\Omega)/20\text{ k}\Omega}\right] 1.2\text{ k}\Omega$$

$= 747.6\ \Omega + 144.72\ \text{k}\Omega$
$= 145.47\ \text{k}\Omega$

$Z_i = R_B \parallel Z_b = 390\ \text{k}\Omega \parallel 145.47\ \text{k}\Omega = \mathbf{105.95\ k\Omega}$
$Z_o = R_C = \mathbf{2.2\ k\Omega}$ (any level of r_o)

$$A_v = \frac{V_o}{V_i} = \frac{-\dfrac{\beta R_C}{Z_b}\left[1+\dfrac{r_e}{r_o}\right]+\dfrac{R_C}{r_o}}{1+\dfrac{R_C}{r_o}}$$

$$= \frac{\dfrac{-(140)(2.2\ \text{k}\Omega)}{145.47\ \text{k}\Omega}\left[1+\cancel{\dfrac{5.34\ \Omega}{20\ \text{k}\Omega}}\right]+\dfrac{2.2\ \text{k}\Omega}{20\ \text{k}\Omega}}{1+\dfrac{2.2\ \text{k}\Omega}{20\ \text{k}\Omega}}$$

$$= \frac{-2.117+0.11}{1.11} = \mathbf{-1.81}$$

16. Even though the condition $r_o \geq 10R_C$ is not met it is sufficiently close to permit the use of the approximate approach.

$$A_v = -\frac{\beta R_C}{Z_b} = -\frac{\beta R_C}{\beta R_E} = -\frac{R_C}{R_E} = -10$$

$$\therefore\ R_E = \frac{R_C}{10} = \frac{8.2\ \text{k}\Omega}{10} = \mathbf{0.82\ k\Omega}$$

$$I_E = \frac{26\ \text{mV}}{r_e} = \frac{26\ \text{mV}}{3.8\ \Omega} = 6.842\ \text{mA}$$

$V_E = I_E R_E = (6.842\ \text{mA})(0.82\ \text{k}\Omega) = 5.61\ \text{V}$
$V_B = V_E + V_{BE} = 5.61\ \text{V} + 0.7\ \text{V} = 6.31\ \text{V}$

$$I_B = \frac{I_E}{(\beta+1)} = \frac{6.842\ \text{mA}}{121} = 56.55\ \mu\text{A}$$

and $R_B = \dfrac{V_{R_B}}{I_B} = \dfrac{V_{CC}-V_B}{I_B} = \dfrac{20\ \text{V}-6.31\ \text{V}}{56.55\ \mu\text{A}} = \mathbf{242.09\ k\Omega}$

17. (a) dc analysis the same
$\therefore\ r_e = \mathbf{5.34\ \Omega}$ (as in #15)

(b) $Z_i = R_B \parallel Z_b = R_B \parallel \beta r_e = 390\ \text{k}\Omega \parallel (140)(5.34\ \Omega) = \mathbf{746.17}\ \Omega$ vs. 118.37 kΩ in #15
$Z_o = R_C = \mathbf{2.2\ k\Omega}$ (as in #15)

(c) $A_v = \dfrac{-R_C}{r_e} = \dfrac{-2.2\ \text{k}\Omega}{5.34\ \Omega} = \mathbf{-411.99}$ **vs** -1.81 in #15

(d) $Z_i = \mathbf{746.17}\ \Omega$ vs. 105.95 kΩ for #15
$Z_o = R_C \parallel r_o = 2.2\ \text{k}\Omega \parallel 20\ \text{k}\Omega = \mathbf{1.98\ k\Omega}$ vs. 2.2 kΩ in #15

$$A_v = -\frac{R_C \| r_o}{r_e} = -\frac{1.98 \text{ k}\Omega}{5.34\ \Omega} = \mathbf{-370.79} \text{ vs. } -1.81 \text{ in \#15}$$

Significant difference in the results for A_v.

18. (a) $$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta+1)R_E}$$

$$= \frac{22 \text{ V} - 0.7 \text{ V}}{330 \text{ k}\Omega + (81)(1.2 \text{ k}\Omega + 0.47 \text{ k}\Omega)} = \frac{21.3 \text{ V}}{465.27 \text{ k}\Omega}$$

$= 45.78\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (81)(45.78\ \mu\text{A}) = 3.71 \text{ mA}$

$$r_e = \frac{26 \text{ mV}}{I_E} = \frac{26 \text{ mV}}{3.71 \text{ mA}} = \mathbf{7\ \Omega}$$

(b) $r_o < 10(R_C + R_E)$

$$\therefore Z_b = \beta r_e + \left[\frac{(\beta+1) + R_C/r_o}{1 + (R_C + R_E)/r_o}\right]R_E$$

$$= (80)(7\ \Omega) + \left[\frac{(81) + 5.6 \text{ k}\Omega/40 \text{ k}\Omega}{1 + 6.8 \text{ k}\Omega/40 \text{ k}\Omega}\right]1.2 \text{ k}\Omega$$

$$= 560\ \Omega + \left[\frac{81 + 0.14}{1 + 0.17}\right]1.2 \text{ k}\Omega$$

(note that $(\beta + 1) = 81 \gg R_C/r_o = 0.14$)

$= 560\ \Omega + [81.14/1.17]1.2 \text{ k}\Omega = 560\ \Omega + 83.22 \text{ k}\Omega$

$= \mathbf{83.78\ k\Omega}$

$Z_i = R_B \| Z_b = 330 \text{ k}\Omega \| 83.78 \text{ k}\Omega = \mathbf{66.82\ k\Omega}$

$$A_v = \frac{\dfrac{-\beta R_C}{Z_b}\left(1 + \dfrac{r_e}{r_o}\right) + \dfrac{R_C}{r_o}}{1 + \dfrac{R_C}{r_o}}$$

$$= \frac{\dfrac{-(80)(5.6 \text{ k}\Omega)}{83.78 \text{ k}\Omega}\left(1 + \cancel{\dfrac{7\ \Omega}{40 \text{ k}\Omega}}\right) + \dfrac{5.6 \text{ k}\Omega}{40 \text{ k}\Omega}}{1 + 5.6 \text{ k}\Omega/40 \text{ k}\Omega}$$

$$= \frac{-(5.35) + 0.14}{1 + 0.14}$$

$= \mathbf{-4.57}$

19. (a) $$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta+1)R_E} = \frac{16 \text{ V} - 0.7 \text{ V}}{270 \text{ k}\Omega + (111)(2.7 \text{ k}\Omega)} = \frac{15.3 \text{ V}}{569.7 \text{ k}\Omega}$$

$= 26.86\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (110 + 1)(26.86\ \mu\text{A})$

$= 2.98\ \text{mA}$

$r_e = \dfrac{26\ \text{mV}}{I_E} = \dfrac{26\ \text{mV}}{2.98\ \text{mA}} = \mathbf{8.72\ \Omega}$

$\beta r_e = (110)(8.72\ \Omega) = \mathbf{959.2\ \Omega}$

(b) $Z_b = \beta r_e + (\beta + 1)R_E$

$= 959.2\ \Omega + (111)(2.7\ \text{k}\Omega)$

$= 300.66\ \text{k}\Omega$

$Z_i = R_B \parallel Z_b = 270\ \text{k}\Omega \parallel 300.66\ \text{k}\Omega$

$= 142.25\ \text{k}\Omega$

$Z_o = R_E \parallel r_e = 2.7\ \text{k}\Omega \parallel 8.72\ \Omega = \mathbf{8.69\ \Omega}$

(c) $A_v = \dfrac{R_E}{R_E + r_e} = \dfrac{2.7\ \text{k}\Omega}{2.7\ \text{k}\Omega + 8.69\ \Omega} \cong \mathbf{0.997}$

20. (a) $I_B = \dfrac{V_{CE} - V_{BE}}{R_B + (\beta + 1)R_E} = \dfrac{8\ \text{V} - 0.7\ \text{V}}{390\ \text{k}\Omega + (121)5.6\ \text{k}\Omega} = 6.84\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (121)(6.84\ \mu\text{A}) = 0.828\ \text{mA}$

$r_e = \dfrac{26\ \text{mV}}{I_E} = \dfrac{26\ \text{mV}}{0.828\ \text{mA}} = 31.4\ \Omega$

$r_o < 10R_E$:

$Z_b = \beta r_e + \dfrac{(\beta + 1)R_E}{1 + R_E / r_o}$

$= (120)(31.4\ \Omega) + \dfrac{(121)(5.6\ \text{k}\Omega)}{1 + 5.6\ \text{k}\Omega/40\ \text{k}\Omega}$

$= 3.77\ \text{k}\Omega + 594.39\ \text{k}\Omega$

$= \mathbf{598.16\ k\Omega}$

$Z_i = R_B \parallel Z_b = 390\ \text{k}\Omega \parallel 598.16\ \text{k}\Omega$

$= \mathbf{236.1\ k\Omega}$

$Z_o \cong R_E \parallel r_e$

$= 5.6\ \text{k}\Omega \parallel 31.4\ \Omega$

$= \mathbf{31.2\ \Omega}$

(b) $A_v = \dfrac{(\beta + 1)R_E / Z_b}{1 + R_E / r_o}$

$= \dfrac{(121)(5.6\ \text{k}\Omega)/598.16\ \text{k}\Omega}{1 + 5.6\ \text{k}\Omega/40\ \text{k}\Omega}$

$= \mathbf{0.994}$

(c) $A_v = \dfrac{V_0}{V_i} = 0.994$

$V_o = A_v V_i = (0.994)(1\ \text{mV}) = \mathbf{0.994\ mV}$

21. (a) Test $\beta R_E \overset{?}{\geq} 10R_2$

$(200)(2\text{ k}\Omega) \geq 10(8.2\text{ k}\Omega)$

$400\text{ k}\Omega \geq 82\text{ k}\Omega$ (checks)!

Use approximate approach:

$$V_B = \frac{8.2\text{ k}\Omega(20\text{ V})}{8.2\text{ k}\Omega + 56\text{ k}\Omega} = 2.5545\text{ V}$$

$$V_E = V_B - V_{BE} = 2.5545\text{ V} - 0.7\text{ V} \cong 1.855\text{ V}$$

$$I_E = \frac{V_E}{R_E} = \frac{1.855\text{ V}}{2\text{ k}\Omega} = \mathbf{0.927\text{ mA}}$$

$$I_B = \frac{I_E}{(\beta+1)} = \frac{0.927\text{ mA}}{(200+1)} = \mathbf{4.61\ \mu A}$$

$$I_C = \beta I_B = (200)(4.61\ \mu\text{A}) = \mathbf{0.922\text{ mA}}$$

(b) $r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{0.927\text{ mA}} = \mathbf{28.05\ \Omega}$

(c) $Z_b = \beta r_e + (\beta + 1)R_E$

$= (200)(28.05\ \Omega) + (200 + 1)2\text{ k}\Omega$

$= 5.61\text{ k}\Omega + 402\text{ k}\Omega = 407.61\text{ k}\Omega$

$Z_i = 56\text{ k}\Omega \parallel 8.2\text{ k}\Omega \parallel 407.61\text{ k}\Omega$

$= 7.15\text{ k}\Omega \parallel 407.61\text{ k}\Omega$

$= \mathbf{7.03\text{ k}\Omega}$

$Z_o = R_E \parallel r_e = 2\text{ k}\Omega \parallel 28.05\ \Omega = \mathbf{27.66\ \Omega}$

(d) $A_v = \dfrac{R_E}{R_E + r_e} = \dfrac{2\text{ k}\Omega}{2\text{ k}\Omega + 28.05\ \Omega} = \mathbf{0.986}$

22. (a) $I_E = \dfrac{V_{EE} - V_{BE}}{R_E} = \dfrac{6\text{ V} - 0.7\text{ V}}{6.8\text{ k}\Omega} = 0.779\text{ mA}$

$r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{0.779\text{ mA}} = \mathbf{33.38\ \Omega}$

(b) $Z_i = R_E \parallel r_e = 6.8\text{ k}\Omega \parallel 33.38\ \Omega$

$= \mathbf{33.22\ \Omega}$

$Z_o = R_C = 4.7\text{ k}\Omega$

(c) $A_v = \dfrac{\alpha R_C}{r_e} = \dfrac{(0.998)(4.7\text{ k}\Omega)}{33.38\ \Omega}$

$= \mathbf{140.52}$

23. $\alpha = \dfrac{\beta}{\beta+1} = \dfrac{75}{76} = 0.9868$

$I_E = \dfrac{V_{EE} - V_{BE}}{R_E} = \dfrac{5\text{ V} - 0.7\text{ V}}{3.9\text{ k}\Omega} = \dfrac{4.3\text{ V}}{3.9\text{ k}\Omega} = 1.1\text{ mA}$

$r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{1.1\text{ mA}} = 23.58\ \Omega$

$A_v = \alpha\dfrac{R_C}{r_e} = \dfrac{(0.9868)(3.9\text{ k}\Omega)}{23.58\ \Omega} = \mathbf{163.2}$

24. (a) $I_B = \dfrac{V_{CC} - V_{BE}}{R_F + \beta R_C} = \dfrac{12\text{ V} - 0.7\text{ V}}{220\text{ k}\Omega + 120(3.9\text{ k}\Omega)}$

$= 16.42\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (120 + 1)(16.42\ \mu\text{A})$

$= 1.987\text{ mA}$

$r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{1.987\text{ mA}} = \mathbf{13.08\ \Omega}$

(b) $Z_i = \beta r_e \parallel \dfrac{R_F}{|A_v|}$

Need A_v!

$A_v = \dfrac{-R_C}{r_e} = \dfrac{-3.9\text{ k}\Omega}{13.08\ \Omega} = -298$

$Z_i = (120)(13.08\ \Omega) \parallel \dfrac{220\text{ k}\Omega}{298}$

$= 1.5696\text{ k}\Omega \parallel 738\ \Omega$

$= \mathbf{501.98\ \Omega}$

$Z_o = R_C \parallel R_F = 3.9\text{ k}\Omega \parallel 220\text{ k}\Omega$

$= \mathbf{3.83\text{ k}\Omega}$

(c) From above, $A_v = \mathbf{-298}$

25. $A_v = \dfrac{-R_C}{r_e} = -160$

$R_C = 160(r_e) = 160(10\ \Omega) = \mathbf{1.6\text{ k}\Omega}$

$A_i = \dfrac{\beta R_F}{R_F + \beta R_C} = 19 \Rightarrow 19 = \dfrac{200R_F}{R_F + 200(1.6\text{ k}\Omega)}$

$19R_F + 3800R_C = 200R_F$

$R_F = \dfrac{3800R_C}{181} = \dfrac{3800(1.6\text{ k}\Omega)}{181}$

$= \mathbf{33.59\text{ k}\Omega}$

$I_B = \dfrac{V_{CC} - V_{BE}}{R_F + \beta R_C}$

$I_B(R_F + \beta R_C) = V_{CC} - V_{BE}$

and $V_{CC} = V_{BE} + I_B(R_F + \beta R_C)$

with $I_E = \dfrac{26\text{ mV}}{r_e} = \dfrac{26\text{ mV}}{10\ \Omega} = 2.6\text{ mA}$

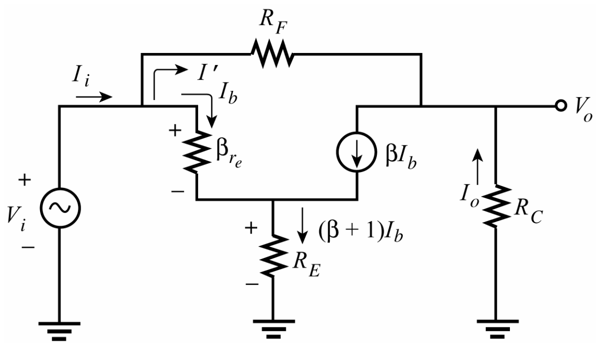
$I_B = \dfrac{I_E}{\beta+1} = \dfrac{2.6\text{ mA}}{200+1} = 12.94\ \mu\text{A}$

$\therefore V_{CC} = V_{BE} + I_B(R_F + \beta R_C)$

$= 0.7\text{ V} + (12.94\ \mu\text{A})(33.59\text{ k}\Omega + (200)(1.6\text{ k}\Omega))$

$= \mathbf{5.28\ V}$

26.



(a) A_v: $V_i = I_b\beta r_e + (\beta + 1)I_bR_E$

$I_o + I' = I_C = \beta I_b$

but $I_i = I' + I_b$

and $I' = I_i - I_b$

Substituting, $I_o + (I_i - I_b) = \beta I_b$

and $I_o = (\beta + 1)I_b - I_i$

Assuming $(\beta + 1)I_b \gg I_i$

$I_o \cong (\beta + 1)I_b$

and $V_o = -I_oR_C = -(\beta + 1)I_bR_C$

Therefore, $\dfrac{V_o}{V_i} = \dfrac{-(\beta+1)I_bR_C}{I_b\beta r_e + (\beta+1)I_bR_E}$

$\cong \dfrac{\cancel{\beta}\cancel{I_b}R_C}{\cancel{\beta}\cancel{I_b}r_e + \cancel{\beta}\cancel{I_b}R_E}$

and $A_v = \dfrac{V_o}{V_i} \cong -\dfrac{R_C}{r_e + R_E} \cong -\dfrac{R_C}{R_E}$

(b) $V_i \cong \beta I_b(r_e + R_E)$

For $r_e \ll R_E$

$V_i \cong \beta I_bR_E$

Now $I_i = I' + I_b$

$= \dfrac{V_i - V_o}{R_F} + I_b$

Since $V_o \gg V_i$

$$I_i = -\frac{V_o}{R_F} + I_b$$

$$\text{or } I_b = I_i + \frac{V_o}{R_F}$$

and $V_i = \beta I_b R_E$

$$V_i = \beta R_E I_i + \beta \frac{V_o}{R_F} R_E$$

but $V_o = A_v V_i$

and $V_i = \beta R_E I_i + \dfrac{\beta A_v V_i R_E}{R_F}$

or $V_i - \dfrac{A_v \beta R_E V_i}{R_F} = \beta R_E I_i$

$$V_i \left[1 - \frac{A_v \beta R_E}{R_F}\right] = [\beta R_E] I_i$$

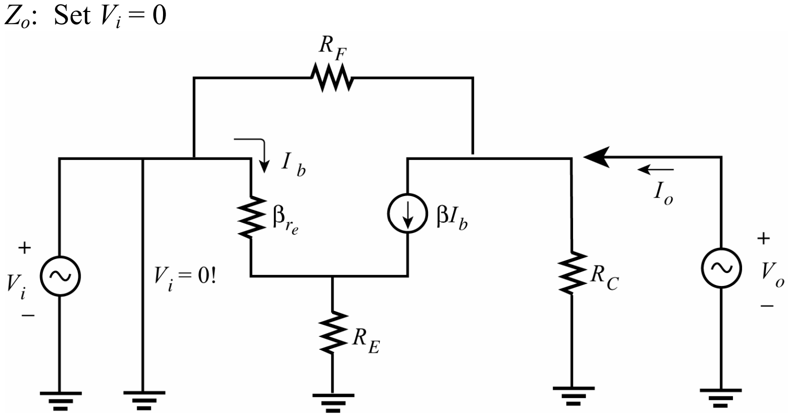
so $Z_i = \dfrac{V_i}{I_i} = \dfrac{\beta R_E}{1 - \dfrac{A_v \beta R_E}{R_F}} = \dfrac{\beta R_E R_F}{R_F + \beta(-A_v) R_E}$

$Z_i = \dfrac{V_i}{I_i} = x \parallel y$ where $x = \beta R_E$ and $y = R_F/|A_v|$

with $Z_i = \dfrac{x \cdot y}{x + y} = \dfrac{(\beta R_E)(R_F/|A_v|)}{\beta R_E + R_F/|A_v|}$

$$Z_i \cong \boldsymbol{\frac{\beta R_E R_F}{\beta R_E |A_v| + R_F}}$$

Z_o: Set $V_i = 0$



$V_i = I_b \beta r_e + (\beta + 1) I_b R_E$
$V_i \cong \beta I_b (r_e + R_E) = 0$
since β, $r_e + R_E \neq 0$ $\quad I_b = 0$ and $\beta I_b = 0$

$$\therefore I_o = \frac{V_o}{R_C} + \frac{V_o}{R_F} = V_o\left[\frac{1}{R_C} + \frac{1}{R_F}\right]$$

and $Z_o = \frac{V_o}{I_o} = \frac{1}{\frac{1}{R_C} + \frac{1}{R_F}} = \frac{R_C R_F}{R_C + R_F} = \boldsymbol{R_C \parallel R_F}$

(c) $A_v \cong -\frac{R_C}{R_E} = -\frac{2.2\text{ k}\Omega}{1.2\text{ k}\Omega} = \mathbf{-1.83}$

$Z_i \cong \frac{\beta R_E R_F}{\beta R_E|A_v| + R_F} = \frac{(90)(1.2\text{ k}\Omega)(120\text{ k}\Omega)}{(90)(1.2\text{ k}\Omega)(1.83) + 120\text{ k}\Omega}$

$= \mathbf{40.8\text{ k}\Omega}$

$Z_o \cong R_C \parallel R_F$

$= 2.2\text{ k}\Omega \parallel 120\text{ k}\Omega$

$= \mathbf{2.16\text{ k}\Omega}$

27. (a) $I_B = \frac{V_{CC} - V_{BE}}{R_F + \beta R_C} = \frac{9\text{ V} - 0.7\text{ V}}{(39\text{ k}\Omega + 22\text{ k}\Omega) + (80)(1.8\text{ k}\Omega)}$

$= \frac{8.3\text{ V}}{61\text{ k}\Omega + 144\text{ k}\Omega} = \frac{8.3\text{ V}}{205\text{ k}\Omega} = 40.49\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (80 + 1)(40.49\ \mu\text{A}) = 3.28\text{ mA}$

$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{3.28\text{ mA}} = 7.93\ \Omega$

$Z_i = R_{F_1} \parallel \beta r_e$

$= 39\text{ k}\Omega \parallel (80)(7.93\ \Omega) = 39\text{ k}\Omega \parallel 634.4\ \Omega = \mathbf{0.62\text{ k}\Omega}$

$Z_o = R_C \parallel R_{F_2} = 1.8\text{ k}\Omega \parallel 22\text{ k}\Omega = \mathbf{1.66\text{ k}\Omega}$

(b) $A_v = \frac{-R'}{r_e} = \frac{-R_C \| R_{F_2}}{r_e} = -\frac{1.8\text{ k}\Omega \| 22\text{ k}\Omega}{7.93\ \Omega}$

$= \frac{-1.664\text{ k}\Omega}{7.93\ \Omega} = \mathbf{-209.82}$

28. $A_i \cong \beta = 60$

29. $A_i \cong \beta = \mathbf{100}$

30. $A_i = -A_v Z_i / R_C = -(-127.6)(1.768\text{ k}\Omega)/3.9\text{ k}\Omega = \mathbf{57.85}$

31. (c) $A_i = \frac{\beta R_B}{R_B + Z_b} = \frac{(140)(390\text{ k}\Omega)}{390\text{ k}\Omega + 0.746\text{ k}\Omega} = \mathbf{139.73}$

(d) $A_i = -A_v \frac{Z_i}{R_C} = -(-370.79)(746.17\ \Omega)/2.2\text{ k}\Omega$

$= \mathbf{125.76}$

32. $A_i = -A_v Z_i/R_E = -(0.986)(7.03\text{ k}\Omega)/2\text{ k}\Omega = \mathbf{-3.47}$

33. $A_i = \dfrac{I_o}{I_i} = \dfrac{\alpha I_e}{I_e} = \alpha = \mathbf{0.9868} \cong 1$

34. $A_i = -A_v Z_i/R_C = -(-298)(501.98\ \Omega)/3.9\text{ k}\Omega = \mathbf{38.37}$

35. $A_i = -A_v\dfrac{Z_i}{R_C} = \dfrac{-(-209.82)(0.62\text{ k}\Omega)}{1.8\text{ k}\Omega} = \mathbf{72.27}$

36. (a) $I_B = \dfrac{V_{CC}-V_{BE}}{R_B} = \dfrac{18\text{ V} - 0.7\text{ V}}{680\text{ k}\Omega} = 25.44\ \mu\text{A}$

$I_E = (\beta+1)I_B = (100+1)(25.44\ \mu\text{A})$
$= 2.57\text{ mA}$

$r_e = \dfrac{26\text{ mV}}{2.57\text{ mA}} = 10.116\ \Omega$

$A_{v_{NL}} = -\dfrac{R_C}{r_e} = -\dfrac{3.3\text{ k}\Omega}{10.116\ \Omega} = \mathbf{-326.22}$

$Z_i = R_B \parallel \beta r_e = 680\text{ k}\Omega \parallel (100)(10.116\ \Omega)$
$= 680\text{ k}\Omega \parallel 1{,}011.6\ \Omega$
$= \mathbf{1.01\ k\Omega}$

$Z_o = R_C = \mathbf{3.3\ k\Omega}$

(b) –

(c) $A_{v_L} = \dfrac{R_L}{R_L+R_o}A_{v_{NL}} = \dfrac{4.7\text{ k}\Omega}{4.7\text{ k}\Omega + 3.3\text{ k}\Omega}(-326.22)$
$= \mathbf{-191.65}$

(d) $A_{i_L} = -A_{v_L}\dfrac{Z_i}{R_L} = -(-191.65)\dfrac{(1.01\text{ k}\Omega)}{4.7\text{ k}\Omega}$
$= \mathbf{41.18}$

(e) $A_{v_L} = \dfrac{V_o}{V_i} = \dfrac{-\beta \cancel{I_b}(R_C \parallel R_L)}{\cancel{I_b}(\beta r_e)} = \dfrac{-\cancel{100}(1.939\text{ k}\Omega)}{\cancel{100}(10.116\ \Omega)}$
$= \mathbf{-191.98}$

$Z_i = R_B \parallel \beta r_e = \mathbf{1.01\ k\Omega}$

$I_L = \dfrac{R_C(\beta I_b)}{R_C+R_L} = 41.25 I_b$

$I_b = \dfrac{R_B I_i}{R_B+\beta r_e} = 0.9985 I_i$

$A_{i_L} = \dfrac{I_o}{I_i} = \dfrac{I_L}{I_i} = \dfrac{I_L}{I_b}\cdot\dfrac{I_b}{I_i} = (41.25)(0.9985)$
$= \mathbf{41.19}$

$Z_o = R_C = \mathbf{3.3\ k\Omega}$

37. (a) $A_{v_{NL}} = -326.22$

$$A_{v_L} = \frac{R_L}{R_L + R_o} A_{v_{NL}}$$

$R_L = 4.7\text{ k}\Omega$: $A_{v_L} = \dfrac{4.7\text{ k}\Omega}{4.7\text{ k}\Omega + 3.3\text{ k}\Omega}(-326.22) = \mathbf{-191.65}$

$R_L = 2.2\text{ k}\Omega$: $A_{v_L} = \dfrac{2.2\text{ k}\Omega}{2.2\text{ k}\Omega + 3.3\text{ k}\Omega}(-326.22) = \mathbf{-130.49}$

$R_L = 0.5\text{ k}\Omega$: $A_{v_L} = \dfrac{0.5\text{ k}\Omega}{0.5\text{ k}\Omega + 2.3\text{ k}\Omega}(-326.22) = \mathbf{-42.92}$

As $R_L\downarrow$, $A_{v_L}\downarrow$

(b) No change for Z_i, Z_o, and $A_{v_{NL}}$!

38. (a) $I_B = \dfrac{V_{CC} - V_{BE}}{R_B} = \dfrac{12\text{ V} - 0.7\text{ V}}{1\text{ M}\Omega} = 11.3\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (181)(11.3\ \mu\text{A}) = 2.045\text{ mA}$

$r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{2.045\text{ mA}} = 12.71\ \Omega$

$A_{V_{NL}} = -\dfrac{R_C}{r_e} = -\dfrac{3\text{ k}\Omega}{12.71\ \Omega} = \mathbf{-236}$

$Z_i = R_B \parallel \beta r_e = 1\text{ M}\Omega \parallel (180)(12.71\ \Omega) = 1\text{ M}\Omega \parallel 2.288\text{ k}\Omega$
$= \mathbf{2.283\text{ k}\Omega}$

$Z_o = R_C = \mathbf{3\text{ k}\Omega}$

(b) –

(c) No-load: $A_v = A_{v_{NL}} = \mathbf{-236}$

(d) $A_{v_s} = \dfrac{Z_i}{Z_i + R_s} A_{v_{NL}} = \dfrac{2.283\text{ k}\Omega(-236)}{2.283\text{ k}\Omega + 0.6\text{ k}\Omega}$
$= \mathbf{-186.9}$

(e) $V_o = -I_oR_C = -\beta I_bR_C$

$V_i = I_b\beta r_e$

$A_v = \dfrac{V_o}{V_i} = -\dfrac{\beta I_b R_C}{\beta I_b r_e} = -\dfrac{R_C}{r_e} = -\dfrac{3\text{ k}\Omega}{12.71\ \Omega} = -236$

$A_{v_s} = \dfrac{V_o}{V_s} = \dfrac{V_o}{V_i}\cdot\dfrac{V_i}{V_s}$

$V_i = \dfrac{(1\text{ M}\Omega \| \beta r_e)V_s}{(1\text{ M}\Omega \| \beta r_e) + R_s} = \dfrac{2.288\text{ k}\Omega(V_s)}{2.288\text{ k}\Omega + 0.6\text{ k}\Omega} = 0.792\ V_s$

$A_{v_s} = (-236)(0.792)$
$= \mathbf{-186.9}$ (same results)

(f) No change!

(g) $A_{v_s} = \dfrac{Z_i}{Z_i + R_s}(A_{v_{NL}}) = \dfrac{2.283\text{ k}\Omega(-236)}{2.283\text{ k}\Omega + 1\text{ k}\Omega} = \mathbf{-164.1}$

$R_s\uparrow$, $A_{v_s}\downarrow$

(h) No change!

39. (a) $I_B = \dfrac{V_{CC} - V_{BE}}{R_B} = \dfrac{24\text{ V} - 0.7\text{ V}}{500\text{ k}\Omega} = 41.61\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (80 + 1)(41.61\ \mu\text{A}) = 3.37\text{ mA}$

$r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{3.37\text{ mA}} = 7.715\ \Omega$

$A_{v_{NL}} = -\dfrac{R_L}{r_e} = -\dfrac{4.3\text{ k}\Omega}{7.715\ \Omega} = \mathbf{-557.36}$

$Z_i = R_B \parallel \beta r_e = 560\text{ k}\Omega \parallel (80)(7.715\ \Omega)$
$= 560\text{ k}\Omega \parallel 617.2\ \Omega$
$= \mathbf{616.52\ \Omega}$

$Z_o = R_C = \mathbf{4.3\ k\Omega}$

(b) –

(c) $A_{v_L} = \dfrac{V_o}{V_i} = \dfrac{R_L}{R_L + R_o} A_{v_{NL}} = \dfrac{2.7\text{ k}\Omega(-557.36)}{2.7\text{ k}\Omega + 4.3\text{ k}\Omega}$

$= \mathbf{-214.98}$

$A_{v_s} = \dfrac{V_o}{V_s} = \dfrac{V_o}{V_i} \cdot \dfrac{V_i}{V_s}$

$V_i = \dfrac{Z_i V_s}{Z_i + R_s} = \dfrac{616.52\ \Omega\ V_s}{616.52\ \Omega + 1\text{ k}\Omega} = 0.381\ V_s$

$A_{v_s} = (-214.98)(0.381)$
$= \mathbf{-81.91}$

(d) $A_{i_s} = -A_{v_s}\left(\dfrac{R_s + Z_i}{R_L}\right) = -(-81.91)\left(\dfrac{1\text{ k}\Omega + 616.52\ \Omega}{2.7\text{ k}\Omega}\right)$

$= \mathbf{49.04}$

(e) $A_{v_L} = \dfrac{V_o}{V_i} = \dfrac{R_L}{R_L + R_o} A_{v_{NL}} = \dfrac{5.6\text{ k}\Omega(-557.36)}{5.6\text{ k}\Omega + 4.3\text{ k}\Omega} = -315.27$

$\dfrac{V_i}{V_s}$ the same $= 0.381$

$A_{v_s} = \dfrac{V_o}{V_i} \cdot \dfrac{V_i}{V_s} = (-315.27)(0.381) = \mathbf{-120.12}$

As $R_L\uparrow$, $A_{v_s}\uparrow$

(f) A_{v_L} the same = –214.98

$$\frac{V_i}{V_s} = \frac{Z_i}{Z_i + R_s} = \frac{616.52\ \Omega}{616.52\ \Omega + 0.5\ \text{k}\Omega} = 0.552$$

$$A_{v_s} = \frac{V_o}{V_i} \cdot \frac{V_i}{V_s} = (-214.98)(0.552) = \mathbf{-118.67}$$

As $R_s\downarrow$, $A_{v_s}\uparrow$

(g) No change!

40. (a) Exact analysis:

$$E_{Th} = \frac{R_2}{R_1 + R_2} V_{CC} = \frac{16\ \text{k}\Omega(16\ \text{V})}{68\ \text{k}\Omega + 16\ \text{k}\Omega} = 3.048\ \text{V}$$

$R_{Th} = R_1 \parallel R_2 = 68\ \text{k}\Omega \parallel 16\ \text{k}\Omega = 12.95\ \text{k}\Omega$

$$I_B = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta + 1)R_E} = \frac{3.048\ \text{V} - 0.7\ \text{V}}{12.95\ \text{k}\Omega + (101)(0.75\ \text{k}\Omega)}$$

$= 26.47\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (101)(26.47\ \mu\text{A})$

$= 2.673\ \text{mA}$

$$r_e = \frac{26\ \text{mV}}{I_E} = \frac{26\ \text{mV}}{2.673\ \text{mA}} = 9.726\ \Omega$$

$$A_{v_{NL}} = \frac{-R_C}{r_e} = -\frac{2.2\ \text{k}\Omega}{9.726\ \Omega} = \mathbf{-226.2}$$

$Z_i = 68\ \text{k}\Omega \parallel 16\ \text{k}\Omega \parallel \beta r_e$

$= 12.95\ \text{k}\Omega \parallel (100)(9.726\ \Omega)$

$= 12.95\ \text{k}\Omega \parallel 972.6\ \Omega$

$= \mathbf{904.66\ \Omega}$

$Z_o = R_C = \mathbf{2.2\ k\Omega}$

(b) –

(c) $$A_{v_L} = \frac{R_L}{R_L + Z_o}(A_{v_{NL}}) = \frac{5.6\ \text{k}\Omega(-226.2)}{5.6\ \text{k}\Omega + 2.2\ \text{k}\Omega} = \mathbf{-162.4}$$

(d) $$A_{i_L} = -A_{v_L}\frac{Z_i}{R_L}$$

$$= -(-162.4)\frac{(904.66\ \Omega)}{5.6\ \text{k}\Omega}$$

$= \mathbf{26.24}$

(e) $A_{v_L} = \dfrac{-R_C \| R_e}{r_e} = \dfrac{-2.2\text{ k}\Omega \| 5.6\text{ k}\Omega}{9.726\ \Omega}$

$= \mathbf{-162.4}$

$Z_i = 68\text{ k}\Omega \;\|\; 16\text{ k}\Omega \;\|\; \underbrace{972.6\ \Omega}_{\beta r_e}$

$= 904.66\ \Omega$

$A_{i_L} = -A_{v_L}\dfrac{Z_i}{R_L}$

$= \dfrac{(-162.4)(904.66\ \Omega)}{5.6\text{ k}\Omega}$

$= \mathbf{26.24}$

$Z_o = R_C = \mathbf{2.2\ k\Omega}$

Same results!

41. (a) $A_{v_L} = \dfrac{R_L}{R_L + Z_o} A_{v_{NL}}$

$R_L = 4.7\text{ k}\Omega$: $A_{v_L} = \dfrac{4.7\text{ k}\Omega}{4.7\text{ k}\Omega + 2.2\text{ k}\Omega}(-226.4) = \mathbf{-154.2}$

$R_L = 2.2\text{ k}\Omega$: $A_{v_L} = \dfrac{2.2\text{ k}\Omega}{2.2\text{ k}\Omega + 2.2\text{ k}\Omega}(-226.4) = \mathbf{-113.2}$

$R_L = 0.5\text{ k}\Omega$: $A_{v_L} = \dfrac{0.5\text{ k}\Omega}{0.5\text{ k}\Omega + 2.2\text{ k}\Omega}(-226.4) = \mathbf{-41.93}$

$R_L\downarrow,\ A_{v_L}\downarrow$

(b) Unaffected!

42. (a) $I_B = \dfrac{V_{CC} - V_{BE}}{R_B + (\beta+1)R_E} = \dfrac{18\text{ V} - 0.7\text{ V}}{680\text{ k}\Omega + (111)(0.82\text{ k}\Omega)}$

$= 22.44\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (110 + 1)(22.44\ \mu\text{A})$

$= 2.49\text{ mA}$

$r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{2.49\text{ mA}} = 10.44\ \Omega$

$A_{v_{NL}} = -\dfrac{R_C}{r_e + R_E} = -\dfrac{3\text{ k}\Omega}{10.44\ \Omega + 0.82\text{ k}\Omega}$

$= \mathbf{-3.61}$

$Z_i \cong R_B \| Z_b = 680\text{ k}\Omega \| (\beta r_e + (\beta + 1)R_E)$

$= 680\text{ k}\Omega \| (610)(10.44\ \Omega) + (110 + 1)(0.82\text{ k}\Omega)$

$= 680\text{ k}\Omega \| 92.17\text{ k}\Omega$

$= \mathbf{81.17\ k\Omega}$

$Z_o \cong R_C = \mathbf{3\ k\Omega}$

(b) –

(c) $A_{v_L} = \dfrac{V_o}{V_i} = \dfrac{R_L}{R_L + R_o} A_{v_{NL}} = \dfrac{4.7\text{ k}\Omega(-3.61)}{4.7\text{ k}\Omega + 3\text{ k}\Omega}$

$= \mathbf{-2.2}$

$A_{v_s} = \dfrac{V_o}{V_s} = \dfrac{V_o}{V_i} \cdot \dfrac{V_i}{V_s}$

$V_i = \dfrac{Z_i V_s}{Z_i + R_s} = \dfrac{81.17\text{ k}\Omega\ (V_s)}{81.17\text{ k}\Omega + 0.6\text{ k}\Omega} = 0.992\ V_s$

$A_{v_s} = (-2.2)(0.992)$

$= \mathbf{-2.18}$

(d) None!

(e) A_{v_L} – none!

$\dfrac{V_i}{V_s} = \dfrac{Z_i}{Z_i + R_s} = \dfrac{81.17\text{ k}\Omega}{81.17\text{ k}\Omega + 1\text{ k}\Omega} = 0.988$

$A_{v_s} = (-2.2)(0.988)$

$= \mathbf{-2.17}$

$R_s\uparrow$, $A_{v_s}\downarrow$, (but only slightly for moderate changes in R_s since Z_i is typically much larger than R_s)

43. Using the exact approach:

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

$= \dfrac{2.33\text{ V} - 0.7\text{ V}}{10.6\text{ k}\Omega + (121)(1.2\text{ k}\Omega)}$

$= 10.46\ \mu\text{A}$

$E_{Th} = \dfrac{R_2}{R_1 + R_2} V_{CC}$

$= \dfrac{12\text{ k}\Omega}{91\text{ k}\Omega + 12\text{ k}\Omega}(20\text{ V}) = 2.33\text{ V}$

$R_{Th} = R_1 \parallel R_2 = 91\text{ k}\Omega \parallel 12\text{ k}\Omega = 10.6\text{ k}\Omega$

$I_E = (\beta + 1)I_B = (121)(10.46\ \mu\text{A})$

$= 1.266\text{ mA}$

$r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{1.266\text{ mA}} = 20.54\ \Omega$

(a) $A_{v_{NL}} \cong \dfrac{R_E}{r_e + R_E} = \dfrac{1.2\text{ k}\Omega}{20.54\ \Omega + 1.2\text{ k}\Omega} = \mathbf{0.983}$

$Z_i = R_1 \parallel R_2 \parallel (\beta r_e + (\beta + 1)R_E)$

$= 91\text{ k}\Omega \parallel 12\text{ k}\Omega \parallel ((120)(20.54\ \Omega) + (120 + 1)(1.2\text{ k}\Omega))$

$= 10.6\text{ k}\Omega \parallel (2.46\text{ k}\Omega + 145.2\text{ k}\Omega)$

$= 10.6\text{ k}\Omega \parallel 147.66\text{ k}\Omega$

$= \mathbf{9.89\text{ k}\Omega}$

$Z_o = R_E \parallel r_e = 1.2\text{ k}\Omega \parallel 20.54\ \Omega$

$= \mathbf{20.19\ \Omega}$

(b) –

(c) $A_{v_L} = \dfrac{R_L}{R_L + Z_o} A_{v_{NL}} = \dfrac{2.7\text{ k}\Omega(0.983)}{2.7\text{ k}\Omega + 20.19\ \Omega}$

$= \mathbf{0.976}$

$A_{v_s} = \dfrac{Z_i}{Z_i + R_s} A_{v_L} = \dfrac{9.89\text{ k}\Omega(0.976)}{9.89\text{ k}\Omega + 0.6\text{ k}\Omega}$

$= \mathbf{0.92}$

(d) $A_{v_L} = 0.976$ (unaffected by change in R_s)

$A_{v_s} = \dfrac{Z_i}{Z_i + R_s} A_{v_L} = \dfrac{9.89\text{ k}\Omega(0.976)}{9.89\text{ k}\Omega + 1\text{ k}\Omega}$

$= \mathbf{0.886}$ (vs. 0.92 with $R_s = 0.6\text{ k}\Omega$)

As $R_s\uparrow$, $A_{v_s}\downarrow$

(e) Changing R_s will have no effect on $A_{v_{NL}}$, Z_i, or Z_o.

(f) $A_{v_L} = \dfrac{R_L}{R_L + Z_o}\left(A_{v_{NL}}\right) = \dfrac{5.6\text{ k}\Omega(0.983)}{5.6\text{ k}\Omega + 20.19\ \Omega}$

$= \mathbf{0.979}$ (vs. 0.976 with $R_L = 2.7\text{ k}\Omega$)

$A_{v_s} = \dfrac{Z_i}{Z_i + R_s}(A_{v_L}) = \dfrac{9.89\text{ k}\Omega(0.979)}{9.89\text{ k}\Omega + 0.6\text{ k}\Omega}$

$= \mathbf{0.923}$ (vs. 0.92 with $R_L = 2.7\text{ k}\Omega$)

As $R_L\uparrow$, $A_{v_L}\uparrow$, $A_{v_s}\uparrow$

44. (a) $I_E = \dfrac{V_{EE} - V_{BE}}{R_E} = \dfrac{6\text{ V} - 0.7\text{ V}}{2.2\text{ k}\Omega}$

$= 2.41\text{ mA}$

$r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{2.41\text{ mA}} = 10.79\ \Omega$

$A_{v_{NL}} = \dfrac{R_C}{r_e} = \dfrac{4.7\text{ k}\Omega}{10.79\ \Omega} = \mathbf{435.59}$

$Z_i = R_E \,\|\, r_e = 2.2\text{ k}\Omega \,\|\, 10.79\ \Omega = \mathbf{10.74\ \Omega}$

$Z_o = R_C = \mathbf{4.7\text{ k}\Omega}$

(b) –

(c) $A_{v_L} = \dfrac{R_L}{R_L + R_o} A_{v_{NL}} = \dfrac{5.6\text{ k}\Omega(435.59)}{5.6\text{ k}\Omega + 4.7\text{ k}\Omega} = \mathbf{236.83}$

$V_i = \dfrac{Z_i}{Z_i + R_s} V_s = \dfrac{10.74\ \Omega\,(V_s)}{10.74\ \Omega + 100\ \Omega} = 0.097\ V_s$

$A_{v_s} = \dfrac{V_o}{V_i} \cdot \dfrac{V_i}{V_s} = (236.83)(0.097)$

$= \mathbf{22.97}$

(d) $V_i = I_e \cdot r_e$

$V_o = -I_o R_L$

$$I_o = \frac{-4.7\text{ k}\Omega(I_e)}{4.7\text{ k}\Omega + 5.6\text{ k}\Omega} = -0.4563 I_e$$

$$A_{v_L} = \frac{V_o}{V_i} = \frac{+(0.4563\cancel{I_e})R_L}{\cancel{I_e} \cdot r_e} = \frac{0.4563(5.6\text{ k}\Omega)}{10.79\ \Omega}$$

$= \mathbf{236.82}$ (vs. 236.83 for part c)

A_{v_s} : 2.2 kΩ || 10.79 Ω = 10.74 Ω

$$V_i = \frac{Z_i}{Z_i + R_s} \cdot V_s = \frac{10.74\ \Omega\,(V_s)}{10.74\ \Omega + 100\ \Omega} = 0.097\ V_s$$

$$A_{v_s} = \frac{V_o}{V_i} \cdot \frac{V_i}{V_s} = (236.82)(0.097)$$

$= \mathbf{22.97}$ (same results)

(e) $A_{v_L} = \dfrac{R_L}{R_L + R_o} A_{v_{NL}} = \dfrac{2.2\text{ k}\Omega}{2.2\text{ k}\Omega + 4.7\text{ k}\Omega}(435.59)$

$= \mathbf{138.88}$

$A_{v_s} = \dfrac{V_0}{V_i} \cdot \dfrac{V_i}{V_s}$, $\dfrac{V_i}{V_s} = \dfrac{Z_i}{Z_i + R_s} = \dfrac{10.74\ \Omega}{10.74\ \Omega + 500\ \Omega} = 0.021$

$A_{v_s} = (138.88)(0.021) = \mathbf{2.92}$

A_{v_s} very sensitive to increase in R_s due to relatively small Z_i; $R_s\uparrow$, $A_{v_s}\downarrow$

A_{v_L} sensitive to R_L; $R_L\downarrow$, $A_{v_L}\downarrow$

(f) $Z_o = R_C =$ **4.7 kΩ** unaffected by value of R_s!

(g) $Z_i = R_E \parallel r_e = 10.74\ \Omega$ unaffected by value of R_L!

45. (a) $A_{v_1} = \dfrac{R_L A_{v_{NL}}}{R_L + R_o} = \dfrac{1\text{ k}\Omega(-420)}{1\text{ k}\Omega + 3.3\text{ k}\Omega} = \mathbf{-97.67}$

$A_{v_2} = \dfrac{R_L A_{v_{NL}}}{R_L + R_o} = \dfrac{2.7\text{ k}\Omega(-420)}{2.7\text{ k}\Omega + 3.3\text{ k}\Omega} = \mathbf{-189}$

(b) $A_{v_L} = A_{v_1} \cdot A_{v_2} = (-97.67)(-189) = \mathbf{18.46 \times 10^3}$

$$A_{v_s} = \frac{V_o}{V_s} = \frac{V_o}{V_{i_2}} \cdot \frac{V_{o_1}}{V_{i_1}} \cdot \frac{V_{i_1}}{V_s}$$

$$= A_{v_2} \cdot A_{v_1} \cdot \frac{V_i}{V_s}$$

$$V_i = \frac{Z_i V_s}{Z_i + R_s} = \frac{1\text{ k}\Omega(V_s)}{1\text{ k}\Omega + 0.6\text{ k}\Omega} = 0.625$$

$A_{v_s} = (-189)(-97.67)(0.625)$

$= \mathbf{11.54 \times 10^3}$

(c) $A_{i_1} = -\dfrac{A_v Z_i}{R_L} = \dfrac{-(-97.67)(1\text{ k}\Omega)}{1\text{ k}\Omega} = \mathbf{97.67}$

$A_{i_2} = \dfrac{-A_v Z_i}{R_L} = \dfrac{-(-189)(1\text{ k}\Omega)}{2.7\text{ k}\Omega} = \mathbf{70}$

(d) $A_{i_L} = A_{i_1} \cdot A_{i_2} = (97.67)(70) = \mathbf{6.84 \times 10^3}$

(e) No effect!

(f) No effect!

(g) In phase

46. (a) $A_{v_1} = \dfrac{Z_{i_2}}{Z_{i_2} + Z_{o_1}} A_{v_{1NL}} = \dfrac{1.2\text{ k}\Omega}{1.2\text{ k}\Omega + 20\ \Omega}(1)$

$= 0.984$

$A_{v_2} = \dfrac{R_L}{R_L + Z_{o_2}} A_{v_{2NL}} = \dfrac{2.2\text{ k}\Omega}{2.2\text{ k}\Omega + 4.6\text{ k}\Omega}(-640)$

$= \mathbf{-207.06}$

(b) $A_{v_L} = A_{v_1} \cdot A_{v_2} = (0.984)(-207.06)$

$= \mathbf{-203.74}$

$A_{v_s} = \dfrac{Z_i}{Z_i + R_s} A_{v_L}$

$= \dfrac{50\text{ k}\Omega}{50\text{ k}\Omega + 1\text{ k}\Omega}(-203.74)$

$= \mathbf{-199.75}$

(c) $A_{i_1} = -A_{v_1} \dfrac{Z_{i_1}}{Z_{i_2}}$

$= -(0.984)\dfrac{(50\text{ k}\Omega)}{1.2\text{ k}\Omega}$

$= \mathbf{-41}$

$A_{i_2} = -A_{v_2} \dfrac{Z_{i_2}}{R_L}$

$= -(-207.06)\dfrac{(1.2\text{ k}\Omega)}{2.2\text{ k}\Omega}$

$= \mathbf{112.94}$

(d) $A_{i_L} = -A_{v_L} \dfrac{Z_{i_1}}{R_L}$

$= -(-203.74)\dfrac{(50\text{ k}\Omega)}{2.2\text{ k}\Omega}$

$= \mathbf{4.63 \times 10^3}$

(e) A load on an emitter-follower configuration will contribute to the emitter resistance (in fact, lower the value) and therefore affect Z_i (reduce its magnitude).

(f) The fact that the second stage is a CE amplifier will isolate Z_o from the first stage and R_s.

(g) The emitter-follower has zero phase shift while the common-emitter amplifier has a 180° phase shift. The system, therefore, has a total phase shift of 180° as noted by the negative sign in front of the gain for A_{v_T} in part b.

47. For each stage:

$$V_B = \frac{6.2\text{ k}\Omega}{24\text{ k}\Omega + 6.2\text{ k}\Omega}(15\text{ V}) = 3.08\text{ V}$$

$$V_E = V_B - 0.7\text{ V} = 3.08\text{ V} - 0.7\text{ V} = 2.38\text{ V}$$

$$I_E \cong I_C = \frac{V_E}{R_E} = \frac{2.38\text{ V}}{1.5\text{ k}\Omega} = 1.59\text{ mA}$$

$$V_C = V_{CC} - I_C R_C = 15\text{ V} - (1.59\text{ mA})(5.1\text{ k}\Omega) = \mathbf{6.89\text{ V}}$$

48. $$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{1.59\text{ mA}} = 16.35\ \Omega$$

$$R_{i_2} = R_1 \parallel R_2 \parallel \beta r_e = 6.2\text{ k}\Omega \parallel 24\text{ k}\Omega \parallel (150)(16.35\ \Omega) = 1.64\text{ k}\Omega$$

$$A_{v_1} = -\frac{R_C \parallel R_{i_2}}{r_e} = \frac{5.1\text{ k}\Omega \parallel 1.64\text{ k}\Omega}{16.35\ \Omega} = \mathbf{-75.8}$$

$$A_{v_2} = -\frac{R_C}{r_e} = \frac{-5.1\text{ k}\Omega}{16.35\ \Omega} = \mathbf{-311.9}$$

$$A_v = A_{v_1} A_{v_2} = (-75.8)(-311.9) = \mathbf{23{,}642}$$

49. $$V_{B_1} = \frac{3.9\text{ k}\Omega}{3.9\text{ k}\Omega + 6.2\text{ k}\Omega + 7.5\text{ k}\Omega}(20\text{ V}) = \mathbf{4.4\text{ V}}$$

$$V_{B_2} = \frac{6.2\text{ k}\Omega + 3.9\text{ k}\Omega}{3.9\text{ k}\Omega + 6.2\text{ k}\Omega + 7.5\text{ k}\Omega}(20\text{ V}) = \mathbf{11.48\text{ V}}$$

$$V_{E_1} = V_{B_1} - 0.7\text{ V} = 4.4\text{ V} - 0.7\text{ V} = 3.7\text{ V}$$

$$I_{C_1} \cong I_{E_1} = \frac{V_{E_1}}{R_E} = \frac{3.7\text{ V}}{1\text{ k}\Omega} = 3.7\text{ mA} \cong I_{E_2} \cong I_{C_2}$$

$$V_{C_2} = V_{CC} - I_C R_C = 20\text{ V} - (3.7\text{ mA})(1.5\text{ k}\Omega) = \mathbf{14.45\text{ V}}$$

50. $r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{3.7\text{ mA}} = 7\ \Omega$

$A_{v_1} = -\dfrac{r_e}{r_e} = \mathbf{-1}$

$A_{v_2} = \dfrac{R_E}{r_e} = \dfrac{1.5\text{ k}\Omega}{7\ \Omega} \cong \mathbf{214}$

$A_{v_T} = A_{v_1}A_{v_2} = (-1)(214) = \mathbf{-214}$

$V_o = A_{v_T}V_i = (-214)(10\text{ mV}) = \mathbf{-2.14\ V}$

51. $R_o = R_D = 1.5\text{ k}\Omega$ (V_o (from problem 50) $= -2.14$ V)

$V_o(\text{load}) = \dfrac{R_L}{R_o + R_L}(V_o) = \dfrac{10\text{ k}\Omega}{10\text{ k}\Omega + 1.5\text{ k}\Omega}(-2.14\text{ V})$

$= \mathbf{-1.86\ V}$

52. $I_B = \dfrac{V_{CC} - V_{BE}}{\beta_D R_E + R_B} = \dfrac{(16\text{ V} - 1.6\text{ V})}{(6000)(510\ \Omega) + 2.4\text{ M}\Omega}$

$= \dfrac{14.4\text{ V}}{5.46\text{ M}\Omega} = 2.64\ \mu\text{A}$

$I_C \cong I_E = \beta_D I_B = 6000(2.64\ \mu\text{A}) = \mathbf{15.8\ mA}$

$V_E = I_E R_E = (15.8\text{ mA})(510\ \Omega) = \mathbf{8.06\ V}$

53. From problem 69, $I_E = 15.8$ mA

$r_e = \dfrac{26}{I_E} = \dfrac{26\text{ V}}{15.8\text{ mA}} = 1.65\ \Omega$

$A_v = \dfrac{R_E}{r_e + R_E} = \dfrac{510\ \Omega}{1.65\ \Omega + 510\ \Omega} = \mathbf{0.997} \approx 1$

54. dc: $I_B \cong \dfrac{V_{CC} - V_{BE}}{R_B + \beta_D R_E} = \dfrac{16\text{ V} - 1.6\text{ V}}{2.4\text{ M}\Omega + (6000)(510\ \Omega)} = 2.64\ \mu\text{A}$

$I_C = \beta_D I_B = (6000)(2.64\ \mu\text{A}) = 15.84\text{ mA}$

$r_{e_2} = \dfrac{26\text{ mV}}{I_{E_2}} = \dfrac{26\text{ mV}}{15.84\text{ mA}} = 1.64\ \Omega$

ac: $Z_i \cong \beta_D r_{e_2} = (6000)(1.64\ \Omega) = 9.84\text{ k}\Omega$

$I_{b_1} = \dfrac{V_i}{9.84\text{ k}\Omega}$

$V_o = (-\beta_D I_{b_1})(R_C) = -(6000)\left(\dfrac{V_i}{9.84\text{ k}\Omega}\right)(200\ \Omega)$

$= -121.95\ Vi$

and $A_v = \dfrac{V_o}{V_i} \cong \mathbf{-121.95}$

55. $I_B = \dfrac{V_{CC} - V_{EB_1}}{R_B + \beta_1\beta_2 R_E} = \dfrac{16\text{ V} - 0.7\text{ V}}{1.5\text{ M}\Omega + (160)(200)(100\ \Omega)}$

$= 3.255\ \mu\text{A}$

$I_C \cong \beta_1\beta_2 I_B = (160)(200)(3.255\mu\text{A}) \cong$ **104.2 mA**

$V_{C_2} = V_{CC} - I_C R_C = 16\text{ V} - (104.2\text{ mA})(100\ \Omega) =$ **5.58 V**

$V_{B_1} = I_B R_B = (3.255\ \mu\text{A})(1.5\text{ M}\Omega) =$ **4.48 V**

56. From problem 55: $I_{E_1} = 0.521$ mA

$r_{e_1} = \dfrac{26\text{ mV}}{I_E\text{ (mA)}} = \dfrac{26\text{ mV}}{0.521\text{ mA}} = 49.9\ \Omega$

$R_{i_1} = \beta r_{e_i} = 160(49.9\ \Omega) = 7.98\text{ k}\Omega$

$A_v = \dfrac{\beta_1\beta_2 R_C}{\beta_1\beta_2 R_C + R_{i_1}} = \dfrac{(160)(200)(100\ \Omega)}{(160)(200)(100\ \Omega) + 7.98\text{ k}\Omega}$

$= 0.9925$

$V_o = A_v V_i = 0.9975\ (120\text{ mV})$

$=$ **119.7 mV**

57. $r_e = \dfrac{26\text{ mV}}{I_{E(\text{dc})}} = \dfrac{26\text{ mV}}{1.2\text{ mA}} =$ **21.67 Ω**

$\beta r_e = (120)(21.67\ \Omega) =$ **2.6 kΩ**

58. –

59. –

60. –

61. –

62. (a) $A_v = \dfrac{V_o}{V_i} = -160$

$V_o = \mathbf{-160\ V_i}$

(b) $I_b = \dfrac{V_i - h_{re}V_o}{h_{ie}} = \dfrac{V_i - h_{re}A_vV_i}{h_{ie}} = \dfrac{V_i(1 - h_{re}A_v)}{h_{ie}}$

$= \dfrac{V_i\left(1 - (2\times10^{-4})(160)\right)}{1\text{ k}\Omega}$

$I_b = \mathbf{9.68 \times 10^{-4} V_i}$

(c) $I_b = \dfrac{V_i}{1\text{ k}\Omega} = \mathbf{1 \times 10^{-3} V_i}$

(d) % Difference = $\dfrac{1\times10^{-3}V_i - 9.68\times10^{-4}V_i}{1\times10^{-3}V_i} \times 100\%$

$= \mathbf{3.2\ \%}$

(e) Valid first approximation

63. % difference in total load = $\dfrac{R_L - R_L \| 1/h_{oe}}{R_L} \times 100\%$

$= \dfrac{2.2\text{ k}\Omega - (2.2\text{ k}\Omega \| 50\text{ k}\Omega)}{2.2\text{ k}\Omega} \times 100\%$

$= \dfrac{2.2\text{ k}\Omega - 2.1073\text{ k}\Omega}{2.2\text{ k}\Omega} \times 100\%$

$= \mathbf{4.2\ \%}$

In this case the effect of $1/h_{oe}$ can be ignored.

64. (a) $V_o = \mathbf{-180}\boldsymbol{V_i}$ $\quad (h_{ie} = 4\text{ k}\Omega,\ h_{re} = 4.05 \times 10^{-4})$

(b) $I_b = \dfrac{V_i - (4.05\times10^{-4})(180V_i)}{4\text{ k}\Omega}$

$= \mathbf{2.32 \times 10^{-4}}\boldsymbol{V_i}$

(c) $I_b = \dfrac{V_i}{h_{ie}} = \dfrac{V_i}{4\text{ k}\Omega} = \mathbf{2.5 \times 10^{-4}}\boldsymbol{V_i}$

(d) % Difference = $\dfrac{2.5\times10^{-4}V_i - 2.32\times10^{-4}V_i}{2.5\times10^{-4}V_i} \times 100\% = \mathbf{7.2\%}$

(e) Yes, less than 10%

65. From Fig. 5.18

	min	max
h_{oe}:	1 μS	30 μS

Avg = $\dfrac{(1+30)\mu\text{S}}{2} = \mathbf{15.5\ \mu S}$

66. (a) $h_{fe} = \beta = \mathbf{120}$

$h_{ie} \cong \beta r_e = (120)(4.5\ \Omega) = \mathbf{540\ \Omega}$

$h_{oe} = \dfrac{1}{r_o} = \dfrac{1}{40\text{ k}\Omega} = \mathbf{25\ \mu S}$

(b) $r_e \cong \dfrac{h_{ie}}{\beta} = \dfrac{1\text{ k}\Omega}{90} = \mathbf{11.11\ \Omega}$

$\beta = h_{fe} = \mathbf{90}$

$r_o = \dfrac{1}{h_{oe}} = \dfrac{1}{20\ \mu\text{S}}$

$= \mathbf{50\ k\Omega}$

67. (a) r_e = **8.31 Ω** (from problem 9)

(b) $h_{fe} = \beta =$ **60**

$h_{ie} = \beta r_e$ = (60)(8.31 Ω) = **498.6 Ω**

(c) $Z_i = R_B \parallel h_{ie}$ = 220 kΩ || 498.6 Ω = **497.47 Ω**

$Z_o = R_C$ = **2.2 kΩ**

(d) $A_v = \dfrac{-h_{fe}R_C}{h_{ie}} = \dfrac{-(60)(2.2\text{ k}\Omega)}{498.6\ \Omega} = \mathbf{-264.74}$

$A_i \cong h_{fe}$ = **60**

(e) Z_i = **497.47 Ω** (the same)

$Z_o = r_o \parallel R_C,\ \ r_o = \dfrac{1}{25\ \mu\text{S}} = 40\text{ k}\Omega$

= 40 kΩ || 2.2 kΩ

= **2.09 kΩ**

(f) $A_v = \dfrac{-h_{fe}(r_o \| R_C)}{h_{ie}} = \dfrac{-(60)(2.085\text{ k}\Omega)}{498.6\ \Omega} = \mathbf{-250.90}$

$A_i = -A_vZ_i/R_C$ = −(−250.90)(497.47 Ω)/2.2 kΩ = **56.73**

68. (a) 68 kΩ || 12 kΩ = 10.2 kΩ

Z_i = 10.2 kΩ || h_{ie} = 10.2 kΩ || 2.75 kΩ

= **2.166 kΩ**

$Z_o = R_C \parallel r_o$

= 2.2 kΩ || 40 kΩ

= **2.085 kΩ**

(b) $A_v = \dfrac{-h_{fe}R'_C}{h_{ie}}$ $\qquad R'_C = R_C \parallel r_o$ = 2.085 kΩ

$= \dfrac{-(180)(2.085\text{ k}\Omega)}{2.75\text{ k}\Omega} = \mathbf{-136.5}$

$$A_i = \frac{I_o}{I_i} = \frac{I_o}{I'_i}\cdot\frac{I'_i}{I_i}$$

$$= \left(\frac{h_{f_e}}{1+h_{oe}R_L}\right)\left(\frac{10.2\text{ k}\Omega}{10.2\text{ k}\Omega + 2.68\text{ k}\Omega}\right)$$

$$= \left(\frac{180}{1+(25\ \mu\text{S})(2.2\text{ k}\Omega)}\right)(0.792)$$

= **135.13**

69. (a) $Z_i = R_E \parallel h_{ib}$
$= 1.2\text{ k}\Omega \parallel 9.45\ \Omega$
$= \mathbf{9.38\ \Omega}$

$$Z_o = R_C \parallel \frac{1}{h_{ob}} = 2.7\text{ k}\Omega \parallel \frac{1}{1\times10^{-6}\,\frac{\text{A}}{\text{V}}} = 2.7\text{ k}\Omega \parallel 1\text{ M}\Omega \cong \mathbf{2.7\text{ k}\Omega}$$

(b) $$A_v = \frac{-h_{fb}(R_C \| 1/h_{ob})}{h_{ib}} = \frac{-(-0.992)(\cong 2.7\text{ k}\Omega)}{9.45\ \Omega}$$
$= \mathbf{284.43}$
$A_i \cong \mathbf{-1}$

(c) $\alpha = -h_{fb} = -(-0.992) = \mathbf{0.992}$
$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.992}{1-0.992} = \mathbf{124}$$
$r_e = h_{ib} = \mathbf{9.45\ \Omega}$
$$r_o = \frac{1}{h_{ob}} = \frac{1}{1\ \mu\text{A/V}} = \mathbf{1\text{ M}\Omega}$$

70. (a) $$Z_i' = h_{ie} - \frac{h_{fe}h_{re}R_L}{1+h_{oe}R_L} = 2.75\text{ k}\Omega - \frac{(180)(2\times10^{-4})(2.2\text{ k}\Omega)}{(1+25\mu\text{S})(2.2\text{ k}\Omega)}$$
$= 2.68\text{ k}\Omega$
$Z_i = 10.2\text{ k}\Omega \parallel Z_i' = \mathbf{2.12\text{ k}\Omega}$
$$Z_o' = \frac{1}{h_{oe} - (h_{fe}h_{re}/h_{ie})} = \frac{1}{25\ \mu\text{S} - (180)(2\times10^{-4})/2.75\text{ k}\Omega}$$
$= 83.75\text{ k}\Omega$
$Z_o = 2.2\text{ k}\Omega \parallel 83.75\text{ k}\Omega = \mathbf{2.14\text{ k}\Omega}$

(b) $$A_v = \frac{-h_{fe}R_L}{h_{ie} + (h_{ie}h_{oe} - h_{fe}h_{re})R_L} = \frac{-(180)(2.2\text{ k}\Omega)}{2.75\text{ k}\Omega + \big((2.75\text{ k}\Omega)(25\mu\text{S}) - (180)(2\times10^{-4})\big)2.2\text{ k}\Omega}$$
$= \mathbf{-140.3}$

(c) $$A_i' = \frac{h_{fe}}{1+h_{oe}R_L} = \frac{(180)}{1+(25\mu\text{S})(2.2\text{ k}\Omega)} = 170.62$$
$$A_i = \frac{I_o}{I_i} = \frac{I_o}{I_i'}\cdot\frac{I_i'}{I_i} = (170.62)\left(\frac{10.2\text{ k}\Omega}{10.2\text{ k}\Omega + 2.68\text{ k}\Omega}\right)$$
$= \mathbf{135.13}$

71. (a) $Z_i = h_{ie} = \dfrac{-h_{fe}h_{re}R_L}{1+h_{oe}R_L}$

$= 0.86\text{ k}\Omega - \dfrac{(140)(1.5\times10^{-4})(2.2\text{ k}\Omega)}{1+(25\ \mu\text{S})(2.2\text{ k}\Omega)}$

$= 0.86\text{ k}\Omega - 43.79\ \Omega$

$= 816.21\ \Omega$

$Z_i' = R_B \parallel Z_i$

$= 470\text{ k}\Omega \parallel 816.21\ \Omega$

$= \mathbf{814.8\ \Omega}$

(b) $A_v = \dfrac{-h_{fe}R_L}{h_{ie}+(h_{ie}h_{oe}-h_{fe}h_{re})R_L}$

$= \dfrac{-(140)(2.2\text{ k}\Omega)}{0.86\text{ k}\Omega+((0.86\text{ k}\Omega)(25\ \mu\text{S})-(140)(1.5\times10^{-4}))2.2\text{ k}\Omega}$

$= \mathbf{-357.68}$

(c) $A_i = \dfrac{I_o}{I_i} = \dfrac{h_{fe}}{1+h_{oe}R_L} = \dfrac{140}{1+(25\ \mu\text{S})(2.2\text{ k}\Omega)}$

$= 132.70$

$A_i' = \dfrac{I_o}{I_i'} = \left(\dfrac{I_o}{I_i}\right)\left(\dfrac{I_i}{I_i'}\right)$ $\qquad I_i = \dfrac{470\text{ k}\Omega\ I_i'}{470\text{ k}\Omega+0.816\text{ k}\Omega}$

$= (132.70)(0.998)$ $\qquad \dfrac{I_i}{I_i'} = 0.998$

$= \mathbf{132.43}$

(d) $Z_o = \dfrac{1}{h_{oe}-\left(h_{fe}h_{re}/(h_{ie}+R_s)\right)} = \dfrac{1}{25\ \mu\text{S}-\left((140)(1.5\times10^{-4})/(0.86\text{ k}\Omega+1\text{ k}\Omega)\right)}$

$= \dfrac{1}{13.71\ \mu\text{S}} \cong \mathbf{72.9\text{ k}\Omega}$

72. (a) $Z_i' = h_{ib} - \dfrac{h_{fb}h_{rb}R_L}{1+h_{ob}R_L} = 9.45\ \Omega - \dfrac{(-0.997)(1\times10^{-4})(2.2\text{ k}\Omega)}{1+(0.5\mu\text{A/V})(2.2\text{ k}\Omega)}$

$= 9.67\ \Omega$

$Z_i = 1.2\text{ k}\Omega \parallel Z_i' = 1.2\text{ k}\Omega \parallel 9.67\ \Omega = \mathbf{9.59\ \Omega}$

(b) $A_i' = \dfrac{h_{fb}}{1+h_{ob}R_L} = \dfrac{-0.997}{1+(0.5\ \mu\text{A/V})(2.2\text{ k}\Omega)} = -0.996$

$A_i = \dfrac{I_o}{I_i'}\cdot\dfrac{I_i'}{I_i} = (-0.996)\left(\dfrac{1.2\text{ k}\Omega}{1.2\text{ k}\Omega+9.67\text{ k}\Omega}\right)$

$\cong \mathbf{-0.988}$

(c) $A_v = \dfrac{-h_{fb}R_L}{h_{ib} + (h_{ib}h_{ob} - h_{fb}h_{rb})R_L}$

$= \dfrac{-(-0.997)(2.2\text{ k}\Omega)}{9.45\ \Omega + \big((9.45\ \Omega)(0.5\ \mu\text{A/V}) - (-0.997)(1\times 10^{-4})\big)(2.2\text{ k}\Omega)}$

$= \mathbf{226.61}$

(d) $Z_o{}' = \dfrac{1}{h_{ob} - \left[h_{fb}h_{rb}/h_{ib}\right]}$

$= \dfrac{1}{0.5\ \mu\text{A/V} - \left[(-0.997)(1\times 10^{-4})/9.45\ \Omega\right]}$

$= 90.5\text{ k}\Omega$

$Z_o = 2.2\text{ k}\Omega \parallel Z_o{}' = \mathbf{2.15\ k\Omega}$

73. –

74. (a) h_{fe} (0.2 mA) ≅ 0.6 (normalized)
h_{fe} (1 mA) = 1.0

% change = $\left|\dfrac{h_{fe}(0.2\text{ mA}) - h_{fe}(1\text{ mA})}{h_{fe}(0.2\text{ mA})}\right| \times 100\%$

$= \left|\dfrac{0.6-1}{0.6}\right| \times 100\%$

= **66.7%**

(b) h_{fe}(1 mA) = 1.0
h_{fe}(5 mA) ≅ 1.5

% change = $\left|\dfrac{h_{fe}(1\text{ mA}) - h_{fe}(5\text{ mA})}{h_{fe}(1\text{ mA})}\right| \times 100\%$

$= \left|\dfrac{1-1.5}{1}\right| \times 100\%$

= **50%**

75. Log-log scale!

(a) I_c = 0.2 mA, h_{ie} = 4 (normalized)
I_c = 1 mA, h_{ie} = 1(normalized)

% change = $\left|\dfrac{4-1}{4}\right| \times 100\%$ = **75%**

(b) I_e = 5 mA, h_{ie} = 0.3 (normalized)

% change = $\left|\dfrac{1-0.3}{1}\right| \times 100\%$ = **70%**

76. (a) $h_{oe} = 20\ \mu S$ @ 1 mA
$I_c = 0.2$ mA, $h_{oe} = 0.2(h_{oe}$ @ 1 mA$)$
$= 0.2(20\ \mu S)$
$= \mathbf{4\ \mu S}$

(b) $r_o = \dfrac{1}{h_{oe}} = \dfrac{1}{4\ \mu S} = 250\text{ k}\Omega \gg 6.8\text{ k}\Omega$
Ignore $1/h_{oe}$

77. (a) $I_c = 10$ mA, $h_{oe} = 10(20\ \mu S) = \mathbf{200\ \mu S}$

(b) $r_o = \dfrac{1}{h_{oe}} = \dfrac{1}{200\mu S} = 5\text{ k}\Omega$ vs. $\mathbf{8.6\ k\Omega}$
Not a good approximation

78. (a) $h_{re}(0.1\text{ mA}) = 4(h_{re}(1\text{ mA}))$
$= 4(2 \times 10^{-4})$
$= \mathbf{8 \times 10^{-4}}$

(b) $h_{re}V_{ce} = h_{re}A_v \cdot V_i$
$= (8 \times 10^{-4})(210)V_i$
$= \mathbf{0.168\ V_i}$
In this case $h_{re}V_{ce}$ is too large a factor to be ignored.

79. (a) h_{fe}

(b) h_{oe}

(c) $h_{oe} \cong 30$ (normalized) to
$h_{oe} \cong 0.1$ (normalized) at low levels of I_c

(d) mid-region

80. (a) h_{ie} is the most temperature-sensitive parameter of Fig. 5.33.

(b) h_{oe} exhibited the smallest change.

(c) Normalized: $h_{fe(\max)} = \mathbf{1.5}$, $h_{fe(\min)} = \mathbf{0.5}$
For $h_{fe} = 100$ the range would extend from 50 to 150—certainly significant.

(d) On a normalized basis r_e increased from 0.3 at −65°C to 3 at 200°C—a significant change.

(e) The parameters show the least change in the region 0° → 100°C.

81. (a) Test:

$\beta R_E \geq 10R_2$

$70(1.5\text{ k}\Omega) \geq 10(39\text{ k}\Omega)$

$105\text{ k}\Omega \overset{?}{\geq} 390\text{ k}\Omega$

No!

$R_{Th} = 39\text{ k}\Omega \parallel 150\text{ k}\Omega = 30.95\text{ k}\Omega$

$$E_{Th} = \frac{39\text{ k}\Omega(14\text{ V})}{39\text{ k}\Omega + 150\text{ k}\Omega} = 2.89\text{ V}$$

$$I_B = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta+1)R_E} = \frac{2.89\text{ V} - 0.7\text{ V}}{30.95\text{ k}\Omega + (71)(1.5\text{ k}\Omega)}$$

$= 15.93\ \mu\text{A}$

$V_B = E_{Th} - I_B R_{Th}$

$= 2.89\text{ V} - (15.93\ \mu\text{A})(30.95\text{ k}\Omega)$

$= 2.397\text{ V}$

$V_E = 2.397\text{ V} - 0.7\text{ V} = 1.697\text{ V}$

and $I_E = \dfrac{V_E}{R_E} = \dfrac{1.697\text{ V}}{1.5\text{ k}\Omega} = 1.13\text{ mA}$

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

$= 14\text{ V} - 1.13\text{ mA}(2.2\text{ k}\Omega + 1.5\text{ k}\Omega)$

$= 9.819\text{ V}$

Biasing OK

(b) R_2 not connected at base:

$$I_B = \frac{V_{CC} - 0}{R_B + (\beta+1)R_E} = \frac{14\text{ V} - 0.7\text{ V}}{150\text{ k}\Omega + (71)(1.5\text{ k}\Omega)} = 51.85\ \mu\text{A}$$

$V_B = V_{CC} - I_B R_B = 14\text{ V} - (51.85\ \mu\text{A})(150\text{ k}\Omega)$

$=$ **6.22 V** as noted in Fig. 5.187.

Chapter 6

1. –

2. From Fig. 6.11:

   $V_{GS} = 0$ V, $I_D =$ **8 mA**
   $V_{GS} = -1$ V, $I_D =$ **4.5 mA**
   $V_{GS} = -1.5$ V, $I_D =$ **3.25 mA**
   $V_{GS} = -1.8$ V, $I_D =$ **2.5 mA**
   $V_{GS} = -4$ V, $I_D =$ **0 mA**
   $V_{GS} = -6$ V, $I_D =$ **0 mA**

3. (a) $V_{DS} \cong \mathbf{1.4\ V}$

   (b) $r_d = \dfrac{V}{I} = \dfrac{1.4\text{ V}}{6\text{ mA}} = \mathbf{233.33\ \Omega}$

   (c) $V_{DS} \cong \mathbf{1.6\ V}$

   (d) $r_d = \dfrac{V}{I} = \dfrac{1.6\text{ V}}{3\text{ mA}} = \mathbf{533.33\ \Omega}$

   (e) $V_{DS} \cong \mathbf{1.4\ V}$

   (f) $r_d = \dfrac{V}{I} = \dfrac{1.4\text{ V}}{1.5\text{ mA}} = \mathbf{933.33\ \Omega}$

   (g) $r_o = 233.33\ \Omega$

   $$r_d = \frac{r_o}{[1 - V_{GS}/V_P]^2} = \frac{233.33\ \Omega}{[1-(-1\text{ V})/(-4\text{ V})]^2} = \frac{233.33\ \Omega}{0.5625}$$
   $= \mathbf{414.81\ \Omega}$

   (h) $$r_d = \frac{233.33\ \Omega}{[1-(-2\text{ V})/(-4\text{ V})]^2} = \frac{233.33\ \Omega}{0.25} = \mathbf{933.2\ \Omega}$$

   (i) $\left.\begin{array}{l} 533.33\ \Omega \text{ vs. } 414.81\ \Omega \\ 933.33\ \Omega \text{ vs } 933.2\ \Omega \end{array}\right\}$ Eq. (6.1) is valid!

4. (a) $V_{GS} = 0$ V, $I_D = 8$ mA (for $V_{DS} > V_P$)
   $V_{GS} = -1$ V, $I_D = 4.5$ mA
   $\Delta I_D =$ **3.5 mA**

   (b) $V_{GS} = -1$ V, $I_D = 4.5$ mA
   $V_{GS} = -2$ V, $I_D = 2$ mA
   $\Delta I_D =$ **2.5 mA**

(c) $V_{GS} = -2$ V, $I_D = 2$ mA
$V_{GS} = -3$ V, $I_D = 0.5$ mA
$\Delta I_D = \mathbf{1.5\ mA}$

(d) $V_{GS} = -3$ V, $I_D = 0.5$ mA
$V_{GS} = -4$ V, $I_D = 0$ mA
$\Delta I_D = \mathbf{0.5\ mA}$

(e) As V_{GS} becomes more negative, the change in I_D gets progressively smaller for the same change in V_{GS}.

(f) Non-linear. Even though the change in V_{GS} is fixed at 1 V, the change in I_D drops from a maximum of 3.5 mA to a minimum of 0.5 mA—a 7:1 change in ΔI_D.

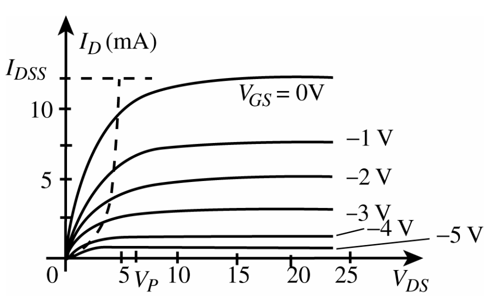
5. The collector characteristics of a BJT transistor are a plot of output current versus the output voltage for different levels of *input current*. The drain characteristics of a JFET transistor are a plot of the output current versus input voltage. For the BJT transistor increasing levels of input current result in increasing levels of output current. For JFETs, increasing magnitudes of input voltage result in lower levels of output current. The spacing between curves for a BJT are sufficiently similar to permit the use of a single beta (on an approximate basis) to represent the device for the dc and ac analysis. For JFETs, however, the spacing between the curves changes quite dramatically with increasing levels of input voltage requiring the use of Shockley's equation to define the relationship between I_D and V_{GS}. $V_{C_{sat}}$ and V_P define the region of nonlinearity for each device.

6. (a) The input current I_G for a JFET is effectively zero since the JFET gate-source junction is reverse-biased for linear operation, and a reverse-biased junction has a very high resistance.

(b) The input impedance of the JFET is high due to the reverse-biased junction between the gate and source.

(c) The terminology is appropriate since it is the electric field established by the applied gate to source voltage that controls the level of drain current. The term "field" is appropriate due to the absence of a conductive path between gate and source (or drain).

7. $V_{GS} = 0$ V, $I_D = I_{DSS} = 12$ mA
$V_{GS} = V_P = -6$ V, $I_D = 0$ mA
Shockley's equation: $V_{GS} = -1$ V, $I_D = 8.33$ mA; $V_{GS} = -2$ V, $I_D = 5.33$ mA; $V_{GS} = -3$ V, $I_D = 3$ mA; $V_{GS} = -4$ V, $I_D = 1.33$ mA; $V_{GS} = -5$ V, $I_D = 0.333$ mA.



8. For a p-channel JFET, all the voltage polarities in the network are reversed as compared to an n-channel device. In addition, the drain current has reversed direction.

9. (b) I_{DSS} = **10 mA**, V_P = **–6 V**

10. $V_{GS} = 0$ V, $I_D = I_{DSS} = 12$ mA
$V_{GS} = V_P = -4$ V, $I_D = 0$ mA
$V_{GS} = \dfrac{V_P}{2} = -2$ V, $I_D = \dfrac{I_{DSS}}{4} = 3$ mA
$V_{GS} = 0.3V_P = -1.2$ V, $I_D = 6$ mA
$V_{GS} = -3$ V, $I_D = 0.75$ mA (Shockley's equation)

11. (a) $I_D = I_{DSS} =$ **9 mA**

(b) $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$
$= 9\text{ mA}(1 - (-2\text{ V})/(-3.5\text{ V}))^2$
= **1.653 mA**

(c) $V_{GS} = V_P = -3.5$ V, I_D = **0 mA**

(d) $V_{GS} < V_P = -3.5$ V, I_D = **0 mA**

12. V_{GS} = **0 V**, I_D = **16 mA**
$V_{GS} = 0.3V_P = 0.3(-5\text{ V})$ = **–1.5 V**, $I_D = I_{DSS}/2$ = **8 mA**
$V_{GS} = 0.5V_P = 0.5(-5\text{ V})$ = **–2.5 V**, $I_D = I_{DSS}/4$ = **4 mA**
$V_{GS} = V_P$ = **–5 V**, I_D = **0 mA**

13. $V_{GS} = 0$ V, $I_D = I_{DSS}$ = **7.5 mA**
$V_{GS} = 0.3V_P = (0.3)(4\text{ V}) = 1.2$ V, $I_D = I_{DSS}/2 = 7.5\text{ mA}/2$ = **3.75 mA**
$V_{GS} = 0.5V_P = (0.5)(4\text{ V}) = 2$ V, $I_D = I_{DSS}/4 = 7.5\text{ mA}/4$ = **1.875 mA**
$V_{GS} = V_P = 4$ V, I_D = **0 mA**

14. (a) $I_D = I_{DSS}(1 - V_{GS}/V_P)^2 = 6\text{ mA}(1 - (-2\text{ V})/(-4.5\text{ V}))^2$
= **1.852 mA**
$I_D = I_{DSS}(1 - V_{GS}/V_P)^2 = 6\text{ mA}(1 - (-3.6\text{ V})/(-4.5\text{ V}))^2$
= **0.24 mA**

(b) $V_{GS} = V_P\left(1 - \sqrt{\dfrac{I_D}{I_{DSS}}}\right) = (-4.5\text{ V})\left(1 - \sqrt{\dfrac{3\text{ mA}}{6\text{ mA}}}\right)$
= **–1.318 V**
$V_{GS} = V_P\left(1 - \sqrt{\dfrac{I_D}{I_{DSS}}}\right) = (-4.5\text{ V})\left(1 - \sqrt{\dfrac{5.5\text{ mA}}{6\text{ mA}}}\right)$
= **–0.192 V**

15. $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$
$3\text{ mA} = I_{DSS}(1 - (-3\text{ V})/(-6\text{ V}))^2$
$3\text{ mA} = I_{DSS}(0.25)$
I_{DSS} = **12 mA**

16. From Fig. 6.22:

$-0.5\text{ V} < V_P < -6\text{ V}$

$1\text{ mA} < I_{DSS} < 5\text{ mA}$

For $I_{DSS} = 5$ mA and $V_P = -6$ V:

$V_{GS} = 0\text{ V}, I_D = 5\text{ mA}$

$V_{GS} = 0.3V_P = -1.8\text{ V}, I_D = 2.5\text{ mA}$

$V_{GS} = V_P/2 = -3\text{ V}, I_D = 1.25\text{ mA}$

$V_{GS} = V_P = -6\text{ V}, I_D = 0\text{ mA}$

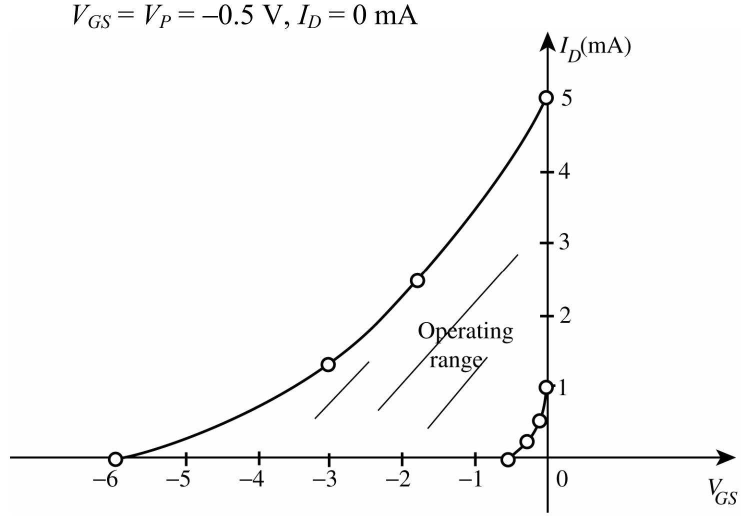
For $I_{DSS} = 1$ mA and $V_P = -0.5$ V:

$V_{GS} = 0\text{ V}, I_D = 1\text{ mA}$

$V_{GS} = 0.3V_P = -0.15\text{ V}, I_D = 0.5\text{ mA}$

$V_{GS} = V_P/2 = -0.25\text{ V}, I_D = 0.25\text{ mA}$

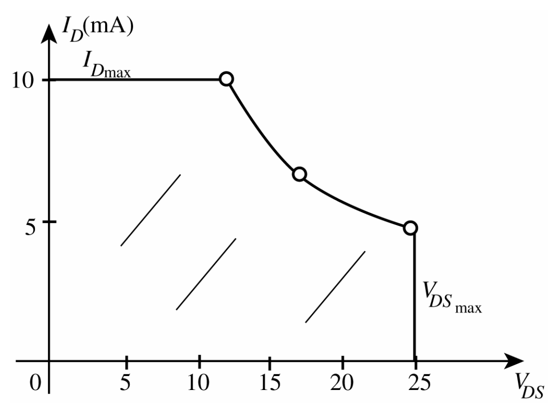
$V_{GS} = V_P = -0.5\text{ V}, I_D = 0\text{ mA}$



17. $V_{DS} = V_{DS_{max}} = \mathbf{25\ V}$, $I_D = \dfrac{P_{D_{max}}}{V_{DS_{max}}} = \dfrac{120\text{ mW}}{25\text{ V}} = \mathbf{4.8\ mA}$

$I_D = I_{DSS} = \mathbf{10\ mA}$, $V_{DS} = \dfrac{P_{D_{max}}}{I_{DSS}} = \dfrac{120\text{ mW}}{10\text{ mA}} = \mathbf{12\ V}$

$I_D = \mathbf{7\ mA}$, $V_{DS} = \dfrac{P_{D_{max}}}{I_D} = \dfrac{120\text{ mW}}{7\text{ mA}} = \mathbf{17.14\ V}$



18. $\left.\begin{array}{l} V_{GS} = -0.5\text{ V}, I_D = 6.5\text{ mA} \\ V_{GS} = -1\text{ V}, I_D = 4\text{ mA} \end{array}\right\}$ 2.5 mA

Determine ΔI_D above 4 mA line:

$$\frac{2.5\text{ mA}}{0.5\text{ V}} = \frac{x}{0.3\text{ V}} \Rightarrow x = 1.5\text{ mA}$$

$I_D = 4\text{ mA} + 1.5\text{ mA} =$ **5.5 mA** corresponding with values determined from a purely graphical approach.

19. Yes, all knees of V_{GS} curves at or below $|V_P| = 3$ V.

20. From Fig 6.25, $I_{DSS} \cong 9$ mA

At $V_{GS} = -1$ V, $I_D = 4$ mA

$I_D = I_{DSS}(1 - V_{GS}/V_P)^2$

$$\sqrt{\frac{I_D}{I_{DSS}}} = 1 - V_{GS}/V_P$$

$$\frac{V_{GS}}{V_P} = 1 - \sqrt{\frac{I_D}{I_{DSS}}}$$

$$V_P = \frac{V_{GS}}{1 - \sqrt{\frac{I_D}{I_{DSS}}}} = \frac{-1\text{ V}}{1 - \sqrt{\frac{4\text{ mA}}{9\text{ mA}}}}$$

$= \mathbf{-3\text{ V}}$ (an exact match)

21. $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$

$= 9\text{ mA}(1 - (-1\text{ V})/(-3\text{ V}))^2$

= **4 mA**, which compares very well with the level obtained using Fig. 6.25.

22. (a) $V_{DS} \cong 0.7$ V @ $I_D = 4$ mA (for $V_{GS} = 0$ V)

$$r = \frac{\Delta V_{DS}}{\Delta I_D} = \frac{0.7\text{ V} - 0\text{ V}}{4\text{ mA} - 0\text{ mA}} = \mathbf{175\ \Omega}$$

(b) For $V_{GS} = -0.5$ V, @ $I_D = 3$ mA, $V_{DS} = 0.7$ V

$$r = \frac{0.7\text{ V}}{3\text{ mA}} = \mathbf{233\ \Omega}$$

(c) $$r_d = \frac{r_o}{(1 - V_{GS}/V_P)^2} = \frac{175\ \Omega}{(1 - (-0.5\text{ V})/(-3\text{ V}))^2}$$

= **252 Ω** vs. 233 Ω from part (b)

23. –

24. The construction of a depletion-type MOSFET and an enchancement-type MOSFET are identical except for the doping in the channel region. In the depletion MOSFET the channel is established by the doping process and exists with no gate-to-source voltage applied. As the gate-to-source voltage increases in magnitude the channel decreases in size until pinch-off occurs. The enhancement MOSFET does not have a channel established by the doping sequence but relies on the gate-to-source voltage to create a channel. The larger the magnitude of the applied gate-to-source voltage, the larger the available channel.

25. –

26. At $V_{GS} = 0$ V, I_D = **6 mA**
At $V_{GS} = -1$ V, $I_D = 6\text{ mA}(1 - (-1\text{ V})/(-3\text{ V}))^2$ = **2.66 mA**
At $V_{GS} = +1$ V, $I_D = 6\text{ mA}(1 - (+1\text{ V})/(-3\text{ V}))^2 = 6\text{ mA}(1.333)^2$ = **10.667 mA**
At $V_{GS} = +2$ V, $I_D = 6\text{ mA}(1 - (+2\text{ V})/(-3\text{ V}))^2 = 6\text{ mA}(1.667)^2$ = **16.67 mA**

V_{GS}	I_D	
–1 V	2.66 mA	ΔI_D = **3.34 mA** (–1 V to 0)
0	6.0 mA	ΔI_D = **4.67 mA** (0 to +1 V)
+1 V	10.67 mA	ΔI_D = **6 mA** (+1 V to +2 V)
+2 V	16.67 mA	

From –1 V to 0 V, ΔI_D = 3.34 mA
while from +1 V to +2 V, ΔI_D = 6 mA – almost a 2:1 margin.
In fact, as V_{GS} becomes more and more positive, I_D will increase at a faster and faster rate due to the squared term in Shockley's equation.

27. $V_{GS} = 0$ V, $I_D = I_{DSS} = 12$ mA; $V_{GS} = -8$ V, $I_D = 0$ mA; $V_{GS} = \dfrac{V_P}{2} = -4$ V, $I_D = 3$ mA;
$V_{GS} = 0.3V_P = -2.4$ V, $I_D = 6$ mA; $V_{GS} = -6$ V, $I_D = 0.75$ mA

28. From problem 20:

$$V_P = \frac{V_{GS}}{1-\sqrt{\dfrac{I_D}{I_{DSS}}}} = \frac{+1\text{ V}}{1-\sqrt{\dfrac{14\text{ mA}}{9.5\text{ mA}}}} = \frac{+1\text{ V}}{1-\sqrt{1.473}} = \frac{+1\text{ V}}{1-1.21395}$$

$$= \frac{1}{-0.21395} \cong \mathbf{-4.67\ V}$$

29. $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$

$$I_{DSS} = \frac{I_D}{\left(1-V_{GS}/V_P\right)^2} = \frac{4\text{ mA}}{(1-(-2\text{ V})/(-5\text{ V}))^2} = \mathbf{11.11\ mA}$$

30. From problem 14(b):

$$V_{GS} = V_P\left(1-\sqrt{\frac{I_D}{I_{DSS}}}\right) = (-5\text{ V})\left(1-\sqrt{\frac{20\text{ mA}}{2.9\text{ mA}}}\right)$$

$= (-5\text{ V})(1 - 2.626) = (-5\text{ V})(-1.626)$
= **8.13 V**

31. From Fig. 6.34, $P_{D_{max}}$ = 200 mW, I_D = 8 mA

$P = V_{DS}I_D$

and $V_{DS} = \dfrac{P_{max}}{I_D} = \dfrac{200\text{ mW}}{8\text{ mA}}$ = **25 V**

32. (a) In a depletion-type MOSFET the channel exists in the device and the applied voltage V_{GS} controls the size of the channel. In an enhancement-type MOSFET the channel is not established by the construction pattern but induced by the applied control voltage V_{GS}.

(b) –

(c) Briefly, an applied gate-to-source voltage greater than V_T will establish a channel between drain and source for the flow of charge in the output circuit.

33. (a) $I_D = k(V_{GS} - V_T)^2 = 0.4 \times 10^{-3}(V_{GS} - 3.5)^2$

V_{GS}	I_D
3.5 V	0
4 V	0.1 mA
5 V	0.9 mA
6 V	2.5 mA
7 V	4.9 mA
8 V	8.1 mA

(b) $I_D = 0.8 \times 10^{-3}(V_{GS} - 3.5)^2$

V_{GS}	I_D	
3.5 V	0	For same levels of V_{GS}, I_D attains
4 V	0.2 mA	twice the current level as part (a).
5 V	1.8 mA	Transfer curve has steeper slope.
6 V	5.0 mA	For both curves, $I_D = 0$ mA for
7 V	9.8 mA	$V_{GS} < 3.5$ V.
8 V	16.2 mA	

34. (a) $k = \dfrac{I_{D(\text{on})}}{\left(V_{GS(\text{on})} - V_T\right)^2} = \dfrac{4\text{ mA}}{(6\text{ V} - 4\text{ V})^2} = 1\text{ mA/V}^2$

$I_D = k(V_{GS} - V_T)^2 = \mathbf{1 \times 10^{-3}(V_{GS} - 4\ V)^2}$

(b) For $V_{GS} < V_T = 4$ V, $I_D = 0$ mA

V_{GS}	I_D
4 V	0 mA
5 V	1 mA
6 V	4 mA
7 V	9 mA
8 V	16 mA

(c) ($V_{GS} < V_T$)

V_{GS}	I_D
2 V	0 mA
5 V	1 mA
10 V	36 mA

35. From Fig. 6.58, $V_T = 2.0$ V

At $I_D = 6.5$ mA, $V_{GS} = 5.5$ V: $\quad I_D = k(V_{GS} - V_T)^2$

$6.5 \text{ mA} = k(5.5 \text{ V} - 2 \text{ V})^2$

$k = \mathbf{5.31 \times 10^{-4}}$

$I_D = \mathbf{5.31 \times 10^{-4}(V_{GS} - 2)^2}$

36. $I_D = k\left(V_{GS(\text{on})} - V_T\right)^2$

and $\left(V_{GS(\text{on})} - V_T\right)^2 = \dfrac{I_D}{k}$

$$V_{GS(\text{on})} - V_T = \sqrt{\frac{I_D}{k}}$$

$$V_T = V_{GS(\text{on})} - \sqrt{\frac{I_D}{k}}$$

$$= 4\text{ V} - \sqrt{\frac{3\text{ mA}}{0.4\times10^{-3}}} = 4\text{ V} - \sqrt{7.5}\text{ V}$$

$= 4 \text{ V} - 2.739 \text{ V}$

$= \mathbf{1.261\ V}$

37. $I_D = k(V_{GS} - V_T)^2$

$$\frac{I_D}{k} = (V_{GS} - V_T)^2$$

$$\sqrt{\frac{I_D}{k}} = V_{GS} - V_T$$

$$V_{GS} = V_T + \sqrt{\frac{I_D}{k}} = 5\text{ V} + \sqrt{\frac{30\text{ mA}}{0.06\times10^{-3}}}$$

$= \mathbf{27.36\ V}$

38. Enhancement-type MOSFET:

$I_D = k(V_{GS} - V_T)^2$

$$\frac{dI_D}{dV_{GS}} = 2k(V_{GS} - V_T)\left[\frac{d}{dV_{GS}}(\underbrace{\cancel{V}_{GS} - V_T}_{1})\right]$$

$$\frac{dI_D}{dV_{GS}} = \mathbf{2k(V_{GS} - V_T)}$$

Depletion-type MOSFET:
$I_D = I_{DSS}(1 - V_{GS}/V_P)^2$

$$\frac{dI_D}{dV_{GS}} = I_{DSS}\frac{d}{dV_{GS}}\left(1-\frac{V_{GS}}{V_P}\right)^2$$

$$= I_{DSS}\,2\underbrace{\left[1-\frac{V_{GS}}{V_P}\right]\frac{d}{dV_{GS}}\left[0-\frac{V_{GS}}{V_P}\right]}_{-\frac{1}{V_P}}$$

$$= 2I_{DSS}\left(1-\frac{V_{GS}}{V_P}\right)\left(-\frac{1}{V_P}\right)$$

$$= -\frac{2I_{DSS}}{V_P}\left(1-\frac{V_{GS}}{V_P}\right)$$

$$= -\frac{2I_{DSS}}{V_P}\left(\frac{V_P}{V_P}\right)\left(1-\frac{V_{GS}}{V_P}\right)$$

$$\frac{dI_D}{dV_{GS}} = \boldsymbol{\frac{2I_{DSS}}{V_P^2}(V_{GS}-V_P)}$$

For both devices $\frac{dI_D}{dV_{GS}} = k_1(V_{GS} - K_2)$
revealing that the drain current of each will increase at about the same rate.

39. $I_D = k(V_{GS} - V_T)^2 = 0.45 \times 10^{-3}(V_{GS} - (-5\text{ V}))^2$
$= 0.45 \times 10^{-3}(V_{GS} + 5\text{ V})^2$
$V_{GS} = -5$ V, $I_D = 0$ mA; $V_{GS} = -6$ V, $I_D = 0.45$ mA; $V_{GS} = -7$ V, $I_D = 1.8$ mA;
$V_{GS} = -8$ V, $I_D = 4.05$ mA; $V_{GS} = -9$ V, $I_D = 7.2$ mA; $V_{GS} = -10$ V, $I_D = 11.25$ mA

41. –

42. (a) –

(b) For the "on" transistor: $R = \frac{V}{I} = \frac{0.1\text{ V}}{4\text{ mA}} = \mathbf{25\ ohms}$

For the "off" transistor: $R = \frac{V}{I} = \frac{4.9\text{ V}}{0.5\ \mu\text{A}} = \mathbf{9.8\ M\Omega}$

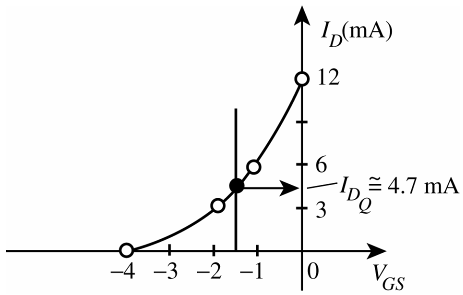
Absolutely, the high resistance of the "off" resistance will ensure V_o is very close to 5 V.

43. –

Chapter 7

1. (a) $V_{GS} = 0$ V, $I_D = I_{DSS} = 12$ mA
$V_{GS} = V_P = -4$ V, $I_D = 0$ mA
$V_{GS} = V_P/2 = -2$ V, $I_D = I_{DSS}/4 = 3$ mA
$V_{GS} = 0.3V_P = -1.2$ V, $I_D = I_{DSS}/2 = 6$ mA

(b)



(c) $I_{D_Q} \cong$ **4.7 mA**

$V_{DS_Q} = V_{DD} - I_{D_Q}R_D = 12\text{ V} - (4.7\text{ mA})(1.2\text{ k}\Omega)$
$= \mathbf{6.36\ V}$

(d) $I_{D_Q} = I_{DSS}(1 - V_{GS}/V_P)^2 = 12\text{ mA}(1 - (-1.5\text{ V})/(-4\text{ V}))^2$
$= \mathbf{4.69\ mA}$

$V_{DS_Q} = V_{DD} - I_{D_Q}R_D = 12\text{ V} - (4.69\text{ mA})(1.2\text{ k}\Omega)$
$= \mathbf{6.37\ V}$
excellent comparison

2. (a) $I_{D_Q} = I_{DSS}(1 - V_{GS}/V_P)^2$
$= 10\text{ mA}\left(1 - (-3\text{ V})/(-4.5\text{ V})\right)^2$
$= 10\text{ mA}(0.333)^2$
$I_{D_Q} = \mathbf{1.11\ mA}$

(b) $V_{GS_Q} = \mathbf{-3\ V}$

(c) $V_{DS} = V_{DD} - I_D(R_D + R_S)$
$= 16\text{ V} - (1.11\text{ mA})(2.2\text{ k}\Omega)$
$= 16\text{ V} - 2.444\text{ V}$
$= \mathbf{13.56\ V}$
$V_D = V_{DS} = \mathbf{13.56\ V}$
$V_G = V_{GS_Q} = \mathbf{-3\ V}$
$V_S = \mathbf{0\ V}$

3. (a) $I_{D_Q} = \dfrac{V_{DD} - V_D}{R_D} = \dfrac{14\text{ V} - 9\text{ V}}{1.6\text{ k}\Omega} = \mathbf{3.125\ mA}$

(b) $V_{DS} = V_D - V_S = 9\text{ V} - 0\text{ V} = \mathbf{9\ V}$

(c) $I_D = I_{DSS}(1 - V_{GS}/V_P)^2 \Rightarrow V_{GS} = V_P\left(1 - \sqrt{\dfrac{I_D}{I_{DSS}}}\right)$

$V_{GS} = (-4\text{ V})\left(1 - \sqrt{\dfrac{3.125\text{ mA}}{8\text{ mA}}}\right)$

$= -1.5\text{ V}$

$\therefore V_{GG} = \mathbf{1.5\ V}$

4. $V_{GS_Q} = 0\text{ V}, I_D = I_{DSS} = 5\text{ mA}$

$V_D = V_{DD} - I_DR_D$

$= 20\text{ V} - (5\text{ mA})(2.2\text{ k}\Omega)$

$= 20\text{ V} - 11\text{ V}$

$= \mathbf{9\ V}$

5. $V_{GS} = V_P = -4\text{ V}$

$\therefore I_{D_Q} = 0\text{ mA}$

and $V_D = V_{DD} - I_{D_Q}R_D = 18\text{ V} - (0)(2\text{ k}\Omega)$

$= \mathbf{18\ V}$

6. (a)(b) $V_{GS} = 0\text{ V}, I_D = 10\text{ mA}$

$V_{GS} = V_P = -4\text{ V}, I_D = 0\text{ mA}$

$V_{GS} = \dfrac{V_P}{2} = -2\text{ V}, I_D = 2.5\text{ mA}$

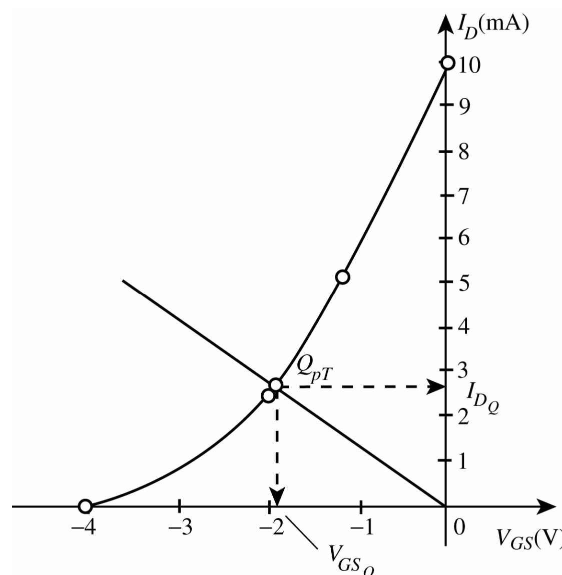
$V_{GS} = 0.3V_P = -1.2\text{ V}, I_D = 5\text{ mA}$

$V_{GS} = -I_DR_S$

$I_D = 5$ mA:

$V_{GS} = -(5\text{ mA})(0.75\text{ k}\Omega)$

$= -3.75\text{ V}$



(c) $I_{D_Q} \cong \mathbf{2.7\ mA}$

$V_{GS_Q} \cong \mathbf{-1.9\ V}$

(d) $V_{DS} = V_{DD} - I_D(R_D + R_S)$

$= 18\text{ V} - (2.7\text{ mA})(1.5\text{ k}\Omega + 0.75\text{ k}\Omega)$

$= \mathbf{11.93\ V}$

$V_D = V_{DD} - I_DR_D$

$= 18\text{ V} - (2.7\text{ mA})(1.5\text{ k}\Omega)$

$= \mathbf{13.95\ V}$

$V_G = \mathbf{0\ V}$

$V_S = I_SR_S = I_DR_S$

$= (2.7\text{ mA})(0.75\text{ k}\Omega)$

$= \mathbf{2.03\ V}$

7. $I_D = I_{DSS}(1 - V_{GS}/V_P)^2 = I_{DSS}\left(1 + \frac{2I_DR_S}{V_P} + \frac{I_D^2R_S^2}{V_P^2}\right)$

$$\left(\frac{I_{DSS}R_S^2}{V_P^2}\right)I_D^2 + \left(\frac{2I_{DSS}R_S}{V_P} - 1\right)I_D + I_{DSS} = 0$$

Substituting: $351.56\,I_D^2 - 4.75I_D + 10\text{ mA} = 0$

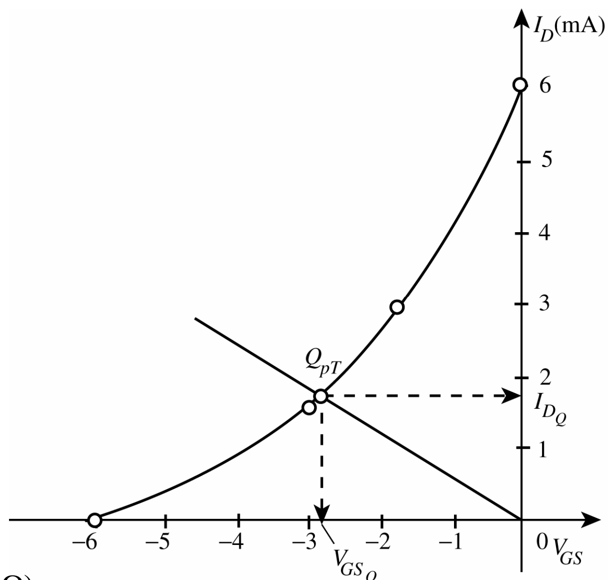
$I_D = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a} = \cancel{10.91\text{ mA}}, 2.60\text{ mA}$

I_{D_Q} = **2.6 mA** (exact match #6)

$V_{GS} = -I_DR_S = -(2.60\text{ mA})(0.75\text{ k}\Omega)$
$= \mathbf{-1.95\ V}$ vs. -2 V (#6)

8. $V_{GS} = 0$ V, $I_D = I_{DSS} = 6$ mA
$V_{GS} = V_P = -6$ V, $I_D = 0$ mA
$V_{GS} = \dfrac{V_P}{2} = -3$ V, $I_D = 1.5$ mA

$V_{GS} = 0.3V_P = -1.8$ V, $I_D = 3$ mA
$V_{GS} = -I_DR_S$
$I_D = 2$ mA:
$V_{GS} = -(2\text{ mA})(1.6\text{ k}\Omega)$
$= -3.2$ V



(a) I_{D_Q} = **1.7 mA**
V_{GS_Q} = **−2.8 V**

(b) $V_{DS} = V_{DD} - I_D(R_D + R_S)$
$= 12\text{ V} - (1.7\text{ mA})(2.2\text{ k}\Omega + 1.6\text{ k}\Omega)$
= **5.54 V**
$V_D = V_{DD} - I_DR_D$
$= 12\text{ V} - (1.7\text{ mA})(2.2\text{ k}\Omega)$
= **8.26 V**
V_G = **0 V**
$V_S = I_SR_S = I_DR_S$
$= (1.7\text{ mA})(1.6\text{ k}\Omega)$
= **2.72 V** (vs. 2.8 V from $V_S = (V_{GS_Q})$)

9. (a) $I_{D_Q} = I_S = \dfrac{V_S}{R_S} = \dfrac{1.7\text{ V}}{0.51\text{ k}\Omega}$ = **3.33 mA**

(b) $V_{GS_Q} = -I_{D_Q}R_S = -(3.33\text{ mA})(0.51\text{ k}\Omega)$
$\cong$ **−1.7 V**

(c) $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$
$3.33 \text{ mA} = I_{DSS}(1 - (-1.7 \text{ V})/(-4 \text{ V}))^2$
$3.33 \text{ mA} = I_{DSS}(0.331)$
$I_{DSS} =$ **10.06 mA**

(d) $V_D = V_{DD} - I_{D_Q} R_D$
$= 18 \text{ V} - (3.33 \text{ mA})(2 \text{ k}\Omega) = 18 \text{ V} - 6.66 \text{ V}$
= **11.34 V**

(e) $V_{DS} = V_D - V_S = 11.34 \text{ V} - 1.7 \text{ V}$
= **9.64 V**

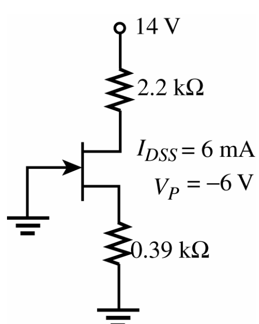
10. (a) $V_{GS} = 0 \text{ V}$
$\therefore I_D = I_{DSS} =$ **4.5 mA**

(b) $V_{DS} = V_{DD} - I_D(R_D + R_S)$
$= 20 \text{ V} - (4.5 \text{ mA})(2.2 \text{ k}\Omega + 0.68 \text{ k}\Omega)$
$= 20 \text{ V} - 12.96$
= **7.04 V**

(c) $V_D = V_{DD} - I_D R_D$
$= 20 \text{ V} - (4.5 \text{ mA})(2.2 \text{ k}\Omega)$
= **10.1 V**

(d) $V_S = I_S R_S = I_D R_S$
$= (4.5 \text{ mA})(0.68 \text{ k}\Omega)$
= **3.06 V**

11. Network redrawn:



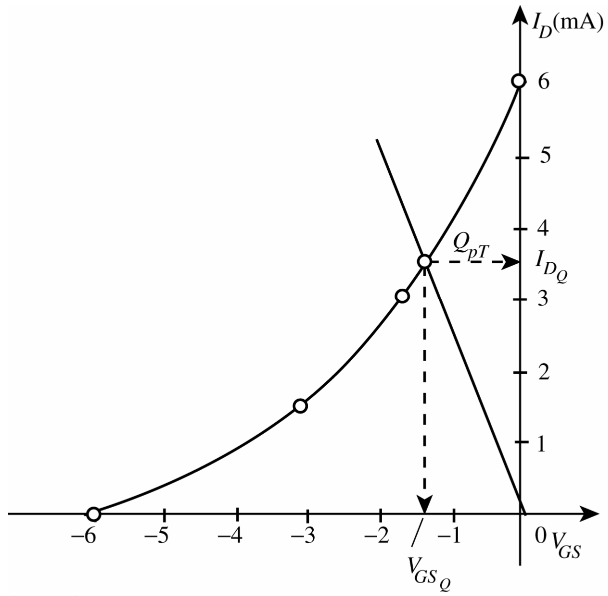
$V_{GS} = 0 \text{ V}, I_D = I_{DSS} = 6 \text{ mA}$
$V_{GS} = V_P = -6 \text{ V}, I_D = 0 \text{ mA}$
$V_{GS} = \dfrac{V_P}{2} = -3 \text{ V}, I_D = 1.5 \text{ mA}$
$V_{GS} = 0.3V_P = -1.8 \text{ V}, I_D = 3 \text{ mA}$
$V_{GS} = -I_D R_S = -I_D(0.39 \text{ k}\Omega)$
For $I_D = 5 \text{ mA}, V_{GS} = -1.95 \text{ V}$

From graph $I_{D_Q} \cong \mathbf{3.55\ mA}$

$V_{GS_Q} \cong \mathbf{-1.4\ V}$

$V_S = -\left(V_{GS_Q}\right) = -(-1.4\text{ V})$

$= \mathbf{+1.4\ V}$



12. (a) $V_G = \dfrac{R_2}{R_1 + R_2}V_{DD} = \dfrac{110\text{ k}\Omega(20\text{ V})}{910\text{ k}\Omega + 110\text{ k}\Omega}$

$= \mathbf{2.16\ V}$

$V_{GS} = 0\text{ V}$, $I_D = I_{DSS} = 10\text{ mA}$

$V_{GS} = V_P = -3.5\text{ V}$, $I_D = 0\text{ mA}$

$V_{GS} = \dfrac{V_P}{2} = -1.75\text{ V}$, $I_D = 2.5\text{ mA}$

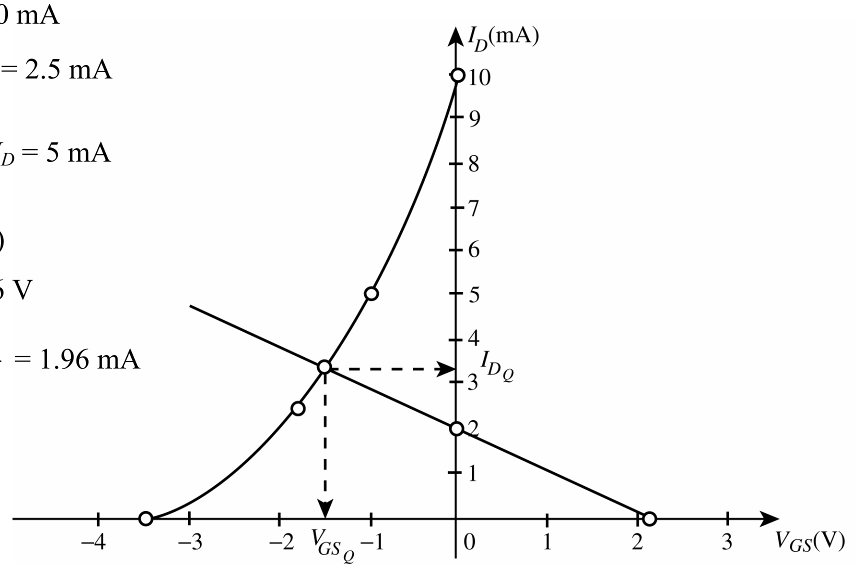
$V_{GS} = 0.3V_P = -1.05\text{ V}$, $I_D = 5\text{ mA}$

$V_{GS_Q} = V_G - I_DR_S$

$V_{GS_Q} = 2.16 - I_D(1.1\text{ k}\Omega)$

$I_D = 0$: $V_{GS_Q} = V_G = 2.16\text{ V}$

$V_{GS_Q} = 0\text{ V}$, $I_D = \dfrac{2.16\text{ V}}{1.1\text{ k}\Omega} = 1.96\text{ mA}$



(b) $I_{D_Q} \cong \mathbf{3.3\ mA}$

$V_{GS_Q} \cong \mathbf{-1.5\ V}$

(c) $V_D = V_{DD} - I_{D_Q}R_D$

$= 20\text{ V} - (3.3\text{ mA})(2.2\text{ k}\Omega)$

$= \mathbf{12.74\ V}$

$V_S = I_SR_S = I_DR_S$

$= (3.3\text{ mA})(1.1\text{ k}\Omega)$

$= \mathbf{3.63\ V}$

(d) $V_{DS_Q} = V_{DD} - I_{D_Q}(R_D + R_S)$

$= 20\text{ V} - (3.3\text{ mA})(2.2\text{ k}\Omega + 1.1\text{ k}\Omega)$

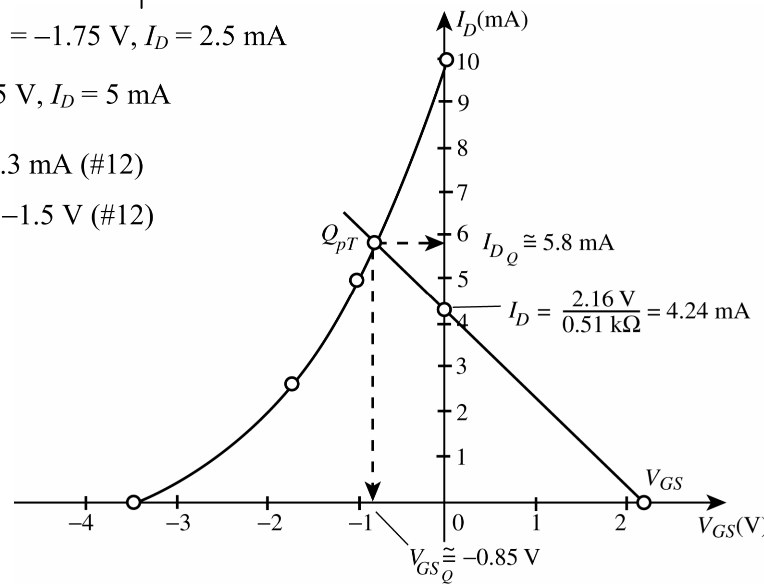
$= 20\text{ V} - 10.89\text{ V}$

$= \mathbf{9.11\ V}$

13. (a) $I_D = I_{DSS} = 10$ mA, $V_P = -3.5$ V
$V_{GS} = 0$ V, $I_D = I_{DSS} = 10$ mA
$V_{GS} = V_P = -3.5$ V, $I_D = 0$ mA
$V_{GS} = \dfrac{V_P}{2} = \dfrac{-3.5\text{ V}}{2} = -1.75$ V, $I_D = 2.5$ mA
$V_{GS} = 0.3V_P = -1.05$ V, $I_D = 5$ mA

$$V_G = \frac{110\text{ k}\Omega(20\text{ V})}{110\text{ k}\Omega + 910\text{ k}\Omega} = \mathbf{2.16\ V}$$

$I_{D_Q} \cong$ **5.8 mA** vs. 3.3 mA (#12)
$V_{GS_Q} \cong$ **−0.85 V** vs. −1.5 V (#12)



(b) As R_S decreases, the intersection on the vertical axis increases. The maximum occurs at $I_D = I_{DSS} = 10$ mA.

$$\therefore R_{S_{\min}} = \frac{V_G}{I_{DSS}} = \frac{2.16\text{ V}}{10\text{ mA}} = \mathbf{216\ \Omega}$$

14. (a) $$I_D = \frac{V_{R_D}}{R_D} = \frac{V_{DD} - V_D}{R_D} = \frac{18\text{ V} - 9\text{ V}}{2\text{ k}\Omega} = \frac{9\text{ V}}{2\text{ k}\Omega} = \mathbf{4.5\ mA}$$

(b) $V_S = I_S R_S = I_D R_S = (4.5\text{ mA})(0.68\text{ k}\Omega)$
$= \mathbf{3.06\ V}$
$V_{DS} = V_{DD} - I_D(R_D + R_S)$
$= 18\text{ V} - (4.5\text{ mA})(2\text{ k}\Omega + 0.68\text{ k}\Omega)$
$= 18\text{ V} - 12.06\text{ V}$
$= \mathbf{5.94\ V}$

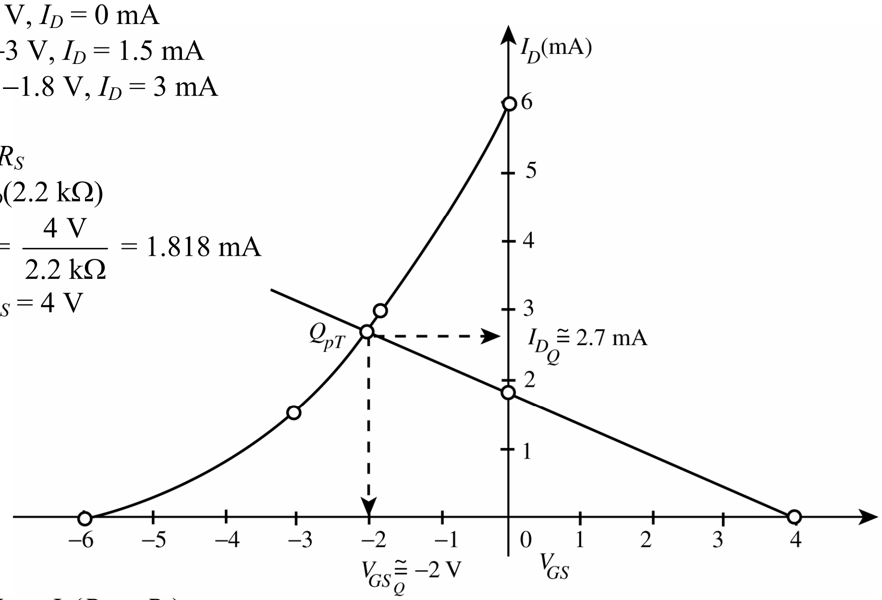
(c) $$V_G = \frac{R_2}{R_1 + R_2}V_{DD} = \frac{91\text{ k}\Omega(18\text{ V})}{750\text{ k}\Omega + 91\text{ k}\Omega} = \mathbf{1.95\ V}$$
$V_{GS} = V_G - V_S = 1.95\text{ V} - 3.06\text{ V} = \mathbf{-1.11\ V}$

(d) $$V_P = \frac{V_{GS}}{1 - \sqrt{\dfrac{I_D}{I_{DSS}}}} = \frac{-1.11\text{ V}}{1 - \sqrt{\dfrac{4.5\text{ mA}}{8\text{ mA}}}} = \mathbf{-4.44\ V}$$
$= \mathbf{-1.48\ V}$

15. (a) $V_{GS} = 0$ V, $I_D = I_{DSS} = 6$ mA
$V_{GS} = V_P = -6$ V, $I_D = 0$ mA
$V_{GS} = V_P/2 = -3$ V, $I_D = 1.5$ mA
$V_{GS} = 0.3V_P = -1.8$ V, $I_D = 3$ mA

$V_{GS} = V_{SS} - I_D R_S$
$V_{GS} = 4\text{ V} - I_D(2.2\text{ k}\Omega)$
$V_{GS} = 0\text{ V}, I_D = \dfrac{4\text{ V}}{2.2\text{ k}\Omega} = 1.818\text{ mA}$
$I_D = 0$ mA, $V_{GS} = 4$ V

$I_{D_Q} \cong$ **2.7 mA**
$V_{GS_Q} \cong$ **−2 V**



(b) $V_{DS} = V_{DD} + V_{SS} - I_D(R_D + R_S)$
$= 16\text{ V} + 4\text{ V} - (2.7\text{ mA})(4.4\text{ k}\Omega)$
= **8.12 V**
$V_S = -V_{SS} + I_D R_S = -4\text{ V} + (2.7\text{ mA})(2.2\text{ k}\Omega)$
= **1.94 V**
or $V_S = -\left(V_{GS_Q}\right) = -(-2\text{ V}) =$ **+2 V**

16. (a) $I_D = \dfrac{V}{R} = \dfrac{V_{DD} + V_{SS} - V_{DS}}{R_D + R_S} = \dfrac{12\text{ V} + 3\text{ V} - 4\text{ V}}{3\text{ k}\Omega + 2\text{ k}\Omega} = \dfrac{11\text{ V}}{5\text{ k}\Omega} =$ **2.2 mA**

(b) $V_D = V_{DD} - I_D R_D = 12\text{ V} - (2.2\text{ mA})(3\text{ k}\Omega)$
= **5.4 V**
$V_S = I_S R_S + V_{SS} = I_D R_S + V_{SS}$
$= (2.2\text{ mA})(2\text{ k}\Omega) + (-3\text{ V})$
$= 4.4\text{ V} - 3\text{ V}$
= **1.4 V**

(c) $V_{GS} = V_G - V_S$
$= 0\text{ V} - 1.4\text{ V}$
= **−1.4 V**

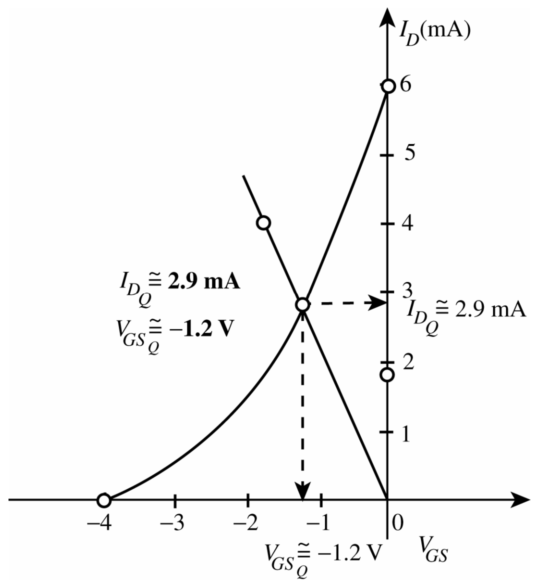
17. (a) $I_{D_Q} =$ **4 mA**

(b) $V_{D_Q} = 12\text{ V} - 4\text{ mA}(1.8\text{ k}\Omega) = 12\text{ V} - 7.2\text{ V} =$ **4.8 V**
$V_{DS_Q} =$ **4.8 V**

(c) $P_s = (12\text{ V})(4\text{ mA}) =$ **48 mW**
$P_d = (4.8\text{ V})(4\text{ mA}) =$ **19.2 mW**

18. $V_{GS} = 0$ V, $I_D = I_{DSS} = 6$ mA
$V_{GS} = V_P = -4$ V, $I_D = 0$ mA
$V_{GS} = V_P/2 = -2$ V, $I_D = I_{DSS}/4 = 1.5$ mA
$V_{GS} = 0.3V_P = -1.2$ V, $I_D = I_{DSS}/2 = 3$ mA

$V_{GS} = -I_DR_S = -I_D(0.43\text{ k}\Omega)$
$I_D = 4$ mA, $V_{GS} = -1.72$ V



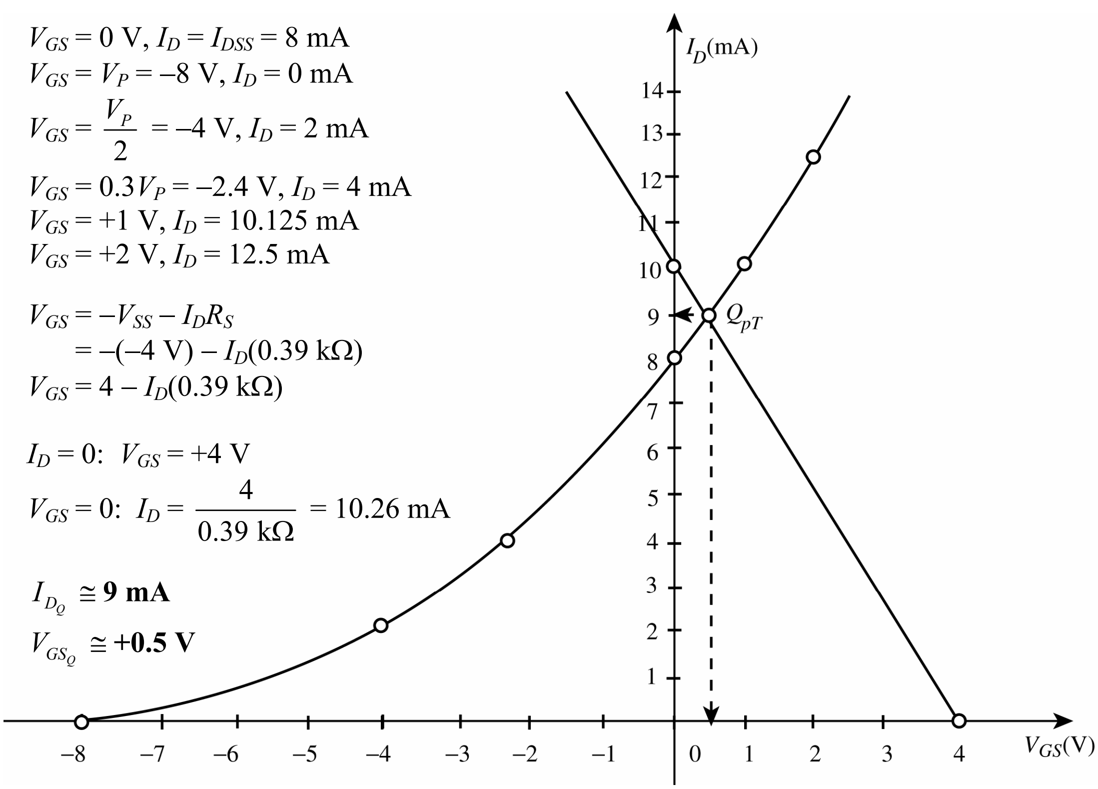
(b) $V_{DS} = V_{DD} - I_D(R_D + R_S)$
$= 14\text{ V} - 2.9\text{ mA}(1.2\text{ k}\Omega + 0.43\text{ k}\Omega)$
$= \mathbf{9.27\ V}$
$V_D = V_{DD} - I_DR_D$
$= 14\text{ V} - (2.9\text{ mA})(1.2\text{ k}\Omega)$
$= \mathbf{10.52\ V}$

19. (a) $V_{GS} = 0$ V, $I_D = I_{DSS} = 8$ mA
$V_{GS} = V_P = -8$ V, $I_D = 0$ mA
$V_{GS} = \dfrac{V_P}{2} = -4$ V, $I_D = 2$ mA
$V_{GS} = 0.3V_P = -2.4$ V, $I_D = 4$ mA
$V_{GS} = +1$ V, $I_D = 10.125$ mA
$V_{GS} = +2$ V, $I_D = 12.5$ mA

$V_{GS} = -V_{SS} - I_DR_S$
$= -(-4\text{ V}) - I_D(0.39\text{ k}\Omega)$
$V_{GS} = 4 - I_D(0.39\text{ k}\Omega)$

$I_D = 0$: $V_{GS} = +4$ V
$V_{GS} = 0$: $I_D = \dfrac{4}{0.39\text{ k}\Omega} = 10.26$ mA

$I_{D_Q} \cong \mathbf{9\ mA}$
$V_{GS_Q} \cong \mathbf{+0.5\ V}$



(b) $V_{DS} = V_{DD} - I_D(R_D + R_S) + V_{SS}$
$= 18\text{ V} - 9\text{ mA}(1.2\text{ k}\Omega + 0.39\text{ k}\Omega) + 4\text{ V}$
$= 22\text{ V} - 14.31\text{ V}$
$= \mathbf{7.69\ V}$
$V_S = -\left(V_{GS_Q}\right) = \mathbf{-0.5\ V}$

20. $I_D = k(V_{GS} - V_T)^2$

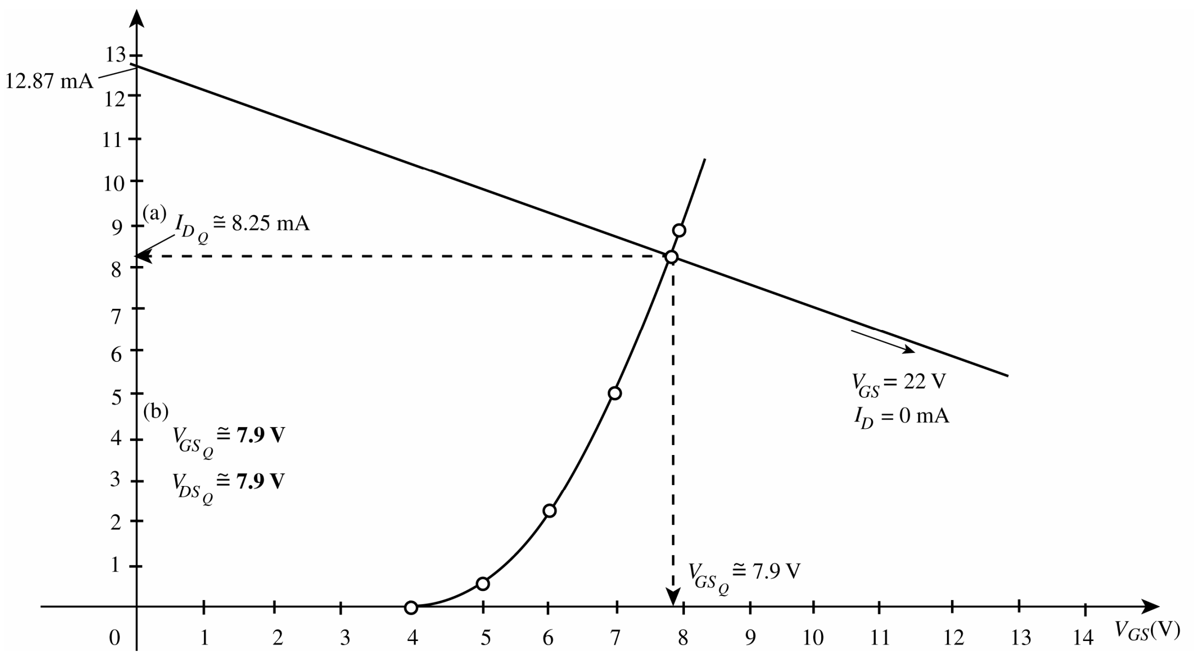
$$k = \frac{I_{D(\text{on})}}{\left(V_{GS(\text{on})} - V_{Th}\right)^2} = \frac{5\text{ mA}}{(7\text{ V} - 4\text{ V})^2} = \frac{5\text{ mA}}{9\text{ V}^2}$$

$K = 0.556 \times 10^{-3}\text{ A/V}^2$
and $I_D = \mathbf{0.556 \times 10^{-3}(V_{GS} - 4\ V)^2}$

$V_{DS} = V_{DD} - I_D(R_D + R_S)$

$$V_{DS} = 0\text{ V};\ I_D = \frac{V_{DD}}{R_D + R_S} = \frac{22\text{ V}}{1.2\text{ k}\Omega + 0.51\text{ k}\Omega} = 12.87\text{ mA}$$

$I_D = 0\text{ mA},\ V_{DS} = V_{DD}$
$= 22\text{ V}$



(c) $V_D = V_{DD} - I_DR_D$
$= 22\text{ V} - (8.25\text{ mA})(1.2\text{ k}\Omega)$
$= \mathbf{12.1\ V}$
$V_S = I_SR_S = I_DR_S$
$= (8.25\text{ mA})(0.51\text{ k}\Omega)$
$= \mathbf{4.21\ V}$

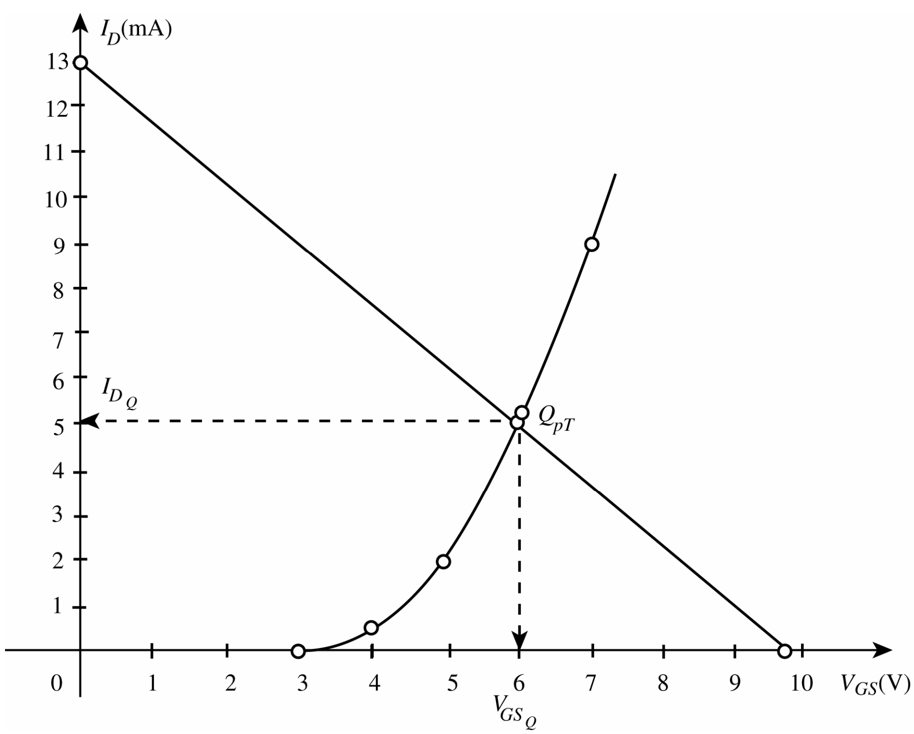
(d) $V_{DS} = V_D - V_S$
$= 12.1\text{ V} - 4.21\text{ V}$
$= \mathbf{7.89\ V}$
vs. 7.9 V obtained graphically

21. (a) $V_G = \dfrac{R_2}{R_1 + R_2} V_{DD} = \dfrac{6.8\text{ M}\Omega}{10\text{ M}\Omega + 6.8\text{ M}\Omega}(24\text{ V}) = 9.71\text{ V}$

$V_{GS} = V_G - I_D R_S$
$V_{GS} = 9.71 - I_D(0.75\text{ k}\Omega)$
At $I_D = 0$ mA, $V_{GS} = 9.71$ V
At $V_{GS} = 0$ V, $I_D = \dfrac{9.71\text{ V}}{0.75\text{ k}\Omega} = 12.95$ mA

$$k = \frac{I_{D(\text{on})}}{\left(V_{GS(\text{on})} - V_{GS(Th)}\right)^2} = \frac{5\text{ mA}}{(6\text{ V} - 3\text{ V})^2} = \frac{5\text{ mA}}{(3\text{ V})^2}$$
$= 0.556 \times 10^{-3}\text{A/V}^2$
$\therefore I_D = \mathbf{0.556 \times 10^{-3}(V_{GS} - 3\text{ V})^2}$

V_{GS}	I_D
3 V	0 mA
4 V	0.556 mA
5 V	2.22 mA
6 V	5 mA
7 V	8.9 mA



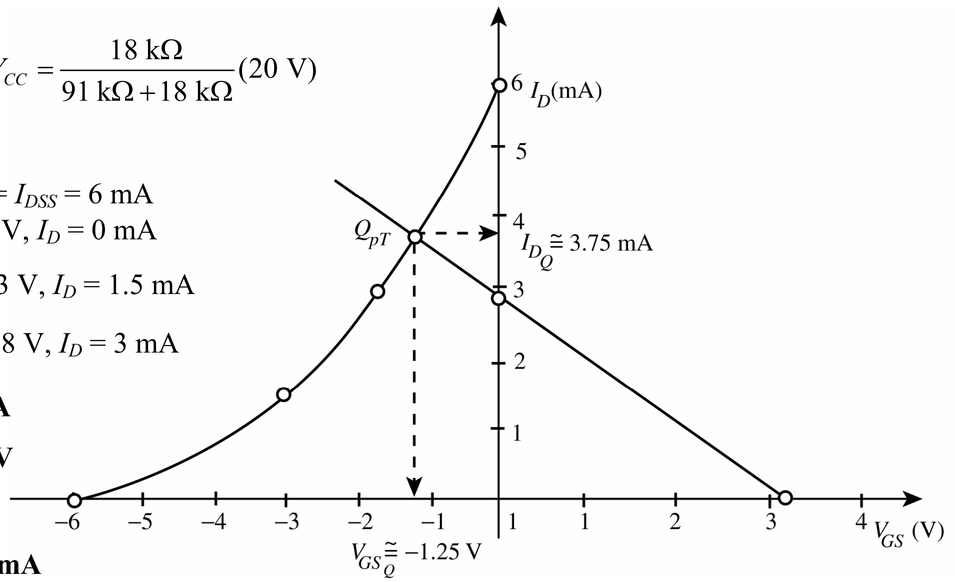
$I_{D_Q} \cong \mathbf{5\text{ mA}}$
$V_{GS_Q} \cong \mathbf{6\text{ V}}$

(b) $V_D = V_{DD} - I_D R_D = 24\text{ V} - (5\text{ mA})(2.2\text{ k}\Omega)$
$= \mathbf{13\ V}$
$V_S = I_S R_S = I_D R_S$
$= (5\text{ mA})(0.75\text{ k}\Omega)$
$= \mathbf{3.75\ V}$

22. (a) $V_G = \dfrac{R_2}{R_1 + R_2} V_{CC} = \dfrac{18\text{ k}\Omega}{91\text{ k}\Omega + 18\text{ k}\Omega}(20\text{ V})$
$= \mathbf{3.3\ V}$

(b) $V_{GS} = 0\text{ V}, I_D = I_{DSS} = 6\text{ mA}$
$V_{GS} = V_P = -6\text{ V}, I_D = 0\text{ mA}$
$V_{GS} = \dfrac{V_P}{2} = -3\text{ V}, I_D = 1.5\text{ mA}$
$V_{GS} = V_P = -1.8\text{ V}, I_D = 3\text{ mA}$

$I_{D_Q} \cong \mathbf{3.75\ mA}$
$V_{GS_Q} \cong \mathbf{-1.25\ V}$



(c) $I_E = I_D = \mathbf{3.75\ mA}$

(d) $I_B = \dfrac{I_C}{\beta} = \dfrac{3.75\text{ mA}}{160} = \mathbf{23.44\ \mu A}$

(e) $V_D = V_E = V_B - V_{BE} = V_{CC} - I_B R_B - V_{BE} = 20\text{ V} - (23.44\ \mu\text{A})(330\text{ k}\Omega) - 0.7\text{ V}$
$= \mathbf{11.56\ V}$

(f) $V_C = V_{CC} - I_C R_C = 20\text{ V} - (3.75\text{ mA})(1.1\text{ k}\Omega)$
$= \mathbf{15.88\ V}$

23. Testing:
$\beta R_E \geq 10R_2$
$(100)(1.2\text{ k}\Omega) \geq 10(10\text{ k}\Omega)$
$120\text{ k}\Omega > 100\text{ k}\Omega$ (satisfied)

(a) $V_B = V_G = \dfrac{R_2 V_{DD}}{R_1 + R_2} = \dfrac{10\text{ k}\Omega(16\text{ V})}{40\text{ k}\Omega + 10\text{ k}\Omega}$
$= \mathbf{3.2\ V}$

(b) $V_E = V_B - V_{BE} = 3.2\text{ V} - 0.7\text{ V} = \mathbf{2.5\ V}$

(c) $I_E = \dfrac{V_E}{R_E} = \dfrac{2.5\text{ V}}{1.2\text{ k}\Omega} = \mathbf{2.08\ mA}$
$I_C \cong I_E = \mathbf{2.08\ mA}$
$I_D = I_C = \mathbf{2.08\ mA}$

(d) $I_B = \dfrac{I_C}{\beta} = \dfrac{2.08\text{ mA}}{100} = \mathbf{20.8\ \mu A}$

(e) $V_C = V_G - V_{GS}$

$$V_{GS} = V_P\left(1 - \sqrt{\frac{I_D}{I_{DSS}}}\right)$$

$$= (-6\text{ V})\left(1 - \sqrt{\frac{2.08\text{ mA}}{6\text{ mA}}}\right)$$

$= -2.47$ V

$V_C = 3.2 - (-2.47\text{ V})$

$= \mathbf{5.67\ V}$

$V_S = V_C = \mathbf{5.67\ V}$

$V_D = V_{DD} - I_D R_D$

$= 16\text{ V} - (2.08\text{ mA})(2.2\text{ k}\Omega)$

$= \mathbf{11.42\ V}$

(f) $V_{CE} = V_C - V_E = 5.67\text{ V} - 2.5\text{ V}$

$= \mathbf{3.17\ V}$

(g) $V_{DS} = V_D - V_S = 11.42\text{ V} - 5.67\text{ V}$

$= \mathbf{5.75\ V}$

24. $$V_{GS} = V_P\left(1 - \sqrt{\frac{I_D}{I_{DSS}}}\right) = (-6\text{ V})\left(1 - \sqrt{\frac{4\text{ mA}}{8\text{ mA}}}\right)$$

$= -1.75$ V

$V_{GS} = -I_D R_S$: $R_S = -\dfrac{V_{GS}}{I_D} = \dfrac{-(-1.75\text{ V})}{4\text{ mA}} = \mathbf{0.44\ k\Omega}$

$R_D = 3R_S = 3(0.44\text{ k}\Omega) = \mathbf{1.32\ k\Omega}$

Standard values: $R_S = \mathbf{0.43\ k\Omega}$

$R_D = \mathbf{1.3\ k\Omega}$

25. $$V_{GS} = V_P\left(1 - \sqrt{\frac{I_D}{I_{DSS}}}\right) = (-4\text{ V})\left(1 - \sqrt{\frac{2.5\text{ mA}}{10\text{ mA}}}\right)$$

$= \mathbf{-2\ V}$

$V_{GS} = V_G - V_S$

and $V_S = V_G - V_{GS} = 4\text{ V} - (-2\text{ V})$

$= 6$ V

$R_S = \dfrac{V_S}{I_D} = \dfrac{6\text{ V}}{2.5\text{ mA}} = \mathbf{2.4\ k\Omega}$ (a standard value)

$R_D = 2.5R_S = 2.5(2.4\text{ k}\Omega) = 6\text{ k}\Omega \Rightarrow$ use $\mathbf{6.2\ k\Omega}$

$V_G = \dfrac{R_2 V_{DD}}{R_1 + R_2} \Rightarrow 4\text{ V} = \dfrac{R_2(24\text{ V})}{22\text{ M}\Omega + R_2} \Rightarrow 88\text{ M}\Omega + 4R_2 = 24R_2$

$20R_2 = 88\text{ M}\Omega$

$R_2 = 4.4\text{ M}\Omega$

Use $R_2 = \mathbf{4.3\ M\Omega}$

26. $I_D = k(V_{GS} - V_T)^2$

$$\frac{I_D}{k} = (V_{GS} - V_T)^2$$

$$\sqrt{\frac{I_D}{k}} = V_{GS} - V_T$$

and $V_{GS} = V_T + \sqrt{\dfrac{I_D}{k}} = 4\text{ V} + \sqrt{\dfrac{6\text{ mA}}{0.5\times10^{-3}\text{ A/V}^2}} = 7.46\text{ V}$

$$R_D = \frac{V_{R_D}}{I_D} = \frac{V_{DD} - V_{DS}}{I_D} = \frac{V_{DD} - V_{GS}}{I_D} = \frac{16\text{ V} - 7.46\text{ V}}{6\text{ mA}} = \frac{8.54\text{ V}}{6\text{ mA}}$$

$= 1.42\text{ k}\Omega$

Standard value: $R_D = \mathbf{0.75\text{ k}\Omega}$

$R_G = \mathbf{10\text{ M}\Omega}$

27. (a) $I_D = I_S = \dfrac{V_S}{R_S} = \dfrac{4\text{ V}}{1\text{ k}\Omega} = 4\text{ mA}$

$V_{DS} = V_{DD} - I_D(R_D + R_S) = 12\text{ V} - (4\text{ mA})(2\text{ k}\Omega + 1\text{ k}\Omega)$
$= 12\text{ V} - (4\text{ mA})(3\text{ k}\Omega)$
$= 12\text{ V} - 12\text{ V}$
$= 0\text{ V}$

JFET in saturation!

(b) $V_S = 0$ V reveals that the JFET is nonconducting and the JFET is either defective or an open-circuit exists in the output circuit. V_S is at the same potential as the grounded side of the 1 kΩ resistor.

(c) Typically, the voltage across the 1 MΩ resistor is ≅ 0 V. The fact that the voltage across the 1 MΩ resistor is equal to V_{DD} suggests that there is a short-circuit connection from gate to drain with $I_D = 0$ mA. Either the JFET is defective or an improper circuit connection was made.

28. $V_G = \dfrac{75\text{ k}\Omega(20\text{ V})}{75\text{ k}\Omega + 330\text{ k}\Omega} = 3.7\text{ V}$ (seems correct!)

$V_{GS} = 3.7\text{ V} - 6.25\text{ V} = -2.55\text{ V}$ (possibly okay)

$I_D = I_{DSS}(1 - V_{GS}/V_P)^2$
$= 10\text{ mA}(1 - (-2.55\text{ V})/(-6\text{ V}))^2$
$= 3.3\text{ mA}$ (reasonable)

However, $I_S = \dfrac{V_S}{R_S} = \dfrac{6.25\text{ V}}{1\text{ k}\Omega} = 6.25\text{ mA} \neq 3.3\text{ mA}$

$V_{R_D} = I_D R_D = I_S R_D = (6.25\text{ mA})(2.2\text{ k}\Omega)$
$= 13.75\text{ V}$

and $V_{R_S} + V_{R_D} = 6.25\text{ V} + 13.75\text{ V}$
$= \mathbf{20\text{ V}} = V_{DD}$

$\therefore V_{DS} = 0\text{ V}$

1. Possible short-circuit from D-S.
2. Actual I_{DSS} and/or V_P may be larger in magnitude than specified.

29. $I_D = I_S = \dfrac{V_S}{R_S} = \dfrac{6.25\text{ V}}{1\text{ k}\Omega} = 6.25\text{ mA}$

$V_{DS} = V_{DD} - I_D(R_D + R_S)$
$= 20\text{ V} - (6.25\text{ mA})(2.2\text{ k}\Omega + 1\text{ k}\Omega)$
$= 20\text{ V} - 20\text{ V}$
$= 0\text{ V}$ (saturation condition)

$V_G = \dfrac{R_2 V_{DD}}{R_1 + R_2} = \dfrac{75\text{ k}\Omega(20\text{ V})}{330\text{ k}\Omega + 75\text{ k}\Omega} = 3.7\text{ V}$ (as it should be)

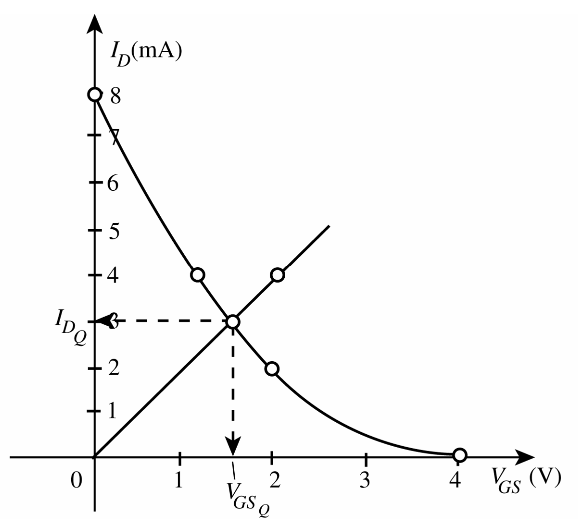
$V_{GS} = V_G - V_S = 3.7\text{ V} - 6.25\text{ V} = -2.55\text{ V}$

$I_D = I_{DSS}\left(1 - \dfrac{V_{GS}}{V_P}\right)^2 = 10\text{ mA}(1 - (-2.55\text{ V})/(6\text{ V}))^2$
$= 3.3\text{ mA} \neq 6.25\text{ mA}$

In all probability, an open-circuit exists between the voltage divider network and the gate terminal of the JFET with the transistor exhibiting saturation conditions.

30. (a) $V_{GS} = 0\text{ V}, I_D = I_{DSS} = 8\text{ mA}$
$V_{GS} = V_P = +4\text{ V}, I_D = 0\text{ mA}$
$V_{GS} = \dfrac{V_P}{2} = +2\text{ V}, I_D = 2\text{ mA}$
$V_{GS} = 0.3V_P = 1.2\text{ V}, I_D = 4\text{ mA}$

$V_{GS} = I_D R_S$
$I_D = 4\text{ mA};$
$V_{GS} = (4\text{ mA})(0.51\text{ k}\Omega)$
$= 2.04\text{ V}$
I_{D_Q} = **3 mA**, V_{GS_Q} = **1.55 V**



(b) $V_{DS} = V_{DD} + I_D(R_D + R_S)$
$= -18\text{ V} + (3\text{ mA})(2.71\text{ k}\Omega)$
$= \mathbf{-9.87\text{ V}}$

(c) $V_D = V_{DD} - I_D R_D$
$= -18\text{ V} - (3\text{ mA})(2.2\text{ k}\Omega)$
$= \mathbf{-11.4\text{ V}}$

31. $k = \dfrac{I_{D(\text{on})}}{\left(V_{GS(\text{on})} - V_{GS(Th)}\right)^2} = \dfrac{4 \text{ mA}}{\left(-7 \text{ V} - (-3 \text{ V})\right)^2} = \dfrac{4 \text{ mA}}{(-4 \text{ V})^2}$

$= 0.25 \times 10^{-3} \text{ A/V}^2$

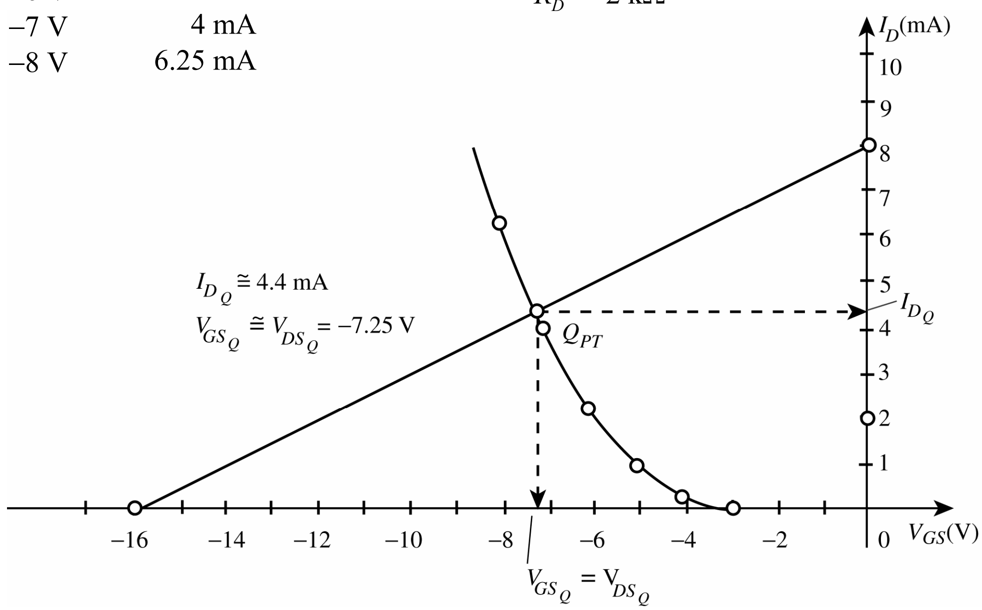
$I_D = \mathbf{0.25 \times 10^{-3}(V_{GS} + 3 \text{ V})^2}$

V_{GS}	I_D
−3 V	0 mA
−4 V	0.25 mA
−5 V	1 mA
−6 V	2.25 mA
−7 V	4 mA
−8 V	6.25 mA

$V_{GS} = V_{DS} = V_{DD} + I_D R_D$

At $I_D = 0$ mA, $V_{GS} = V_{DD} = -16$ V

At $V_{GS} = 0$ V, $I_D = \dfrac{V_{DD}}{R_D} = \dfrac{16 \text{ V}}{2 \text{ k}\Omega} = 8$ mA



(b) $V_{DS} = V_{GS} = \mathbf{-7.25 \text{ V}}$

(c) $V_D = V_{DS} = \mathbf{-7.25 \text{ V}}$

or $V_{DS} = V_{DD} + I_D R_D$

$= -16 \text{ V} + (4.4 \text{ mA})(2 \text{ k}\Omega)$

$= -16 \text{ V} + 8.8 \text{ V}$

$V_{DS} = \mathbf{-7.2 \text{ V}} = V_D$

32. $\dfrac{V_{GS}}{|V_P|} = \dfrac{-1.5 \text{ V}}{4 \text{ V}} = -0.375$

Find −0.375 on the horizontal axis.

Then move vertically to the $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$ curve.

Finally, move horizontally from the intersection with the curve to the left to the I_D/I_{DSS} axis.

$\dfrac{I_D}{I_{DSS}} = 0.39$

and $I_D = 0.39(12 \text{ mA}) = \mathbf{4.68 \text{ mA}}$ vs. 4.69 mA (#1)

$V_{DS_Q} = V_{DD} - I_D R_D = 12 \text{ V} - (4.68 \text{ mA})(1.2 \text{ k}\Omega)$

$= \mathbf{6.38 \text{ V}}$ vs. 6.37 V (#1)

33. $m = \dfrac{|V_P|}{I_{DSS}R_S} = \dfrac{4\text{ V}}{(10\text{ mA})(0.75\text{ k}\Omega)}$

$= \mathbf{0.533}$

$M = m\dfrac{V_{GG}}{|V_P|} = \dfrac{0.533(0)}{4\text{ V}}$

$= \mathbf{0}$

Draw a straight line from $M = 0$ through $m = 0.533$ until it crosses the normalized curve of $I_D = I_{DSS}\left(1 - \dfrac{V_{GS}}{V_P}\right)^2$. At the intersection with the curve drop a line down to determine

$$\frac{V_{GS}}{|V_P|} = -0.49$$

so that $V_{GS_Q} = -0.49V_P = -0.49(4\text{ V})$

$= \mathbf{-1.96\text{ V}}$ (vs. -1.9 V #6)

If a horizontal line is drawn from the intersection to the left vertical axis we find

$$\frac{I_D}{I_{DSS}} = 0.27$$

and $I_D = 0.27(I_{DSS}) = 0.27(10\text{ mA}) = \mathbf{2.7\text{ mA}}$
(vs. 2.7 mA from #6)

(a) $V_{GS_Q} = \mathbf{-1.96\text{ V}}$, $I_{D_Q} = \mathbf{2.7\text{ mA}}$

(b) –

(c) –

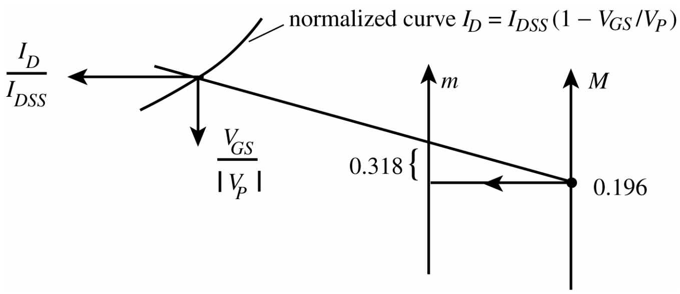
(d) $V_{DS} = V_{DD} - I_D(R_D + R_S) = \mathbf{11.93\text{ V}}$ (like #6)
$V_D = V_{DD} - I_DR_D = \mathbf{13.95\text{ V}}$ (like #6)
$V_G = 0$ V, $V_S = I_DR_S = \mathbf{2.03\text{ V}}$ (like #6)

34. $V_{GG} = \dfrac{R_2V_{DD}}{R_1 + R_2} = \dfrac{110\text{ k}\Omega(20\text{ V})}{110\text{ k}\Omega + 910\text{ k}\Omega} = 2.16\text{ V}$

$m = \dfrac{|V_P|}{I_{DSS}R_S} = \dfrac{3.5\text{ V}}{(10\text{ mA})(1.1\text{ k}\Omega)} = 0.318$

$M = m \times \dfrac{V_{GG}}{|V_P|} = 0.318\dfrac{(2.16\text{ V})}{3.5} = 0.196$

Find 0.196 on the vertical axis labeled M and mark the location. Move horizontally to the vertical axis labeled m and then add $m = 0.318$ to the vertical height ($\cong 1.318$ in total)—mark the spot. Draw a straight line through the two points located above, as shown below.



Continue the line until it intersects the $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$ curve. At the intersection move horizontally to obtain the I_D/I_{DSS} ratio and move down vertically to obtain the $V_{GS}/|V_p|$ ratio.

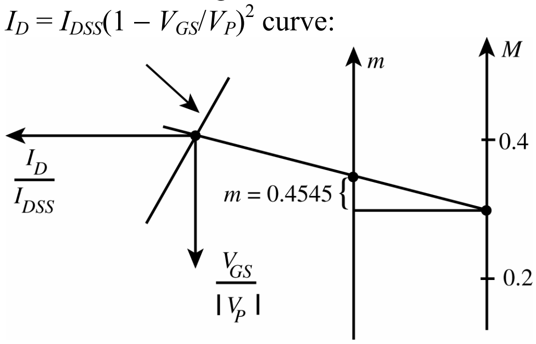
$$\frac{I_D}{I_{DSS}} = 0.33 \text{ and } I_{D_Q} = 0.33(10 \text{ mA}) = \mathbf{3.3\ mA}$$
vs. 3.3 mA (#12)

$$\frac{V_{GS}}{|V_P|} = -0.425 \text{ and } V_{GS_Q} = -0.425(3.5 \text{ V}) = \mathbf{-1.49\ V}$$
vs. 1.5 V (#12)

35. $m = \dfrac{|V_P|}{I_{DSS}R_S} = \dfrac{6 \text{ V}}{(6 \text{ mA})(2.2 \text{ k}\Omega)}$
$= \mathbf{0.4545}$

$M = m\dfrac{V_{GG}}{|V_P|} = 0.4545\dfrac{(4 \text{ V})}{(6 \text{ V})}$
$= \mathbf{0.303}$

Find 0.303 on the vertical *M* axis.
Draw a horizontal line from $M = 0.303$ to the vertical *m* axis.
Add 0.4545 to the vertical location on the *m* axis defined by the horizontal line.
Draw a straight line between $M = 0.303$ and the point on the *m* axis resulting from the addition of $m = 0.4545$.
Continue the straight line as shown below until it crosses the normalized $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$ curve:



At the intersection drop a vertical line to determine

$$\frac{V_{GS}}{|V_P|} = -0.34$$

and $V_{GS_Q} = -0.34(6\text{ V})$

$= \mathbf{-2.04\ V}$ (vs. –2 V from problem 15)

At the intersection draw a horizontal line to the I_D/I_{DSS} axis to determine

$$\frac{I_D}{I_{DSS}} = 0.46$$

and $I_{D_Q} = 0.46(6\text{ mA})$

$= \mathbf{2.76\ mA}$ (vs. 2.7 mA from problem 15)

(a) I_{D_Q} = **2.76 mA**, V_{GS_Q} = **–2.04 V**

(b) $V_{DS} = V_{DD} + V_{SS} - I_D(R_D + R_S)$

$= 16\text{ V} + 4\text{ V} - (2.76\text{ mA})(4.4\text{ k}\Omega)$

$= \mathbf{7.86\ V}$ (vs. 8.12 V from problem 15)

$V_S = -V_{SS} + I_DR_S = -4\text{ V} + (2.76\text{ mA})(2.2\text{ k}\Omega)$

$= -4\text{ V} + 6.07\text{ V}$

$= \mathbf{2.07\ V}$ (vs. 1.94 V from problem 15)

Chapter 8

1. $g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(15\text{ mA})}{|-5\text{ V}|}$ = **6 mS**

2. $g_{m0} = \dfrac{2I_{DSS}}{|V_P|} \Rightarrow |V_P| = \dfrac{2I_{DSS}}{g_{m0}} = \dfrac{2(12\text{ mA})}{10\text{ mS}}$ = 2.4 V

   V_P = **–2.4 V**

3. $g_{m0} = \dfrac{2I_{DSS}}{|V_P|} \Rightarrow I_{DSS} = \dfrac{(g_{mO})(|V_P|)}{2} = \dfrac{5\text{ mS}(3.5\text{ V})}{2}$ = **8.75 mA**

4. $g_m = g_{m0}\left(1 - \dfrac{V_{GS_Q}}{V_P}\right) = \dfrac{2(12\text{ mA})}{|-3\text{ V}|}\left(1 - \dfrac{-1\text{ V}}{-3\text{ V}}\right)$ = **5.3 mS**

5. $g_m = \dfrac{2I_{DSS}}{|V_P|}\left(1 - \dfrac{V_{GS_Q}}{V_P}\right)$

   $6\text{ mS} = \dfrac{2I_{DSS}}{2.5\text{ V}}\left(1 - \dfrac{-1\text{ V}}{-2.5\text{ V}}\right)$

   I_{DSS} = **12.5 mA**

6. $g_m = g_{m0}\sqrt{\dfrac{I_D}{I_{DSS}}} = \dfrac{2I_{DSS}}{|V_P|}\sqrt{\dfrac{I_{DSS}/4}{I_{DSS}}} = \dfrac{2(10\text{ mA})}{5\text{ V}}\sqrt{\dfrac{1}{4}}$

   $= \dfrac{20\text{ mA}}{5\text{ V}}\left(\dfrac{1}{2}\right)$ = **2 mS**

7. $g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(8\text{ mA})}{5\text{ V}}$ = 3.2 mS

   $g_m = g_{m0}\left(1 - \dfrac{V_{GS_Q}}{V_P}\right) = 3.2\text{ mS}\left(1 - \dfrac{V_P/4}{V_P}\right) = 3.2\text{ mS}\left(1 - \dfrac{1}{4}\right) = 3.2\text{ mS}\left(\dfrac{3}{4}\right)$

   = **2.4 mS**

8. (a) $g_m = y_{fs}$ = **4.5 mS**

   (b) $r_d = \dfrac{1}{y_{os}} = \dfrac{1}{25\mu\text{S}}$ = **40 kΩ**

9. $g_m = y_{fs}$ = 4.5 mS

   $r_d = \dfrac{1}{y_{os}} = \dfrac{1}{25\mu\text{S}}$ = 40 kΩ

   $Z_o = r_d$ = **40 kΩ**

   A_v(FET) = $-g_m r_d$ = –(4.5 mS)(40 kΩ) = **–180**

10. $A_v = -g_m r_d \Rightarrow g_m = \dfrac{-A_v}{r_d} = -\dfrac{(-200)}{(100\text{ k}\Omega)}$ = **2 mS**

11. (a) $g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(10\text{ mA})}{5\text{ V}}$ = **4 mS**

(b) $g_m = \dfrac{\Delta I_D}{\Delta V_{GS}} = \dfrac{6.4\text{ mA} - 3.6\text{ mA}}{2\text{ V} - 1\text{ V}}$ = **2.8 mS**

(c) Eq. 8.6: $g_m = g_{m0}\left(1 - \dfrac{V_{GS_Q}}{V_P}\right) = 4\text{ mS}\left(1 - \dfrac{-1.5\text{ V}}{-5\text{ V}}\right)$ = **2.8 mS**

(d) $g_m = \dfrac{\Delta I_D}{\Delta V_{GS}} = \dfrac{3.6\text{ mA} - 1.6\text{ mA}}{3\text{ V} - 2\text{ V}}$ = **2 mS**

(e) $g_m = g_{m0}\left(1 - \dfrac{V_{GS_Q}}{V_P}\right) = 4\text{ mS}\left(1 - \dfrac{-2.5\text{ V}}{-5\text{ V}}\right)$ = **2 mS**

12. (a) $r_d = \left.\dfrac{\Delta V_{DS}}{\Delta I_D}\right|_{V_{GS}\text{ constant}} = \dfrac{(15\text{ V} - 5\text{ V})}{(9.1\text{ mA} - 8.8\text{ mA})} = \dfrac{10\text{ V}}{0.3\text{ mA}}$ = **33.33 kΩ**

(b) At $V_{DS} = 10$ V, $I_D = 9$ mA on $V_{GS} = 0$ V curve

$\therefore g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(9\text{ mA})}{4\text{ V}}$ = **4.5 mS**

13. From 2N4220 data:

$g_m = y_{fs} = 750\ \mu\text{S}$ = **0.75 mS**

$r_d = \dfrac{1}{y_{os}} = \dfrac{1}{10\mu\text{S}}$ = **100 kΩ**

14. (a) g_m (@ $V_{GS} = -6$ V) = **0**, g_m (@ $V_{GS} = 0$ V) = $g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(8\text{ mA})}{6\text{ V}}$ = **2.67 mS**

(b) g_m (@ $I_D = 0$ mA) = **0**, g_m (@ $I_D = I_{DSS} = 8$ mA) = g_{m0} = **2.67 mS**

15. $g_m = y_{fs}$ = **5.6 mS**, $r_d = \dfrac{1}{y_{os}} = \dfrac{1}{15\ \mu\text{S}}$ = **66.67 kΩ**

16. $g_m = \dfrac{2I_{DSS}}{|V_P|}\left(1 - \dfrac{V_{GS_Q}}{V_P}\right) = \dfrac{2(10\text{ mA})}{4\text{ V}}\left(1 - \dfrac{-2\text{ V}}{-4\text{ V}}\right)$ = **2.5 mS**

$r_d = \dfrac{1}{y_{os}} = \dfrac{1}{25\ \mu\text{S}}$ = **40 kΩ**

17. Graphically, $V_{GS_Q} = -1.5$ V

$$g_m = \frac{2I_{DSS}}{|V_P|}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = \frac{2(10\text{ mA})}{4\text{ V}}\left(1 - \frac{-1.5\text{ V}}{-4\text{ V}}\right) = 3.125\text{ mS}$$

$Z_i = R_G = \mathbf{1\ M\Omega}$

$Z_o = R_D \parallel r_d = 1.8\text{ k}\Omega \parallel 40\text{ k}\Omega = \mathbf{1.72\ k\Omega}$

$A_v = -g_m(R_D \parallel r_d) = -(3.125\text{ mS})(1.72\text{ k}\Omega)$

$= \mathbf{-5.375}$

18. $V_{GS_Q} = -1.5$ V

$$g_m = \frac{2I_{DSS}}{|V_P|}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = \frac{2(12\text{ mA})}{6\text{ V}}\left(1 - \frac{-1.5\text{ V}}{-6\text{ V}}\right) = 3\text{ mS}$$

$Z_i = R_G = \mathbf{1\ M\Omega}$

$Z_o = R_D \parallel r_d,\ r_d = \dfrac{1}{y_{os}} = \dfrac{1}{40\ \mu\text{S}} = 25\text{ k}\Omega$

$= 1.8\text{ k}\Omega \parallel 25\text{ k}\Omega$

$= \mathbf{1.68\ k\Omega}$

$A_v = -g_m(R_D \parallel r_d) = -(3\text{ mS})(1.68\text{ k}\Omega) = \mathbf{-5.04}$

19. $g_m = y_{fs} = 3000\ \mu\text{S} = 3\text{ mS}$

$r_d = \dfrac{1}{y_{os}} = \dfrac{1}{50\ \mu\text{S}} = 20\text{ k}\Omega$

$Z_i = R_G = \mathbf{10\ M\Omega}$

$Z_o = r_d \parallel R_D = 20\text{ k}\Omega \parallel 3.3\text{ k}\Omega = \mathbf{2.83\ k\Omega}$

$A_v = -g_m(r_d \parallel R_D)$

$= -(3\text{ mS})(2.83\text{ k}\Omega)$

$= \mathbf{-8.49}$

20. $V_{GS_Q} = 0\text{ V},\ g_m = g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(6\text{ mA})}{6\text{ V}} = 2\text{ mS},\ r_d = \dfrac{1}{y_{os}} = \dfrac{1}{40\ \mu\text{S}} = 25\text{ k}\Omega$

$Z_i = \mathbf{1\ M\Omega}$

$Z_o = r_d \parallel R_D = 25\text{ k}\Omega \parallel 2\text{ k}\Omega = \mathbf{1.852\ k\Omega}$

$A_v = -g_m(r_d \parallel R_D) = -(2\text{ mS})(1.852\text{ k}\Omega) \cong \mathbf{-3.7}$

21. $g_m = 3$ mS, $r_d = 20$ kΩ

$Z_i =$ **10 MΩ**

$$Z_o = \frac{R_D}{1 + g_m R_S + \dfrac{R_D + R_S}{r_d}} = \frac{3.3\text{ k}\Omega}{1 + (3\text{ mS})(1.1\text{ k}\Omega) + \dfrac{3.3\text{ k}\Omega + 1.1\text{ k}\Omega}{20\text{ k}\Omega}}$$

$$= \frac{3.3\text{ k}\Omega}{1 + 3.3 + 0.22} = \frac{3.3\text{ k}\Omega}{4.52} = \mathbf{730\ \Omega}$$

$$A_v = \frac{-g_m R_D}{1 + g_m R_S + \dfrac{R_D + R_S}{r_d}} = \frac{-(3\text{ mS})(3.3\text{ k}\Omega)}{1 + (3\text{ mS})(1.1\text{ k}\Omega) + \dfrac{3.3\text{ k}\Omega + 1.1\text{ k}\Omega}{20\text{ k}\Omega}}$$

$$= \frac{-9.9}{1 + 3.3 + 0.22} = -\frac{9.9}{4.52} = \mathbf{-2.19}$$

22. $g_m = y_{fs} = 3000\ \mu$S $= 3$ mS

$$r_d = \frac{1}{y_{os}} = \frac{1}{10\ \mu\text{S}} = 100\text{ k}\Omega$$

$Z_i = R_G =$ **10 MΩ** (the same)

$Z_o = r_d \| R_D = 100$ kΩ $\|$ 3.3 kΩ = **3.195 kΩ** (higher)

$A_v = -g_m(r_d \| R_D)$

$= -(3$ mS$)(3.195$ kΩ$)$

$=$ **–9.59** (higher)

23. $V_{GS_Q} = -0.95$ V

$$g_m = \frac{2I_{DSS}}{V_P}\left(1 - \frac{V_{GS_Q}}{V_P}\right)$$

$$= \frac{2(12\text{ mA})}{3\text{ V}}\left(1 - \frac{-0.95\text{ V}}{-3\text{ V}}\right)$$

$= 5.47$ mS

$Z_i = 82$ MΩ $\|$ 11 MΩ = **9.7 MΩ**

$Z_o = r_d \| R_D = 100$ kΩ $\|$ 2 kΩ = **1.96 kΩ**

$A_v = -g_m(r_d \| R_D) = -(5.47$ mS$)(1.96$ kΩ$) =$ **–10.72**

$V_o = A_v V_i = (-10.72)(20$ mV$) =$ **–214.4 mV**

24. $V_{GS_Q} = -0.95$ V (as before), $g_m = 5.47$ mS (as before)

$Z_i =$ **9.7 MΩ** as before

$$Z_o = \frac{R_D}{1 + g_m R_S + \dfrac{R_D + R_S}{r_d}}$$

but $r_d \geq 10(R_D + R_S)$

$$\therefore Z_o = \frac{R_D}{1+g_mR_S} = \frac{2\text{ k}\Omega}{1+(5.47\text{ mS})(0.61\text{ k}\Omega)} = \frac{2\text{ k}\Omega}{1+3.337} = \frac{2\text{ k}\Omega}{4.337}$$

= **461.1 Ω**

$$A_v = \frac{-g_mR_D}{1+g_mR_S} \quad \text{since } r_d \geq 10(R_D + R_S)$$

$$= \frac{-(5.47\text{ mS})(2\text{ k}\Omega)}{4.337\ \text{(from above)}} = -\frac{10.94}{4.337} = \mathbf{-2.52}\ \text{(a big reduction)}$$

$V_o = A_vV_i$ = (–2.52)(20 mV) = **–50.40 mV** (compared to –214.4 mV earlier)

25. V_{GS_Q} = –0.95 V, g_m (problem 23) = 5.47 mS

Z_i (the same) = **9.7 MΩ**
Z_o (reduced) = $r_d \| R_D$ = 20 kΩ || 2 kΩ = **1.82 kΩ**
A_v (reduced) = $-g_m(r_d \| R_D)$ = –(5.47 mS)(1.82 kΩ) = **–9.94**
V_o (reduced) = A_vV_i = (–9.94)(20 mV) = **–198.8 mV**

26. V_{GS_Q} = –0.95 V (as before), g_m = 5.47 mS (as before)

Z_i = **9.7 MΩ** as before

$$Z_o = \frac{R_D}{1+g_mR_S+\dfrac{R_D+R_S}{r_d}} \quad \text{since } r_d < 10(R_D + R_S)$$

$$= \frac{2\text{ k}\Omega}{1+(5.47\text{ mS})(0.61\text{ k}\Omega)+\dfrac{2\text{ k}\Omega+0.61\text{ k}\Omega}{20\text{ k}\Omega}}$$

$$= \frac{2\text{ k}\Omega}{1+3.33+0.13} = \frac{2\text{ k}\Omega}{4.46}$$

= **448.4 Ω** (slightly less than 461.1 Ω obtained in problem 24)

$$A_v = \frac{-g_mR_D}{1+g_mR_S+\dfrac{R_D+R_S}{r_d}}$$

$$= \frac{-(5.47\text{ mS})(2\text{ k}\Omega)}{1+(5.47\text{ mS})(0.61\text{ k}\Omega)+\dfrac{2\text{ k}\Omega+0.61\text{ k}\Omega}{20\text{ k}\Omega}}$$

$$= \frac{-10.94}{1+3.33+0.13} = \frac{-10.94}{4.46} = \mathbf{-2.45}\ \text{slightly less than } -2.52 \text{ obtained in problem 24)}$$

27. $V_{GS_Q} = -2.85\text{ V},\ g_m = \dfrac{2I_{DSS}}{V_P}\left(1-\dfrac{V_{GS_Q}}{V_P}\right) = \dfrac{2(9\text{ mA})}{4.5\text{ V}}\left(1-\dfrac{-2.85\text{ V}}{-4.5\text{ V}}\right) = 1.47\text{ mS}$

$Z_i = R_G$ = **10 MΩ**

$Z_o = r_d \| R_S \| 1/g_m = 40\text{ k}\Omega \| 2.2\text{ k}\Omega \| \underbrace{1/1.47\text{ mS}}_{680.27\ \Omega}$ = **512.9 Ω**

$$A_v = \frac{g_m(r_d \| R_S)}{1+g_m(r_d \| R_S)} = \frac{(1.47\text{ mS})(40\text{ k}\Omega \| 2.2\text{ k}\Omega)}{1+(1.47\text{ mS})(40\text{ k}\Omega \| 2.2\text{ k}\Omega)} = \frac{3.065}{1+3.065}$$

= **0.754**

28. $V_{GS_Q} = -2.85$ V, $g_m = 1.47$ mS

Z_i = **10 MΩ** (as in problem 27)

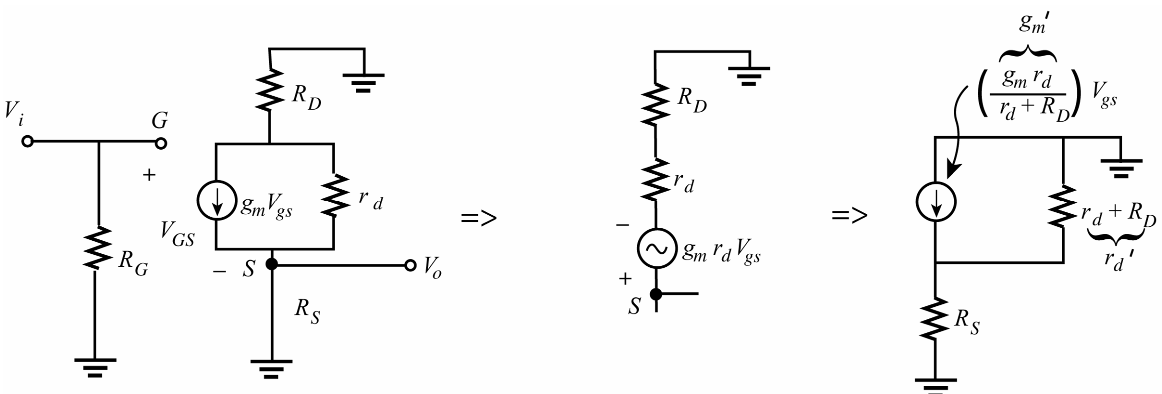
$Z_o = r_d \parallel R_S \parallel 1/g_m = \underbrace{20\text{ k}\Omega \parallel 2.2\text{ k}\Omega}_{1.982\text{ k}\Omega} \parallel 680.27\ \Omega$ = **506.4 Ω** < 512.9 Ω (#27)

$$A_v = \frac{g_m(r_d \| R_S)}{1+g_m(r_d \| R_S)} = \frac{1.47\text{ mS}(20\text{ k}\Omega \| 2.2\text{ k}\Omega)}{1+1.47\text{ mS}(20\text{ k}\Omega \| 2.2\text{ k}\Omega)} = \frac{2.914}{1+2.914}$$

= **0.745** < 0.754 (#27)

29. $V_{GS_Q} = -3.8$ V

$$g_m = \frac{2I_{DSS}}{V_P}\left(1-\frac{V_{GS_Q}}{V_P}\right) = \frac{2(6\text{ mA})}{6\text{ V}}\left(1-\frac{-3.8\text{ V}}{-6\text{ V}}\right) = 0.733\text{ mS}$$



The network now has the format examined in the text and

$Z_i = R_G$ = **10 MΩ** $\qquad r_d' = r_d + R_D = 30\text{ k}\Omega + 3.3\text{ k}\Omega = 33.3\text{ k}\Omega$

$$Z_o = r_d' \parallel R_S \parallel 1/g_m' = \qquad g_m' = \frac{g_m r_d}{r_d + R_D} = \frac{(0.733\text{ mS})(30\text{ k}\Omega)}{30\text{ k}\Omega + 3.3\text{ k}\Omega} = \frac{21.99}{33.3\text{ k}\Omega} = 0.66\text{ mS}$$

= 33.3 kΩ || 3.3 kΩ || 1/0.66 mS
= 3 kΩ || 1.52 kΩ
≅ **1 kΩ**

$$A_v = \frac{g_m'(r_d' \| R_S)}{1+g_m'(r_d' \| R_S)} = \frac{0.66\text{ mS}(3\text{ k}\Omega)}{1+0.66\text{ mS}(3\text{ k}\Omega)} = \frac{1.98}{1+1.98} = \frac{1.98}{2.98}$$

= **0.66**

30. $V_{GS_Q} = -1.75$ V, $g_m = 2.14$ mS

$r_d \ge 10R_D$, $\therefore Z_i \cong R_S \parallel 1/g_m$ = 1.5 kΩ || 1/2.14 mS
= 1.5 kΩ || 467.29 Ω
= **356.3 Ω**

$r_d \ge 10R_D$, $\therefore Z_o \cong R_D$ = **3.3 kΩ**

$r_d \ge 10R_D$, $\therefore A_v \cong g_m R_D$ = (2.14 mS)(3.3 kΩ) = **7.06**

$V_o = A_v V_i$ = (7.06)(0.1 mV) = **0.706 mV**

31. $V_{GS_Q} = -1.75$ V, $g_m = \dfrac{2I_{DSS}}{V_P}\left(1-\dfrac{V_{GS_Q}}{V_P}\right) = \dfrac{2(8\text{ mA})}{2.8\text{ V}}\left(1-\dfrac{-1.75\text{ V}}{-2.8\text{ V}}\right)$ = 2.14 mS

$Z_i = R_S \,\|\, \left[\dfrac{r_d + R_D}{1+g_m r_d}\right] = 1.5\text{ k}\Omega \,\|\, \left[\dfrac{25\text{ k}\Omega + 3.3\text{ k}\Omega}{1+(2.14\text{ mS})(25\text{ k}\Omega)}\right] = 1.5\text{ k}\Omega \,\|\, \dfrac{28.3\text{ k}\Omega}{54.5}$

$= 1.5\text{ k}\Omega \,\|\, 0.52\text{ k}\Omega =$ **386.1 Ω**

$Z_o = R_D \,\|\, r_d = 3.3\text{ k}\Omega \,\|\, 25\text{ k}\Omega =$ **2.92 kΩ**

$A_v = \dfrac{g_m R_D + R_D / r_d}{1+R_D / r_d} = \dfrac{(2.14\text{ mS})(3.3\text{ k}\Omega) + 3.3\text{ k}\Omega / 25\text{ k}\Omega}{1+3.3\text{ k}\Omega/25\text{ k}\Omega}$

$= \dfrac{7.062+0.132}{1+0.132} = \dfrac{7.194}{1.132} = 6.36$

$V_o = A_v V_i = (6.36)(0.1\text{ mV}) =$ **0.636 mV**

32. $V_{GS_Q} \cong -1.2$ V, $g_m = 2.63$ mS

$r_d \geq 10R_D$, ∴ $Z_i \cong R_S \,\|\, 1/g_m = 1\text{ k}\Omega \,\|\, 1/2.63\text{ mS} = 1\text{ k}\Omega \,\|\, 380.2\ \Omega =$ **275.5 Ω**

$Z_o \cong R_D =$ **2.2 kΩ**

$A_v \cong g_m R_D = (2.63\text{ mS})(2.2\text{ k}\Omega) =$ **5.79**

33. $r_d = \dfrac{1}{y_{os}} = \dfrac{1}{20\ \mu\text{S}} = 50\text{ k}\Omega$, $V_{GS_Q} = 0$ V

$g_m = g_{m0} = \dfrac{2I_{DSS}}{V_P} = \dfrac{2(8\text{ mA})}{3} = 5.33$ mS

$A_v = -g_m R_D = -(5.33\text{ mS})(1.1\text{ k}\Omega) = -5.863$

$V_o = A_v V_i = (-5.863)(2\text{ mV}) =$ **11.73 mV**

34. $V_{GS_Q} = -0.75$ V, $g_m = 5.4$ mS

$Z_i =$ **10 MΩ**

$r_o \geq 10R_D$, ∴ $Z_o \cong R_D =$ **1.8 kΩ**

$r_o \geq 10R_D$, ∴ $A_v \cong -g_m R_D = -(5.4\text{ mS})(1.8\text{ k}\Omega)$

= **–9.72**

35. $Z_i =$ **10 MΩ**

$Z_o = r_d \,\|\, R_D = 25\text{ k}\Omega \,\|\, 1.8\text{ k}\Omega =$ **1.68 kΩ**

$A_v = -g_m(r_d \,\|\, R_D)$

$g_m = \dfrac{2I_{DSS}}{V_P}\left(1-\dfrac{V_{GS_Q}}{V_P}\right) = \dfrac{2(12\text{ mA})}{3.5\text{ V}}\left(1-\dfrac{-0.75\text{ V}}{-3.5\text{ V}}\right) = 5.4$ mS

$A_v = -(5.4\text{ mS})(1.68\text{ k}\Omega)$

= **–9.07**

36. $g_m = y_{fs} = 6000\ \mu\text{S} = 6\ \text{mS}$

$$r_d = \frac{1}{y_{os}} = \frac{1}{35\ \mu\text{S}} = 28.57\ \text{k}\Omega$$

$$\begin{aligned} r_d \le 10R_D,\ \therefore A_v &= -g_m(r_d \parallel R_D) \\ &= -(6\ \text{mS})(\underbrace{28.57\ \text{k}\Omega \parallel 6.8}_{5.49\ \text{k}\Omega}\ \text{k}\Omega) \\ &= \mathbf{-32.94} \end{aligned}$$

$$\begin{aligned} V_o = A_v V_i &= (-32.94)(4\ \text{mV}) \\ &= \mathbf{-131.76\ mV} \end{aligned}$$

37. $Z_i = 10\ \text{M}\Omega \parallel 91\ \text{M}\Omega \cong \mathbf{9\ M\Omega}$

$$g_m = \frac{2I_{DSS}}{V_P}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = \frac{2(12\ \text{mA})}{3\ \text{V}}\left(1 - \frac{-1.45\ \text{V}}{-3\ \text{V}}\right) = 4.13\ \text{mS}$$

$$\begin{aligned} Z_o = r_d \parallel R_S \parallel 1/g_m &= 45\ \text{k}\Omega \parallel 1.1\ \text{k}\Omega \parallel 1/4.13\ \text{mS} \\ &= 1.074\ \text{k}\Omega \parallel 242.1\ \Omega \\ &= \mathbf{197.6\ \Omega} \end{aligned}$$

$$\begin{aligned} A_v = \frac{g_m(r_d \| R_S)}{1 + g_m(r_d \| R_S)} &= \frac{(4.13\ \text{mS})(45\ \text{k}\Omega \| 1.1\ \text{k}\Omega)}{1 + (4.13\ \text{mS})(45\ \text{k}\Omega \| 1.1\ \text{k}\Omega)} \\ &= \frac{(4.13\ \text{mS})(1.074\ \text{k}\Omega)}{1 + (4.13\ \text{mS})(1.074\ \text{k}\Omega)} = \frac{4.436}{1 + 4.436} \\ &= \mathbf{0.816} \end{aligned}$$

38. $$\begin{aligned} g_m &= 2k\left(V_{GS_Q} - V_{GS(Th)}\right) \\ &= 2(0.3 \times 10^{-3})(8\ \text{V} - 3\ \text{V}) \\ &= \mathbf{3\ mS} \end{aligned}$$

39. $V_{GS_Q} = 6.7\ \text{V}$

$$g_m = 2k\left(V_{GS_Q} - V_T\right) = 2(0.3 \times 10^{-3})(6.7\ \text{V} - 3\ \text{V}) = 2.22\ \text{mS}$$

$$\begin{aligned} Z_i &= \frac{R_F + r_d \| R_D}{1 + g_m(r_d \| R_D)} = \frac{10\ \text{M}\Omega + 100\ \text{k}\Omega \| 2.2\ \text{k}\Omega}{1 + (2.22\ \text{mS})(100\ \text{k}\Omega \| 2.2\ \text{k}\Omega)} \\ &= \frac{10\ \text{M}\Omega + 2.15\ \text{k}\Omega}{1 + 2.22\ \text{mS}(2.15\ \text{k}\Omega)} \cong \mathbf{1.73\ M\Omega} \end{aligned}$$

$Z_o = R_F \parallel r_d \parallel R_D = 10\ \text{M}\Omega \parallel 100\ \text{k}\Omega \parallel 2.2\ \text{k}\Omega = \mathbf{2.15\ k\Omega}$

$A_v = -g_m(R_F \parallel r_d \parallel R_D) = -2.22\ \text{mS}(2.15\ \text{k}\Omega) = \mathbf{-4.77}$

40. $g_m = 2k\left(V_{GS_Q} - V_T\right) = 2(0.2 \times 10^{-3})(6.7\text{ V} - 3\text{ V})$

$= 1.48\text{ mS}$

$$Z_i = \frac{R_F + r_d \| R_D}{1 + g_m(r_d \| R_D)} = \frac{10\text{ M}\Omega + 100\text{ k}\Omega \| 2.2\text{ k}\Omega}{1 + (1.48\text{ mS})(100\text{ k}\Omega \| 2.2\text{ k}\Omega)}$$

$$= \frac{10\text{ M}\Omega + 2.15\text{ k}\Omega}{1 + (1.48\text{ mS})(2.15\text{ k}\Omega)} = \mathbf{2.39\text{ M}\Omega} > 1.73\text{ M}\Omega\ (\#39)$$

$Z_o = R_F \| r_d \| R_D = \mathbf{2.15\text{ k}\Omega} = 2.15\text{ k}\Omega$ (#39)
$A_v = -g_m(R_F \| r_d \| R_D) = -(1.48\text{ mS})(2.15\text{ k}\Omega)$
$= \mathbf{-3.182} < -4.77$ (#39)

41. $V_{GS_Q} = 5.7\text{ V}$, $g_m = 2k\left(V_{GS_Q} - V_T\right) = 2(0.3 \times 10^{-3})(5.7\text{ V} - 3.5\text{ V})$

$= 1.32\text{ mS}$

$$r_d = \frac{1}{30\ \mu\text{S}} = 33.33\text{ k}\Omega$$

$A_v = -g_m(R_F \| r_d \| R_D) = -1.32\text{ mS}(22\text{ M}\Omega \| 33.33\text{ k}\Omega \| 10\text{ k}\Omega)$
$= -10.15$
$V_o = A_vV_i = (-10.15)(20\text{ mV}) = \mathbf{-203\text{ mV}}$

42. $I_D = k(V_{GS} - V_T)^2$

$$\therefore k = \frac{I_{D(\text{on})}}{(V_{GS(\text{on})} - V_T)^2} = \frac{4\text{ mA}}{(7\text{ V} - 4\text{ V})^2} = 0.444 \times 10^{-3}$$

$g_m = 2k(V_{GS_Q} - V_{GS(Th)}) = 2(0.444 \times 10^{-3})(7\text{ V} - 4\text{ V})$
$= 2.66\text{ mS}$

$$A_v = -g_m(R_F \| r_d \| R_D) = -(2.66\text{ mS})\underbrace{(22\text{ M}\Omega \| \underbrace{50\text{ k}\Omega \| 10\text{ k}\Omega}_{8.33\text{ k}\Omega})}_{\cong 8.33\text{ k}\Omega} = -22.16$$

$V_o = A_vV_i = (-22.16)(4\text{ mV}) = \mathbf{-88.64\text{ mV}}$

43. $V_{GS_Q} = 4.8\text{ V}$, $g_m = 2k\left(V_{GS_Q} - V_{GS_{(Th)}}\right) = 2(0.4 \times 10^{-3})(4.8\text{ V} - 3\text{ V}) = 1.44\text{ mS}$

$A_v = -g_m(r_d \| R_D) = -(1.44\text{ mS})(40\text{ k}\Omega \| 3.3\text{ k}\Omega) = -4.39$
$V_o = A_vV_i = (-4.39)(0.8\text{ mV}) = \mathbf{-3.51\text{ mV}}$

44. $r_d = \dfrac{1}{y_{os}} = \dfrac{1}{25\ \mu\text{S}} = 40\ \text{k}\Omega$

$V_{GS_Q} = 0\ \text{V},\ \therefore g_m = g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(8\ \text{mA})}{2.5\ \text{V}} = 6.4\ \text{mS}$

$|A_v| = g_m(r_d \parallel R_D)$

$8 = (6.4\ \text{mS})(40\ \text{k}\Omega \parallel R_D)$

$\dfrac{8}{6.4\ \text{mS}} = 1.25\ \text{k}\Omega = \dfrac{40\ \text{k}\Omega \cdot R_D}{40\ \text{k}\Omega + R_D}$

and R_D = **1.29 kΩ**

Use R_D = **1.3 kΩ**

45. $V_{GS_Q} = \dfrac{1}{3}V_P = \dfrac{1}{3}(-3\ \text{V}) = -1\ \text{V}$

$I_{D_Q} = I_{DSS}\left(1 - \dfrac{V_{GS_Q}}{V_P}\right)^2 = 12\ \text{mA}\left(1 - \dfrac{-1\ \text{V}}{-3\ \text{V}}\right)^2 = 5.33\ \text{mA}$

$R_S = \dfrac{V_S}{I_{D_Q}} = \dfrac{1\ \text{V}}{5.33\ \text{mA}} = 187.62\ \Omega\ \therefore$ Use R_S = **180 Ω**

$g_m = \dfrac{2I_{DSS}}{V_P}\left(1 - \dfrac{V_{GS_Q}}{V_P}\right) = \dfrac{2(12\ \text{mA})}{3\ \text{V}}\left(1 - \dfrac{-1\ \text{V}}{-3\ \text{V}}\right) = 5.33\ \text{mS}$

$A_v = -g_m(R_D \parallel r_d) = -10$

or $R_D \parallel 40\ \text{k}\Omega = \dfrac{-10}{5.33\ \text{mS}} = 1.876\ \text{k}\Omega$

$\dfrac{R_D \cdot 40\ \text{k}\Omega}{R_D + 40\ \text{k}\Omega} = 1.876\ \text{k}\Omega$

$40\ \text{k}\Omega R_D = 1.876\ \text{k}\Omega R_D + 75.04\ \text{k}\Omega^2$

$38.124 R_D = 75.04\ \text{k}\Omega$

$R_D = 1.97\ \text{k}\Omega \Rightarrow R_D =$ **2 kΩ**

Chapter 9

1. (a) **3**, **1.699**, **−1.151**
   (b) **6.908**, **3.912**, **−0.347**
   (c) results differ by magnitude of 2.3

2. (a) $\log_{10} 2.2 \times 10^3 = \mathbf{3.3424}$

   (b) $\log_e (2.2 \times 10^3) = 2.3 \log_{10}(2.2 \times 10^3) = \mathbf{7.6962}$

   (c) $\log_e (2.2 \times 10^3) = \mathbf{7.6962}$

3. (a) same **13.98**
   (b) same **−13.01**
   (c) same **0.699**

4. (a) $\text{dB} = 10 \log_{10} \dfrac{P_o}{P_i} = 10 \log_{10} \dfrac{100 \text{ W}}{5 \text{ W}} = 10 \log_{10} 20 = 10(1.301)$
   $= \mathbf{13.01\ dB}$

   (b) $\text{dB} = 10 \log_{10} \dfrac{100 \text{ mW}}{5 \text{ mW}} = 10 \log_{10} 20 = 10(1.301)$
   $= \mathbf{13.01\ dB}$

   (c) $\text{dB} = 10 \log_{10} \dfrac{100\ \mu\text{W}}{20\ \mu\text{W}} = 10 \log_{10} 5 = 10(0.6987)$
   $= \mathbf{6.9897\ dB}$

5. $G_{\text{dBm}} = 10 \log_{10} \left.\dfrac{P_2}{1 \text{ mW}}\right|_{600\,\Omega} = 10 \log_{10} \left.\dfrac{25 \text{ W}}{1 \text{ mW}}\right|_{600\,\Omega}$
   $= \mathbf{43.98\ dBm}$

6. $G_{\text{dB}} = 20 \log_{10} \dfrac{V_2}{V_1} = 20 \log_{10} \dfrac{100 \text{ V}}{25 \text{ V}} = 20 \log_{10} 4 = 20(0.6021)$
   $= \mathbf{12.04\ dB}$

7. $G_{\text{dB}} = 20 \log_{10} \dfrac{V_2}{V_1} = 20 \log_{10} \dfrac{25 \text{ V}}{10 \text{ mV}} = 20 \log_{10} 2500$
   $= 20(3.398) = \mathbf{67.96\ dB}$

8. (a) Gain of stage 1 = A dB
   Gain of stage 2 = 2 A dB
   Gain of stage 3 = 2.7 A dB
   A + 2A +2.7A = 120
   A = **21.05 dB**

(b) Stage 1: $A_{v_1} = 21.05\text{ dB} = 20\log_{10}\dfrac{V_{o_1}}{V_{i_1}}$

$$\frac{21.05}{20} = 1.0526 = \log_{10}\frac{V_{o_1}}{V_{i_1}}$$

$$10^{1.0526} = \frac{V_{o_1}}{V_{i_1}}$$

and $\dfrac{V_{o_1}}{V_{i_1}} = \mathbf{11.288}$

Stage 2: $A_{v_2} = 42.1\text{ dB} = 20\log_{10}\dfrac{V_{o_2}}{V_{i_2}}$

$$2.105 = \log_{10}\frac{V_{o_2}}{V_{i_2}}$$

$$10^{2.105} = \frac{V_{o_2}}{V_{i_2}}$$

and $\dfrac{V_{o_2}}{V_{i_2}} = \mathbf{127.35}$

Stage 3: : $A_{v_3} = 56.835\text{ dB} = 20\log_{10}\dfrac{V_{o_3}}{V_{i_3}}$

$$2.8418 = \log_{10}\frac{V_{o_3}}{V_{i_3}}$$

$$10^{2.8418} = \frac{V_{o_3}}{V_{i_3}}$$

and $\dfrac{V_{o_3}}{V_{i_3}} = \mathbf{694.624}$

$A_{v_T} = A_{v_1}\cdot A_{v_2}\cdot A_{V_3} = (11.288)(127.35)(694.624) = \mathbf{99{,}8541.1}$

$A_T = 120\text{ dB} \overset{?}{=} 20\log_{10}99{,}8541.1$

120 dB ≅ 119.99 dB (difference due to level of accuracy carried through calculations)

9. (a) $G_{\text{dB}} = 20\log_{10}\dfrac{P_2}{P_1} = 10\log_{10}\dfrac{48\text{ W}}{5\ \mu\text{W}} = \mathbf{69.83\ dB}$

(b) $G_v = 20\log_{10}\dfrac{V_o}{V_i} = 20\log_{10}\dfrac{\sqrt{P_oR_o}}{V_i} = \dfrac{20\log_{10}\sqrt{(48\text{ W})(40\text{ k}\Omega)}}{100\text{ mV}}$

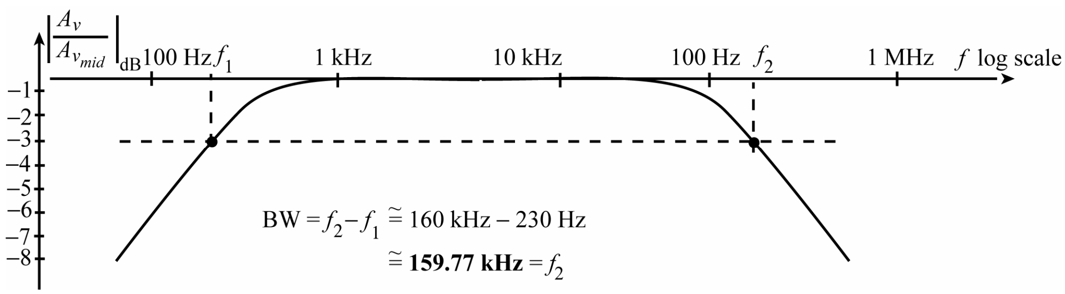
$= \mathbf{82.83\ dB}$

(c) $R_i = \dfrac{V_i^2}{P} = \dfrac{(100\text{ mV})^2}{5\ \mu\text{W}} = \mathbf{2\ k\Omega}$

(d) $P_o = \dfrac{V_o^2}{R_o} \Rightarrow V_o = \sqrt{P_o R_o} = \sqrt{(48\text{ W})(40\text{ k}\Omega)} = \mathbf{1385.64\ V}$

10. (a) Same shape except $A_v = 190$ is now level of 1. In fact, all levels of A_v are divided by 190 to obtain normalized plot.
$0.707(190) = \mathbf{134.33}$ defining cutoff frequencies
at low end $f_1 \cong$ **230 Hz** (remember this is a log scale)
at high end $f_2 \cong$ **160 kHz**

(b)



11. (a) $|A_v| = \left|\dfrac{V_o}{V_i}\right| = \dfrac{1}{\sqrt{1+(f_1/f)^2}}$ $\qquad f_l = \dfrac{1}{2\pi RC} = \dfrac{1}{2\pi(1.2\text{ k}\Omega)(0.068\ \mu\text{F})}$

$= 1950.43$ Hz

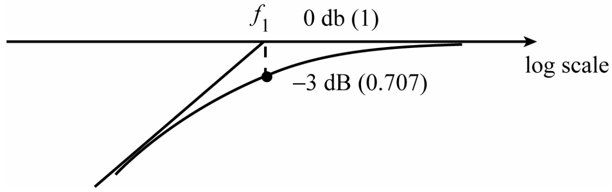
$$|A_v| = \frac{1}{\sqrt{1+\left(\dfrac{1950.43\text{ Hz}}{f}\right)^2}}$$

(b)

		$A_{V_{dB}}$
100 Hz:	$\lvert A_v\rvert = 0.051$	–25.8
1 kHz:	$\lvert A_v\rvert = 0.456$	–6.81
2 kHz:	$\lvert A_v\rvert = 0.716$	–2.90
5 kHz:	$\lvert A_v\rvert = 0.932$	–0.615
10 kHz:	$\lvert A_v\rvert = 0.982$	–0.162

(c) $f_1 \cong$ **1950 Hz**

(d)(e)

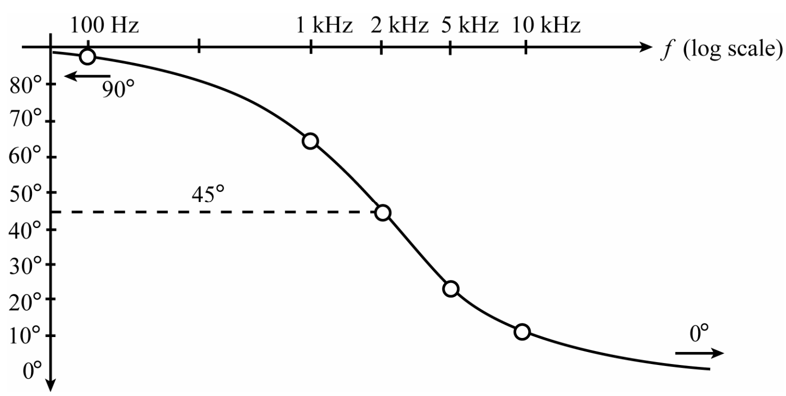


12. (a) $f_1 = \dfrac{1}{2\pi RC} = 1.95 \text{ kHz}$

$\theta = \tan^{-1}\dfrac{f_1}{f} = \tan^{-1}\dfrac{1.95 \text{ kHz}}{f}$

(b)

f	$\theta = \tan^{-1}\dfrac{1.95 \text{ kHz}}{f}$
100 Hz	87.06°
1 kHz	62.85°
2 kHz	44.27°
5 kHz	21.3°
10 kHz	11.03°



(c) $f_1 = \dfrac{1}{2\pi RC} = 1.95 \text{ kHz}$

(d) First find $\theta = 45°$ at $f_1 = 1.95$ kHz. Then sketch an approach to 90° at low frequencies and 0° at high frequencies. Use an expected shape for the curve noting that the greatest change in θ occurs near f_1. The resulting curve should be quite close to that plotted above.

13. (a) **10 kHz**

(b) **1 kHz**

(c) 20 kHz → 10 kHz → **5 kHz**

(d) 1 kHz → 10 kHz → **100 kHz**

14. From example 9.9, r_e = 15.76 Ω

$$A_v = \frac{-R_C \parallel R_L \parallel r_o}{r_e} = \frac{-4\ \text{k}\Omega \parallel 2.2\ \text{k}\Omega \parallel 40\ \text{k}\Omega}{15.76\ \Omega}$$

= –86.97 (vs. –90 for Ex. 9.9)

f_{L_s}: r_o does not affect R_i ∴ $f_{L_s} = \dfrac{1}{2\pi(R_s + R_i)C_S}$ the same ≅ **6.86 Hz**

$$f_{L_C} = \frac{1}{2\pi(R_o + R_L)C_C} = \frac{1}{2\pi(R_C \parallel r_o + R_L)C_C}$$

$R_C \parallel r_o$ = 4 kΩ || 40 kΩ = 5.636 kΩ

$$f_{L_C} = \frac{1}{2\pi(5.636\ \text{k}\Omega + 2\ \text{k}\Omega)(1\ \mu\text{F})}$$

= **28.23** Hz (vs. 25.68 Hz for Ex. 9.9)

f_{L_E}: R_e not affected by r_o, therefore, $f_{L_E} = \dfrac{1}{2\pi R_e C_E}$ ≅ **327 Hz** is the same.

In total, the effect of r_o on the frequency response was to slightly reduce the mid-band gain.

15. (a) $\beta R_E \geq 10R_2$

(120)(1.2 kΩ) ≥ 10(10 kΩ)

144 kΩ ≥ 100 kΩ (checks!)

$$V_B = \frac{10\ \text{k}\Omega(14\ \text{V})}{10\ \text{k}\Omega + 68\ \text{k}\Omega} = 1.795\ \text{V}$$

$V_E = V_B - V_{BE}$ = 1.795 V – 0.7 V

= 1.095 V

$$I_E = \frac{V_E}{R_E} = \frac{1.095\ \text{V}}{1.2\ \text{k}\Omega} = 0.913\ \text{mA}$$

$$r_e = \frac{26\ \text{mV}}{I_E} = \frac{26\ \text{mV}}{0.913\ \text{mA}} = \mathbf{28.48\ \Omega}$$

(b) $$A_{V_{\text{mid}}} = -\frac{(R_L \parallel R_C)}{r_e} = \frac{-(3.3\ \text{k}\Omega \parallel 5.6\ \text{k}\Omega)}{28.48\ \Omega}$$

= **–72.91**

(c) $Z_i = R_1 \parallel R_2 \parallel \beta r_e$

$= 68\ \text{k}\Omega \parallel 10\ \text{k}\Omega \parallel \underbrace{(120)(28.48\ \Omega)}_{3.418\ \text{k}\Omega}$

= **2.455 kΩ**

(d) $A_{v_s} = \dfrac{V_o}{V_s} = \dfrac{V_o}{V_i} \cdot \dfrac{V_i}{V_s}$

$\dfrac{V_i}{V_s} = \dfrac{Z_i}{Z_i + R_s} = \dfrac{2.455\text{ k}\Omega}{2.455\text{ k}\Omega + 0.82\text{ k}\Omega}$

$= 0.75$

$A_{v_s} = (-72.91)(0.75)$

$= \mathbf{-54.68}$

(e) $f_{L_S} = \dfrac{1}{2\pi(R_s + R_i)C_s} = \dfrac{1}{2\pi(0.82\text{ k}\Omega + 2.455\text{ k}\Omega)(0.47\ \mu\text{F})}$

$= \mathbf{103.4\ Hz}$

$f_{L_C} = \dfrac{1}{2\pi(R_o + R_L)C_C} = \dfrac{1}{2\pi(5.6\text{ k}\Omega + 3.3\text{ k}\Omega)(0.47\ \mu\text{F})}$

$= \mathbf{38.05\ Hz}$

$f_{L_E} = \dfrac{1}{2\pi R_e C_E}$: $R_e = R_E \parallel \left(\dfrac{R_s'}{\beta} + r_e\right)$

$R_s' = R_s \parallel R_1 \parallel R_2 = 0.82\text{ k}\Omega \parallel 68\text{ k}\Omega \parallel 10\text{ k}\Omega$

$= 749.51\ \Omega$

$R_e = 1.2\text{ k}\Omega \parallel \left(\dfrac{749.51\ \Omega}{120} + 28.48\ \Omega\right)$

$= 1.2\text{ k}\Omega \parallel 34.73\ \Omega$

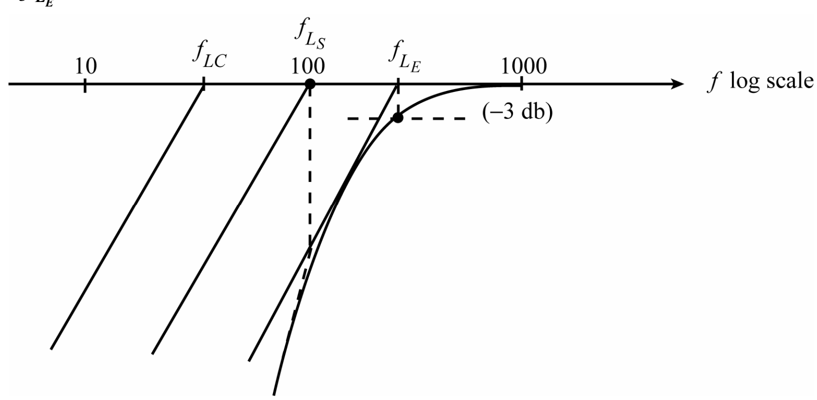
$= 33.75\ \Omega$

$f_{L_E} = \dfrac{1}{2\pi R_e C_E} = \dfrac{1}{2\pi(33.75\ \Omega)(20\ \mu\text{F})}$

$= \mathbf{235.79\ Hz}$

(f) $f_1 \cong \boldsymbol{f_{L_E}} = \mathbf{235.79\ Hz}$

(g)(h)



16. (a) $I_B = \dfrac{V_{CC} - V_{BE}}{R_B + (\beta+1)R_E} = \dfrac{20\text{ V} - 0.7\text{ V}}{470\text{ k}\Omega + (111)(0.91\text{ k}\Omega)} = \dfrac{19.3\text{ V}}{470\text{ k}\Omega + 101.01\text{ k}\Omega}$

$= 33.8\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (111)(33.8\ \mu\text{A})$

$= 3.752\text{ mA}$

$r_e = \dfrac{26\text{ mV}}{3.752\text{ mA}} = \mathbf{6.93\ \Omega}$

(b) $A_{v_{\text{mid}}} = \dfrac{V_o}{V_i} = \dfrac{-(R_C \,\|\, R_L)}{r_e} = \dfrac{-(3\text{ k}\Omega \,\|\, 4.7\text{ k}\Omega)}{6.93\ \Omega} = \dfrac{-1.831\text{ k}\Omega}{6.93\ \Omega}$

$= \mathbf{-264.24}$

(c) $Z_i = R_B \,\|\, \beta r_e = 470\text{ k}\Omega \,\|\, (110)(6.93\ \Omega) = 470\text{ k}\Omega \,\|\, 762.3\ \Omega$

$= \mathbf{761.07\ \Omega}$

(d) $A_{v_{s(\text{mid})}} = \dfrac{Z_i}{Z_i + R_s} A_{v_{\text{mid}}} = \dfrac{761.07\ \Omega}{761.07\ \Omega + 0.6\text{ k}\Omega}(-264.24)$

$= \mathbf{-147.76}$

(e) $f_{L_S} = \dfrac{1}{2\pi(R_S + Z_i)C_S} = \dfrac{1}{2\pi(600\ \Omega + 761.07\ \Omega)(1\ \mu\text{F})}$

$= \mathbf{116.93\ Hz}$

$f_{L_C} = \dfrac{1}{2\pi(R_o + R_L)C_C} = \dfrac{1}{2\pi(3\text{ k}\Omega + 4.7\text{ k}\Omega)(1\ \mu\text{F})}$

$= \mathbf{20.67\ Hz}$

$f_{L_E} = \dfrac{1}{2\pi R_e C_E}$

$= \dfrac{1}{2\pi(12.21\ \Omega)(6.8\ \mu\text{F})}$

$= \mathbf{1.917\ kHz}$

$R_e = R_E \,\|\left(\dfrac{R_s'}{\beta} + r_e\right)$

$= 0.91\text{ k}\Omega \,\|\left(\dfrac{R_s \,\|\, R_B}{\beta} + r_e\right)$

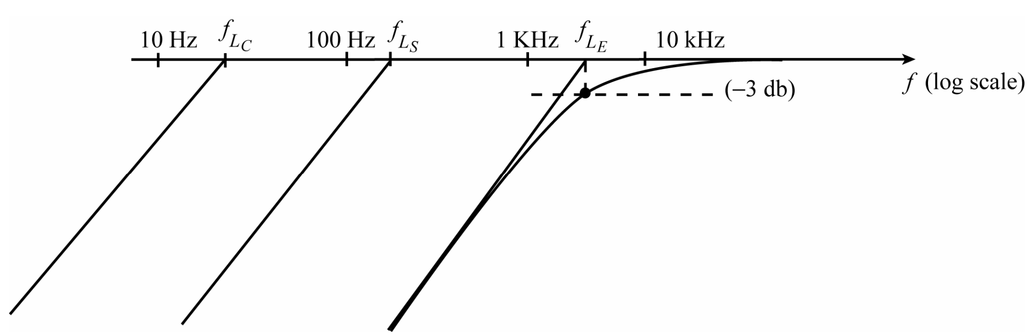
$= 0.91\text{ k}\Omega \,\|\left(\dfrac{0.6\text{ k}\Omega \,\|\, 470\text{ k}\Omega}{110} + 6.93\ \Omega\right)$

$= 910\ \Omega \,\|\, 12.38\ \Omega$

$= 12.21\ \Omega$

(f) $f_1 \cong f_{L_E} = \mathbf{1.917\ kHz}$

(g, h)



17. (a) $\beta R_E \geq 10R_2$

$(100)(2.2\text{ k}\Omega) \geq 10(30\text{ k}\Omega)$

$220\text{ k}\Omega \not\geq 300\text{ k}\Omega$ (No!)

$R_{Th} = R_1 \parallel R_2 = 120\text{ k}\Omega \parallel 30\text{ k}\Omega = 24\text{ k}\Omega$

$$E_{Th} = \frac{30\text{ k}\Omega(14\text{ V})}{30\text{ k}\Omega + 120\text{ k}\Omega} = 2.8\text{ V}$$

$$I_B = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta+1)R_E} = \frac{2.8\text{ V} - 0.7\text{ V}}{24\text{ k}\Omega + 222.2\text{ k}\Omega}$$

$= 8.53\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (101)(8.53\ \mu\text{A})$

$= 0.86\text{ mA}$

$$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{0.86\text{ mA}} = \mathbf{30.23\ \Omega}$$

(b) $$A_{v_{\text{mid}}} = \frac{R_E \| R_L}{r_e + R_E \| R_L}$$

$$= \frac{2.2\text{ k}\Omega \| 8.2\text{ k}\Omega}{30.23\ \Omega + 2.2\text{ k}\Omega \| 8.2\text{ k}\Omega}$$

$= \mathbf{0.983}$

(c) $Z_i = R_1 \parallel R_2 \parallel \beta(r_e + R'_E)$ $\qquad R'_E = R_E \parallel R_L = 2.2\text{ k}\Omega \parallel 8.2\text{ k}\Omega = 1.735\text{ k}\Omega$

$= 120\text{ k}\Omega \parallel 30\text{ k}\Omega \parallel (100)(30.23\ \Omega + 1.735\text{ k}\Omega)$

$= \mathbf{21.13\ k\Omega}$

(d) $$A_{v_s} = \frac{V_o}{V_s} = \frac{V_o}{V_i} \cdot \frac{V_i}{V_s} \qquad \frac{V_i}{V_s} = \frac{Z_i}{Z_i + R_s} = \frac{21.13\text{ k}\Omega}{21.13\text{ k}\Omega + 1\text{ k}\Omega} = 0.955$$

(e) $$f_{L_S} = \frac{1}{2\pi(R_s + R_i)C_s}$$

$$= \frac{1}{2\pi(1\text{ k}\Omega + 21.13\text{ k}\Omega)(0.1\ \mu\text{F})}$$

$= \mathbf{71.92\ Hz}$

$$f_{L_C} = \frac{1}{2\pi(R_o + R_L)C_C}$$

$$R_o = R_E \parallel \left(\frac{R'_s}{\beta} + r_e\right)$$

$$R'_s = R_s \parallel R_1 \parallel R_2$$
$$= 1\text{ k}\Omega \parallel 120\text{ k}\Omega \parallel 30\text{ k}\Omega$$
$$= 0.96\text{ k}\Omega$$

$$= (2.2\text{ k}\Omega) \parallel \left(\frac{0.96\text{ k}\Omega}{100} + 30.23\ \Omega\right)$$

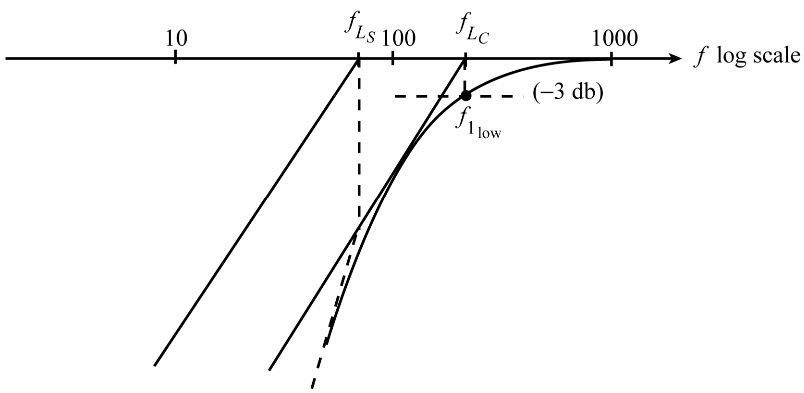
$= 39.12\ \Omega$

$$f_{L_C} = \frac{1}{2\pi(39.12\ \Omega + 8.2\text{ k}\Omega)(0.1\ \mu\text{F})}$$

$= \mathbf{193.16\ Hz}$

(f) $f_{1_{low}} \cong$ **193.16 Hz**

(g)(h)



18. (a) $I_E = \dfrac{V_{EE} - V_{EB}}{R_E} = \dfrac{4\text{ V} - 0.7\text{ V}}{1.2\text{ k}\Omega} = 2.75\text{ mA}$

$r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{2.75\text{ mA}} = 9.45\ \Omega$

(b) $A_{v_{\text{mid}}} = \dfrac{R_C \parallel R_L}{r_e} = \dfrac{3.3\text{ k}\Omega \parallel 4.7\text{ k}\Omega}{9.45\ \Omega}$

$= \mathbf{205.1}$

(c) $Z_i = R_E \parallel r_e = 1.2\text{ k}\Omega \parallel 9.45\ \Omega$

$= \mathbf{9.38\ \Omega}$

(d) $A_{v_{s(\text{mid})}} = \dfrac{Z_i}{Z_i + R_s} A_{v_{\text{mid}}} = \dfrac{9.38\ \Omega(205.1)}{9.38\ \Omega + 100\ \Omega}$

$= \mathbf{17.59}$

(e) $f_{L_s} = \dfrac{1}{2\pi(R_s + Z_i)C_s} = \dfrac{1}{2\pi(100\ \Omega + 9.38\ \Omega)(10\ \mu\text{F})}$

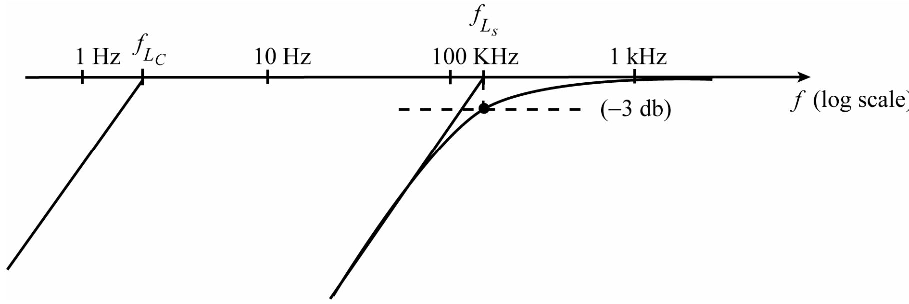
$=$ **145.5 Hz**

$f_{L_C} = \dfrac{1}{2\pi(R_o + R_L)C_E} = \dfrac{1}{2\pi(3.3\text{ k}\Omega + 4.7\text{ k}\Omega)(10\ \mu\text{F})}$

$=$ **1.989 Hz**

(f) $f = f_{L_s} \cong$ **145.5 Hz**

(g, h)



19. (a) $V_{GS} = -I_D R_S$

$$\left.\begin{array}{l} V_{GS} = -I_D R_S \\ I_D = I_{DSS}\left(1 - \dfrac{V_{GS}}{V_P}\right)^2 \end{array}\right\} \begin{array}{l} V_{GS_Q} \cong \mathbf{-2.45\ V} \\ I_{D_Q} \cong \mathbf{2.1\ mA} \end{array}$$

(b) $g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(6\text{ mA})}{6\text{ V}} = \mathbf{2\ mS}$

$$g_m = g_{m0}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = 2\text{ mS}\left(1 - \frac{(-2.45\text{ V})}{(-6\text{ V})}\right)$$
$$= \mathbf{1.18\ mS}$$

(c) $A_{v_{\text{mid}}} = -g_m(R_D \parallel R_L)$
$= -1.18\text{ mS}(3\text{ k}\Omega \parallel 3.9\text{ k}\Omega) = -1.18\text{ mS}(1.6956\text{ k}\Omega)$
$= \mathbf{-2}$

(d) $Z_i = R_G = \mathbf{1\ M\Omega}$

(e) $A_{v_s} = A_v = \mathbf{-2}$

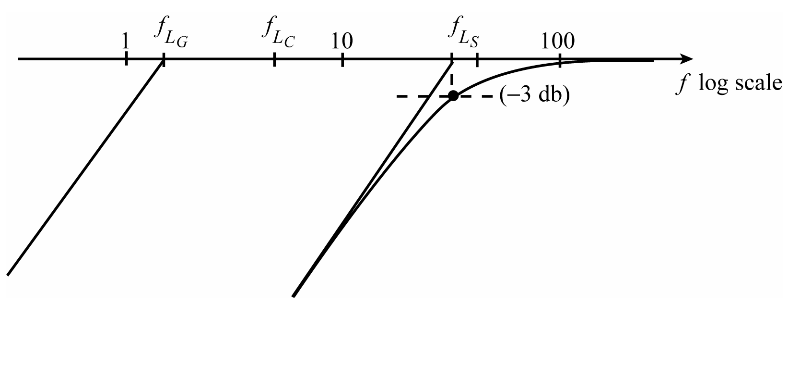
(f) $$f_{L_G} = \frac{1}{2\pi(R_{\text{sig}} + R_i)C_G} = \frac{1}{2\pi(1\text{ k}\Omega + 1\text{ M}\Omega)(0.1\ \mu\text{F})}$$
$$= \mathbf{1.59\ Hz}$$

$$f_{L_C} = \frac{1}{2\pi(R_o + R_L)C_C}$$
$$= \frac{1}{2\pi(3\text{ k}\Omega + 3.9\text{ k}\Omega)(4.7\ \mu\text{F})}$$
$$= \mathbf{4.91\ Hz}$$

$$f_{L_S} = \frac{1}{2\pi R_{\text{eq}} C_S} \qquad R_{\text{eq}} = R_S \parallel \frac{1}{g_m} = 1.2\text{ k}\Omega \parallel \frac{1}{1.18\text{ mS}} = 1.2\text{ k}\Omega \parallel 847.46\ \Omega$$
$$= \frac{1}{2\pi(496.69\ \Omega)(10\ \mu\text{F})} \qquad = 496.69\ \Omega$$
$$= \mathbf{32.04\ Hz}$$

(g) $f_1 \cong f_{L_S} \cong \mathbf{32\ Hz}$

(h, i)



20. (a) same as problem 19

$V_{GS_Q} \cong \mathbf{-2.45\ V},\ I_{D_Q} \cong \mathbf{2.1\ mA}$

(b) g_{m0} = **2 mS**, g_m = **1.18 mS** (r_d has no effect!)

(c) $A_{v_{\text{mid}}} = -g_m (R_D \parallel R_L \parallel r_d)$

$= -1.18\text{ mS}(3\text{ k}\Omega \parallel 3.9\text{ k}\Omega \parallel 100\text{ k}\Omega)$

$= -1.18\text{ mS }(1.67\text{ k}\Omega)$

$= \mathbf{-1.971}$ (vs. –2 for problem 19)

(d) $Z_i = R_G = \mathbf{1\ M\Omega}$ (the same)

(e) $$A_{v_{s(\text{mid})}} = \frac{Z_i}{Z_i + R_{\text{sig}}}(A_{v_{\text{mid}}}) = \frac{1\text{ M}\Omega}{1\text{ M}\Omega + 1\text{ k}\Omega}(-1.971)$$

$= \mathbf{-1.969}$ vs. –2 for problem 19

(f) f_{L_G} = **1.59 Hz** (no effect)

f_{L_C}: $R_o = R_D \parallel r_d = 3\text{ k}\Omega \parallel 100\text{ k}\Omega = 2.91\text{ k}\Omega$

$$f_{L_C} = \frac{1}{2\pi(R_o + R_L)C_C} = \frac{1}{2\pi(2.91\text{ k}\Omega + 3.9\text{ k}\Omega)(4.7\ \mu\text{F})}$$

= **4.97 Hz** vs. 4.91 Hz for problem 19

$$f_{L_S}:\ R_{\text{eq}} = \frac{R_S}{1 + R_S(1 + g_m r_d)/(r_d + (R_D \parallel R_L))}$$

$$= \frac{1.2\text{ k}\Omega}{1 + (1.2\text{ k}\Omega)(1 + (1.18\text{ mS})(100\text{ k}\Omega))/(100\text{ k}\Omega + 3\text{ k}\Omega \parallel 3.9\text{ k}\Omega)}$$

$$= \frac{1.2\text{ k}\Omega}{1 + 1.404}$$

$\cong 499.2\ \Omega$

$$f_{L_S} := \frac{1}{2\pi R_{\text{eq}} C_S} = \frac{1}{2\pi(499.2\ \Omega)(10\ \mu\text{F})}$$

= **31.88** Hz vs. 32.04 for problem 19.

Effect of r_d = 100 kΩ insignificant!

21. (a) $$V_G = \frac{68\text{ k}\Omega(20\text{ V})}{68\text{ k}\Omega + 220\text{ k}\Omega} = 4.72\text{ V}$$

$V_{GS} = V_G - I_D R_S$

$$\left.\begin{array}{l} V_{GS} = 4.72\text{ V} - I_D(2.2\text{ k}\Omega) \\ I_D = I_{DSS}(1 - V_{GS}/V_P)^2 \end{array}\right\} \begin{array}{l} V_{GS_Q} \cong \mathbf{-2.55\ V} \\ I_{D_Q} \cong \mathbf{3.3\ mA} \end{array}$$

(b) $$g_{m0} = \frac{2I_{DSS}}{|V_P|} = \frac{2(10\text{ mA})}{6\text{ V}} = 3.33\text{ mS}$$

$$g_m = g_{m0}\left(1 - \frac{V_{GS}}{V_P}\right) = 3.33\text{ mS}\left(1 - \frac{(-2.55\text{ V})}{-6\text{ V}}\right)$$

= **1.91 mS**

(c) $A_{v_{\text{mid}}} = -g_m(R_D \parallel R_L)$

$= -(1.91\text{ mS})(3.9\text{ k}\Omega \parallel 5.6\text{ k}\Omega)$

$= \mathbf{-4.39}$

(d) $Z_i = 68\text{ k}\Omega \parallel 220\text{ k}\Omega = \mathbf{51.94\ k\Omega}$

(e) $$A_{v_{s(\text{mid})}} = \frac{V_o}{V_i} \cdot \frac{V_i}{V_s}$$

$$\frac{V_i}{V_s} = \frac{Z_i}{Z_i + R_s} = \frac{51.94\text{ k}\Omega}{51.94\text{ k}\Omega + 1.5\text{ k}\Omega} = 0.972$$

$A_{v_{s(\text{mid})}} = (-4.39)(0.972) = \mathbf{-4.27}$

(f) $$f_{L_G} = \frac{1}{2\pi(R_{\text{sig}} + R_i)C_G} = \frac{1}{2\pi(1.5\text{ k}\Omega + 51.94\text{ k}\Omega)(1\ \mu\text{F})}$$

$= \mathbf{2.98\ Hz}$

$$f_{L_C} = \frac{1}{2\pi(R_o + R_L)C_C} = \frac{1}{2\pi(3.9\text{ k}\Omega + 5.6\text{ k}\Omega)(6.8\ \mu\text{F})}$$

$= \mathbf{2.46\ Hz}$

$$f_{L_S} = \frac{1}{2\pi R_{\text{eq}} C_S}$$

$$= \frac{1}{2\pi(388.1\ \Omega)(10\ \mu\text{F})}$$

$= \mathbf{41\ Hz}$

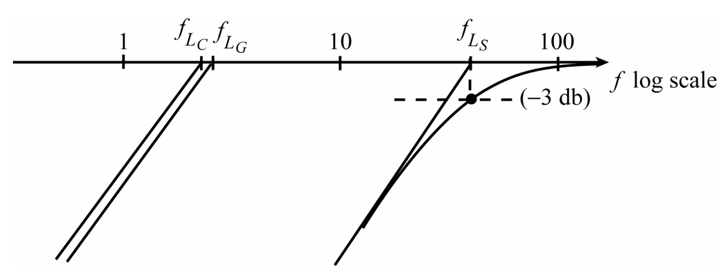
$$R_{\text{eq}} = R_S \parallel \frac{1}{g_m} = 1.5\text{ k}\Omega \parallel \frac{1}{1.91\text{ mS}}$$

$= 1.5\text{ k}\Omega \parallel 523.56\ \Omega$

$= 388.1\ \Omega$

(g) $f_1 \cong f_{L_S} = \mathbf{41\ Hz}$

(h, i)



22. (a) $f_{H_i} = \dfrac{1}{2\pi R_{Th_1} C_i}$

$= \dfrac{1}{2\pi(614.56\ \Omega)(931.92\ \text{pF})}$

$=$ **277.89 kHz**

$R_{Th_1} = R_s \parallel R_1 \parallel R_2 \parallel R_i$

$= \underbrace{0.82\ \text{k}\Omega \parallel 68\ \text{k}\Omega}_{0.81\ \text{k}\Omega} \parallel \underbrace{10\ \text{k}\Omega \parallel 3.418\ \text{k}\Omega}_{2.547\ \text{k}\Omega}$

$= 614.56\ \Omega$

$C_i = C_{W_1} + C_{be} + C_{bc}(1 - A_v)$

$= 5\ \text{pF} + 40\ \text{pF} + 12\ \text{pF}(1 - (-72.91))$

$= 931.92\ \text{pF}$ ↑Prob. 15

$f_{H_o} = \dfrac{1}{2\pi R_{Th_2} C_o}$

$= \dfrac{1}{2\pi(2.08\ \text{k}\Omega)(28\ \text{pF})}$

$=$ **2.73 MHz**

$R_{Th_2} = R_C \parallel R_L = 5.6\ \text{k}\Omega \parallel 3.3\ \text{k}\Omega$

$= 2.08\ \text{k}\Omega$

$C_o = C_{W_o} + C_{ce} + C_{M_o}$

$= 8\ \text{pF} + 8\ \text{pF} + 12\ \text{pF}$

$= 28\ \text{pF}$

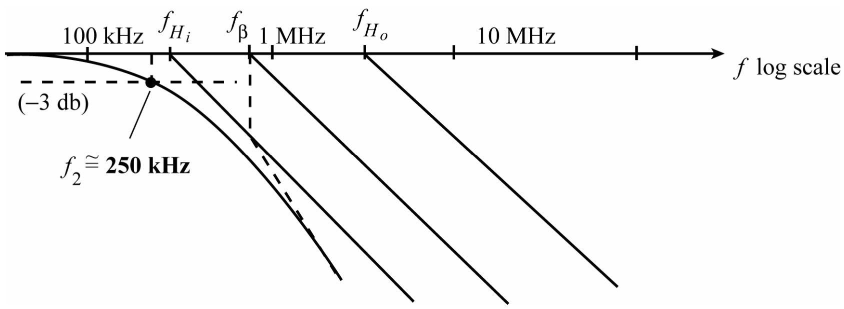
(b) $f_\beta \cong \dfrac{1}{2\pi\beta_{\text{mid}} r_e (C_{be} + C_{bc})} = \dfrac{1}{2\pi(120)(28.48\ \Omega)(40\ \text{pF} + 12\ \text{pF})}$

$=$ **895.56 kHz** ↑ Prob. 15

$f_T = \beta f_\beta = (120)(895.56\ \text{kHz})$

$=$ **107.47 MHz**

(c)



23. (a) $f_{H_i} = \dfrac{1}{2\pi R_{Th_1} C_i}$

$R_{Th_1} = R_s \parallel R_B \parallel R_i$

R_i: $I_B = \dfrac{V_{CC} - V_{BE}}{R_B + (\beta + 1)R_E} = \dfrac{20\ \text{V} - 0.7\ \text{V}}{470\ \text{k}\Omega + (111)(0.91\ \text{k}\Omega)}$

$= 33.8\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (110 + 1)(33.8\ \mu\text{A})$

$= 3.75\ \text{mA}$

$r_e = \dfrac{26\ \text{mV}}{I_E} = \dfrac{26\ \text{mV}}{3.75\ \text{mA}} = 6.93\ \Omega$

$R_i = \beta r_e = (110)(6.93\ \Omega)$

$= 762.3\ \Omega$

$R_{Th_1} = R_s \parallel R_B \parallel R_i = 0.6\ \text{k}\Omega \parallel 470\ \text{k}\Omega \parallel 762.3\ \Omega$

$= 335.50\ \Omega$

$$f_{H_i} = \frac{1}{2\pi(335.50\ \Omega)(C_i)}$$

C_i: $C_i = C_{W_i} + C_{be} + (1 - A_v)C_{bc}$

A_v: $A_{v_{\text{mid}}} = \dfrac{-(R_L \parallel R_C)}{r_e} = \dfrac{-(4.7\ \text{k}\Omega \parallel 3\ \text{k}\Omega)}{6.93\ \Omega}$

$= -264.2$

$C_i = 7\ \text{pF} + 20\ \text{pF} + (1 - (-264.2)6\ \text{pF}$

$= 1.62\ \text{nF}$

$$f_{H_i} = \frac{1}{2\pi(335.50\ \Omega)(1.62\ \text{nF})}$$

$\cong$ **293 kHz**

$$f_{H_o} = \frac{1}{2\pi R_{Th_2} C_o}$$

$R_{Th_2} = R_C \parallel R_L = 3\ \text{k}\Omega \parallel 4.7\ \text{k}\Omega = 1.831\ \text{k}\Omega$

$$C_o = C_{W_o} + C_{ce} + \underbrace{C_{M_o}}_{\cong C_f = C_{bc}}$$

$= 11\ \text{pF} + 10\ \text{pF} + 6\ \text{pF}$

$= 27\ \text{pF}$

$$f_{H_o} = \frac{1}{2\pi(1.831\ \text{k}\Omega)(27\ \text{pF})}$$

= **3.22 MHz**

(b) $f_\beta = \dfrac{1}{2\pi\beta_{\text{mid}} r_e (C_{be} + C_{bc})}$

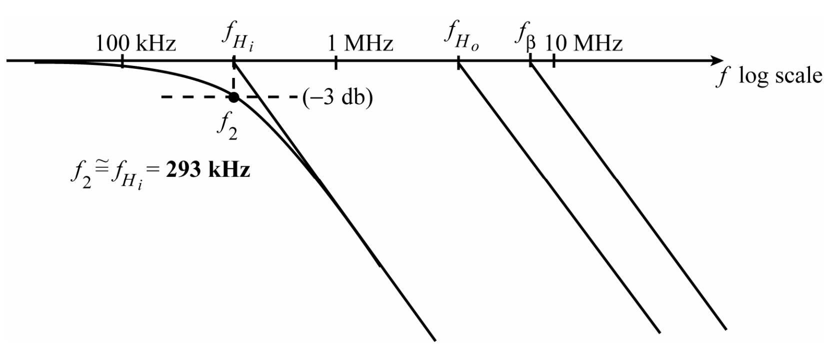
$= \dfrac{1}{2\pi(110)(6.93\ \Omega)(20\ \text{pF} + 6\ \text{pF})}$

= **8.03 MHz**

$f_T = \beta_{\text{mid}} f_\beta = (110)(8.03\ \text{MHz})$

= **883.3 MHz**

(c)



24. (a)
$$f_{H_i} = \frac{1}{2\pi R_{Th_1} C_i} = \frac{1}{2\pi(955\ \Omega)(58\ \text{pF})} = 2.87\ \text{MHz}$$

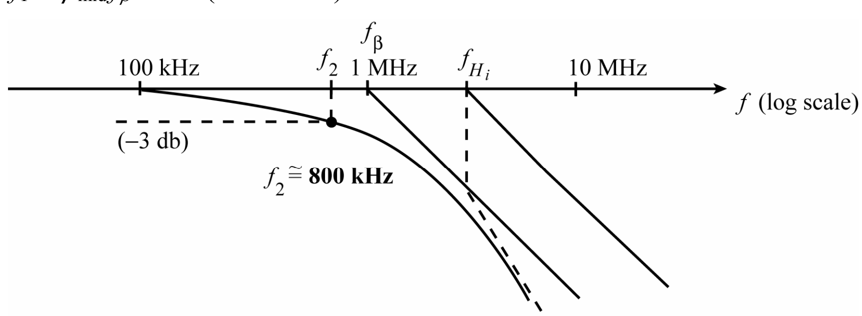
$$R_{Th_1} = R_s \,\|\, R_1 \,\|\, R_2 \,\|\, Z_b$$
$$\begin{aligned} Z_b &= \beta r_e + (\beta + 1)(R_E \,\|\, R_L) \\ &= (100)(30.23\ \Omega) + (101)(2.2\ \text{k}\Omega \,\|\, 8.2\ \text{k}\Omega) \\ &= 3.023\ \text{k}\Omega + 175.2\ \text{k}\Omega \\ &= 178.2\ \text{k}\Omega \end{aligned}$$
$$\begin{aligned} R_{Th_1} &= 1\ \text{k}\Omega \,\|\, 120\ \text{k}\Omega \,\|\, 30\ \text{k}\Omega \,\|\, 178.2\ \text{k}\Omega \\ &= 955\ \Omega \end{aligned}$$
$$\begin{aligned} C_i &= C_{W_i} + C_{be} + C_{bc} \quad \text{(No Miller effect)} \\ &= 8\ \text{pF} + 30\ \text{pF} + 20\ \text{pF} \\ &= 58\ \text{pF} \end{aligned}$$

$$f_{H_o} = \frac{1}{2\pi R_{Th_2} C_o} = \frac{1}{2\pi(38.94\ \Omega)(32\ \text{pF})} = \mathbf{127.72\ MHz}$$

$$\begin{aligned} R_{Th_2} &= R_E \,\|\, R_L \,\|\, \left(r_e + \frac{\overbrace{R_1 \,\|\, R_2 \,\|\, R_3}^{24\ \text{k}\Omega}}{\beta} \right) \\ &= 2.2\ \text{k}\Omega \,\|\, 8.2\ \text{k}\Omega \,\|\, \left(30.23\ \Omega + \frac{24\ \text{k}\Omega \,\|\, 1\ \text{k}\Omega}{100} \right) \\ &= 1.735\ \text{k}\Omega \,\|\, (30.23\ \Omega + 9.6\ \Omega) \\ &= 1.735\ \text{k}\Omega \,\|\, 39.83\ \Omega \\ &= 38.94\ \Omega \end{aligned}$$
$$\begin{aligned} C_o &= C_{W_o} + C_{ce} \\ &= 10\ \text{pF} + 12\ \text{pF} \\ &= 32\ \text{pF} \end{aligned}$$

(b)
$$f_\beta = \frac{1}{2\pi \beta_{\text{mid}} r_e (C_{be} + C_{bc})} = \frac{1}{2\pi(100)(30.23\ \Omega)(30\ \text{pF} + 20\ \text{pF})} = \mathbf{1.05\ MHz}$$
$f_T = \beta_{\text{mid}} f_\beta = 100(1.05\ \text{MHz}) = \mathbf{105\ MHz}$

(c)



25. (a) $f_{H_i} = \dfrac{1}{2\pi R_{Th_1} C_i}$

$R_{Th_1} = R_s \parallel R_E \parallel R_i$

R_i: $I_E = \dfrac{V_{EE} - V_{BE}}{R_E} = \dfrac{4\text{ V} - 0.7\text{ V}}{1.2\text{ k}\Omega} = 2.75\text{ mA}$

$r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{2.75\text{ mA}} = 9.45\ \Omega$

$R_i = R_E \parallel r_e = 1.2\text{ k}\Omega \parallel 9.45\ \Omega$
$= 9.38\ \Omega$

C_i: $C_i = C_{W_i} + C_{be}$ (no Miller cap-noninverting!)
$= 8\text{ pF} + 24\text{ pF}$
$= 32\text{ pF}$

$R_i = 0.1\text{ k}\Omega \parallel 1.2\text{ k}\Omega \parallel 9.38\ \Omega = 8.52\ \Omega$

$f_{H_i} = \dfrac{1}{2\pi(8.52\ \Omega)(32\text{ pF})} \cong$ **584 MHz**

$f_{H_o} = \dfrac{1}{2\pi R_{Th_2} C_o}$ $\qquad R_{Th_2} = R_C \parallel R_L = 3.3\text{ k}\Omega \parallel 4.7\text{ k}\Omega = 1.94\text{ k}\Omega$

$C_o = C_{W_o} + C_{bc} +$ (no Miller)
$= 10\text{ pF} + 18\text{ pF}$
$= 28\text{ pF}$

$f_{H_o} = \dfrac{1}{2\pi(1.94\text{ k}\Omega)(28\text{ pF})}$
= **2.93 MHz**

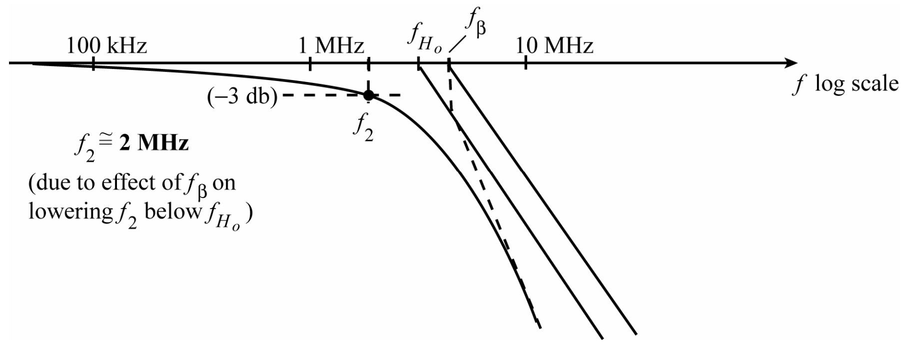
(b) $f_\beta = \dfrac{1}{2\pi\beta_{\text{mid}} r_e (C_{be} + C_{bc})}$

$= \dfrac{1}{2\pi(80)(9.45\ \Omega)(24\text{ pF} + 18\text{ pF})}$

= **5.01 MHz**

$f_T = \beta_{\text{mid}} f_\beta = (80)(5.01\text{ MHz})$
= **400.8 MHz**

(c)



26. (a) From problem 19 g_{m0} = **2 mS**, g_m = **1.18 mS**

(b) From problem 19 $A_{v_{\text{mid}}} \cong A_{v_{s\,(\text{mid})}} = \mathbf{-2}$

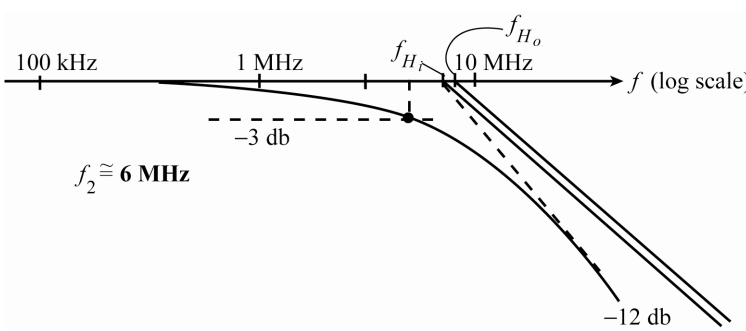
(c)
$$f_{H_i} = \frac{1}{2\pi R_{Th_1} C_i}$$
$$f_{H_i} = \frac{1}{2\pi(999\ \Omega)(21\ \text{pF})}$$
$$= \mathbf{7.59\ MHz}$$

$R_{Th_1} = R_{\text{sig}} \parallel R_G$
$= 1\text{ k}\Omega \parallel 1\text{ M}\Omega$
$= 999\ \Omega$
$C_i = C_{W_i} + C_{gs} + C_{M_i}$
$C_{M_i} = (1 - A_v)C_{gd}$
$= (1 - (-2)4\text{ pF}$
$= 12\text{ pF}$
$C_i = 3\text{ pF} + 6\text{ pF} + 12\text{ pF}$
$= 21\text{ pF}$

$$f_{H_o} = \frac{1}{2\pi R_{Th_2} C_o}$$
$$= \frac{1}{2\pi(1.696\text{ k}\Omega)(12\text{ pF})}$$
$$= \mathbf{7.82\ MHz}$$

$R_{Th_2} = R_D \parallel R_L$
$= 3\text{ k}\Omega \parallel 3.9\text{ k}\Omega$
$= 1.696\text{ k}\Omega$
$C_o = C_{W_o} + C_{ds} + C_{M_o}$
$C_{M_o} = \left(1 - \frac{1}{-2}\right)4\text{ pF}$
$= (1.5)(4\text{ pF})$
$= 6\text{ pF}$
$C_o = 5\text{ pF} + 1\text{ pF} + 6\text{ pF}$
$= 12\text{ pF}$

(d)



27. (a) $g_{m0} = \frac{2I_{DSS}}{|V_P|} = \frac{2(10\text{ mA})}{6\text{ V}}$ = **3.33 mS**

From problem #21 $V_{GS_Q} \cong$ **−2.55 V**, $I_{D_Q} \cong$ **3.3 mA**

$$g_m = g_{m0}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = 3.33\text{ mS}\left(1 - \frac{-2.55\text{ V}}{-6\text{ V}}\right) = \mathbf{1.91\ mS}$$

(b) $A_{v_{\text{mid}}} = -g_m(R_D \parallel R_L)$

$= -(1.91\text{ mS})(3.9\text{ k}\Omega \parallel 5.6\text{ k}\Omega)$

$= \mathbf{-4.39}$

$Z_i = 68\text{ k}\Omega \parallel 220\text{ k}\Omega = 51.94\text{ k}\Omega$

$$\frac{V_i}{V_s} = \frac{Z_i}{Z_i + R_{\text{sig}}} = \frac{51.94\text{ k}\Omega}{51.94\text{ k}\Omega + 1.5\text{ k}\Omega} = 0.972$$

$A_{v_{s\,(\text{mid})}} = (-4.39)(0.972)$

$= \mathbf{-4.27}$

(c) $f_{H_i} = \dfrac{1}{2\pi R_{Th_1} C_i}$ $\qquad R_{Th_1} = R_{\text{sig}} \parallel R_1 \parallel R_2$

$= 1.5\text{ k}\Omega \parallel 51.94\text{ k}\Omega$

$= 1.46\text{ k}\Omega$

$C_i = C_{W_i} + C_{gs} + (1 - A_v)C_{gd}$

$= 4\text{ pF} + 12\text{ pF} + (1 - (-4.39))8\text{ pF}$

$= 59.12\text{ pF}$

$$f_{H_i} = \frac{1}{2\pi(1.46\text{ k}\Omega)(59.12\text{ pF})}$$

$= \mathbf{1.84\ MHz}$

$f_{H_o} = \dfrac{1}{2\pi R_{Th_2} C_o}$ $\qquad R_{Th_2} = R_D \parallel R_L = 3.9\text{ k}\Omega \parallel 5.6\text{ k}\Omega$

$= 2.3\text{ k}\Omega$

$$C_o = C_{W_o} + C_{ds} + \left(1 - \frac{1}{A_v}\right)C_{gd}$$

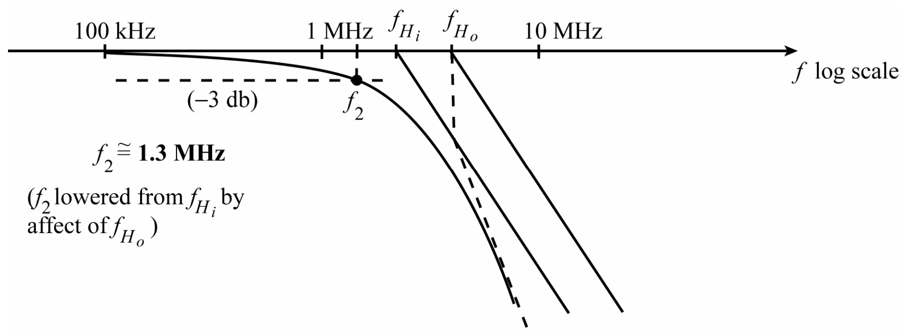
$$= 6\text{ pF} + 3\text{ pF} + \left(1 - \frac{1}{(-4.39)}\right)8\text{ pF}$$

$= 18.82\text{ pF}$

$$f_{H_o} = \frac{1}{2\pi(2.3\text{ k}\Omega)(18.82\text{ pF})}$$

$= \mathbf{3.68\ MHz}$

(d)



28. $A_{v_T} = A_{v_1} \cdot A_{v_2} \cdot A_{v_3} \cdot A_{v_4}$
$= A_v^{\,4}$
$= (20)^4$
$= \mathbf{16 \times 10^4}$

29. $$f_2' = \left(\sqrt{2^{1/n}-1}\right) f_2$$
$$= \left(\sqrt{\underbrace{2^{1/4}}_{1.18}-1}\right)(2.5\text{ MHz})$$
$= 0.435(2.5\text{ MHz})$
$= \mathbf{1.09\ MHz}$

30. $$f_1' = \frac{f_1}{\sqrt{2^{1/n}-1}} = \frac{40\text{ Hz}}{\sqrt{2^{1/4}-1}}$$
$$= \frac{40\text{ Hz}}{0.435}$$
$= \mathbf{91.96\ Hz}$

31. (a) $$v = \frac{4}{\pi} V_m\left[\sin 2\pi f_s t + \frac{1}{3}\sin 2\pi(3f_s)t + \frac{1}{5}\sin 2\pi(5f_s)t + \frac{1}{7}\sin 2\pi(7f_s)t + \frac{1}{9}\sin 2\pi(9f_s)t + \ldots\right]$$
$$= 12.73 \times 10^{-3}(\sin 2\pi(100\times10^3)t + \frac{1}{3}\sin 2\pi(300\times10^3)t + \frac{1}{5}\sin 2\pi(500\times10^3)t + \frac{1}{7}\sin 2\pi(700\times10^3)t + \frac{1}{9}\sin 2\pi(900\times10^3)t)$$

(b) $$BW \cong \frac{0.35}{t_r} \cong \frac{0.35}{0.7\ \mu\text{s}} \cong 500\text{ kHz}$$

At 90% or 81 mV, $t \cong 0.75\ \mu$s
At 10% or 9 mV, $t \cong 0.05\ \mu$s
$t_r \cong 0.75\ \mu\text{s} - 0.05\ \mu\text{s} = 0.7\ \mu\text{s}$

(c) $$P = \frac{V - V'}{V} = \frac{90\text{ mV} - 80\text{ mV}}{90\text{ mV}} = 0.111$$
$$f_{L_o} = \frac{P}{\pi} f_s = \frac{(0.111)(100\text{ kHz})}{\pi} \cong \mathbf{3.53\ kHz}$$

Chapter 10

1. $$V_o = -\frac{R_F}{R_1}V_1 = -\frac{250\text{ k}\Omega}{20\text{ k}\Omega}(1.5\text{ V}) = \mathbf{-18.75\ V}$$

2. $$A_v = \frac{V_o}{V_i} = -\frac{R_F}{R_1}$$

For $R_1 = 10\text{ k}\Omega$:

$$A_v = -\frac{500\text{ k}\Omega}{10\text{ k}\Omega} = \mathbf{-50}$$

For $R_1 = 20\text{ k}\Omega$:

$$A_v = -\frac{500\text{ k}\Omega}{20\text{ k}\Omega} = \mathbf{-25}$$

3. $$V_o = -\frac{R_f}{R_1}V_1 = -\left(\frac{1\text{ M}\Omega}{20\text{ k}\Omega}\right)V_1 = 2\text{ V}$$

$$V_1 = \frac{2\text{ V}}{-50} = \mathbf{-40\ mV}$$

4. $$V_o = -\frac{R_F}{R_1}V_1 = -\frac{200\text{ k}\Omega}{20\text{ k}\Omega}V_1 = -10\ V_1$$

For $V_1 = 0.1$ V:

$V_o = -10(0.1\text{ V}) = \mathbf{-1\ V}$

For $V_1 = 0.5$ V:

$V_o = -10(0.5\text{ V}) = \mathbf{-5\ V}$

V_o ranges from **–1 V to –5 V**

5. $$V_o = \left(1 + \frac{R_F}{R_1}\right)V_1 = \left(1 + \frac{360\text{ k}\Omega}{12\text{ k}\Omega}\right)(-0.3\text{ V})$$

$$= 31(-0.3\text{ V}) = \mathbf{-9.3\ V}$$

6. $$V_o = \left(1 + \frac{R_F}{R_1}\right)V_1 = \left(1 + \frac{360\text{ k}\Omega}{12\text{ k}\Omega}\right)V_1 = 2.4\text{ V}$$

$$V_1 = \frac{2.4\text{ V}}{31} = \mathbf{77.42\ mV}$$

7. $$V_o = \left(1 + \frac{R_F}{R_1}\right)V_1$$

For R_1 = 10 kΩ:

$$V_o = \left(1 + \frac{200\text{ k}\Omega}{10\text{ k}\Omega}\right)(0.5\text{ V}) = 21(0.5\text{ V}) = \mathbf{10.5\text{ V}}$$

For R_1 = 20 kΩ:

$$V_o = \left(1 + \frac{200\text{ k}\Omega}{20\text{ k}\Omega}\right)(0.5\text{ V}) = 11(0.5\text{ V}) = \mathbf{5.5\text{ V}}$$

V_o ranges from 5.5 V to 10.5 V.

8. $$V_o = -\left[\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3\right]$$

$$= -\left[\frac{330\text{ k}\Omega}{33\text{ k}\Omega}(0.2\text{ V}) + \frac{330\text{ k}\Omega}{22\text{ k}\Omega}(-0.5\text{ V}) + \frac{330\text{ k}\Omega}{12\text{ k}\Omega}(0.8\text{ V})\right]$$

$$= -[10(0.2\text{ V}) + 15(-0.5\text{ V}) + 27.5(0.8\text{ V})]$$

$$= -[2\text{ V} + (-7.5\text{ V}) + 2.2\text{ V}]$$

$$= -[24\text{ V} - 7.5\text{ V}] = \mathbf{-16.5\text{ V}}$$

9. $$V_o = -\left[\frac{R_F}{R_1}V_1 + \frac{R_F}{R_2}V_2 + \frac{R_F}{R_3}V_3\right]$$

$$= -\left[\frac{68\text{ k}\Omega}{33\text{ k}\Omega}(0.2\text{ V}) + \frac{68\text{ k}\Omega}{22\text{ k}\Omega}(-0.5\text{ V}) + \frac{68\text{ k}\Omega}{12\text{ k}\Omega}(+0.8\text{ V})\right]$$

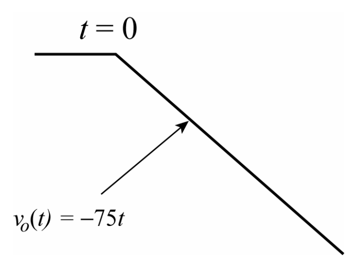
$$= -[0.41\text{ V} - 1.55\text{ V} + 4.53\text{ V}]$$

$$= \mathbf{-3.39\text{ V}}$$

10. $$v_o(t) = -\frac{1}{RC}\int v_1(t)dt$$

$$= -\frac{1}{(200\text{ k}\Omega)(0.1\ \mu\text{F})}\int 1.5\ dt$$

$$= -50(1.5t) = \mathbf{-75}\boldsymbol{t}$$



11. $V_o = V_1 = \mathbf{+0.5\text{ V}}$

12. $$V_o = -\frac{R_f}{R_1}V_1 = -\frac{100\text{ k}\Omega}{20\text{ k}\Omega}(1.5\text{ V})$$

$$= -5(1.5\text{ V}) = \mathbf{-7.5\text{ V}}$$

13. $$V_2 = -\left[\frac{200\text{ k}\Omega}{20\text{ k}\Omega}\right](0.2\text{ V}) = \mathbf{-2\text{ V}}$$

$$V_3 = \left(1 + \frac{200\text{ k}\Omega}{10\text{ k}\Omega}\right)(0.2\text{ V}) = \mathbf{+4.2\text{ V}}$$

14. $V_o = \left(1 + \dfrac{400\text{ k}\Omega}{20\text{ k}\Omega}\right)(0.1\text{ V}) \cdot \left(\dfrac{-100\text{ k}\Omega}{20\text{ k}\Omega}\right) + \left(-\dfrac{100\text{ k}\Omega}{10\text{ k}\Omega}\right)(0.1\text{ V})$

$= (2.1\text{ V})(-5) + (-10)(0.1\text{ V})$

$= -10.5\text{ V} - 1\text{ V} = \mathbf{-11.5\text{ V}}$

15. $V_o = -\left[\dfrac{600\text{ k}\Omega}{15\text{ k}\Omega}(25\text{ mV}) + \dfrac{600\text{ k}\Omega}{30\text{ k}\Omega}(-20\text{ mV})\right]\left(-\dfrac{300\text{ k}\Omega}{30\text{ k}\Omega}\right)$

$+\left[-\left(\dfrac{300\text{ k}\Omega}{15\text{ k}\Omega}\right)(-20\text{ mV})\right]$

$= -[40(25\text{ mV}) + (20)(-20\text{ mV})](-10) + (-20)(-20\text{ mV})$

$= -[1\text{ V} - 0.4\text{ V}](-10) + 0.4\text{ V}$

$= 6\text{ V} + 0.4\text{ V} = \mathbf{6.4\text{ V}}$

16. $V_o = \left(1 + \dfrac{R_f}{R_1}\right)V_{Io} + I_{Io}R_f$

$= \left(1 + \dfrac{200\text{ k}\Omega}{2\text{ k}\Omega}\right)(6\text{ mV}) + (120\text{ nA})(200\text{ k}\Omega)$

$= 101(6\text{ mV}) + 24\text{ mV}$

$= 606\text{ mV} + 24\text{ mV} = \mathbf{630\text{ mV}}$

17. $I_{IB}^{+} = I_{IB^+} + \dfrac{I_{Io}}{2} = 20\text{ nA} + \dfrac{4\text{ nA}}{2} = \mathbf{22\text{ nA}}$

$I_{IB}^{-} = I_{IB^-} - \dfrac{I_{Io}}{2} = 20\text{ nA} - \dfrac{4\text{ nA}}{2} = \mathbf{18\text{ nA}}$

18. $f_1 = 800\text{ kHz}$

$f_c = \dfrac{f_1}{A_{v_2}} = \dfrac{800\text{ kHz}}{150 \times 10^3} = \mathbf{5.3\text{ Hz}}$

19. $A_{CL} = \dfrac{SR}{\Delta V_i / \Delta t} = \dfrac{2.4\text{ V}/\mu\text{s}}{0.3\text{ V}/10\ \mu\text{s}} = \mathbf{80}$

20. $A_{CL} = \dfrac{R_f}{R_1} = \dfrac{200\text{ k}\Omega}{2\text{ k}\Omega} = 100$

$K = A_{CL}\, V_i = 100(50\text{ mV}) = 5\text{ V}$

$w_s \le \dfrac{SR}{K} = \dfrac{0.4\text{ V}/\mu\text{s}}{5\text{ V}} = \mathbf{80 \times 10^3\text{ rad/s}}$

$f_s = \dfrac{w_s}{2\pi} = \dfrac{80 \times 10^3}{2\pi} = \mathbf{12.73\text{ kHz}}$

21. V_{Io} = 1 mV, typical
I_{Io} = 20 nA, typical

$$V_o(\text{offset}) = \left(1+\frac{R_f}{R_1}\right)V_{Io} + I_{Io}R_f$$
$$= \left(1+\frac{200\text{ k}\Omega}{20\text{ k}\Omega}\right)(1\text{ mV}) + (200\text{ k}\Omega)(20\text{ nA})$$
$$= 101(1\text{ mV}) + 4000 \times 10^{-6}$$
$$= 101\text{ mV} + 4\text{ mV} = \mathbf{105\text{ mV}}$$

22. Typical characteristics for 741
$R_o = 25\ \Omega$, A = 200 K

(a) $A_{CL} = -\frac{R_f}{R_1} = -\frac{200\text{ k}\Omega}{2\text{ k}\Omega} = \mathbf{-100}$

(b) $Z_i = R_1 = \mathbf{2\text{ k}\Omega}$

(c) $Z_o = \frac{R_o}{1+\beta A} = \frac{25\ \Omega}{1+\frac{1}{100}(200{,}000)}$

$$= \frac{25\ \Omega}{2001} = \mathbf{0.0125\ \Omega}$$

23. $A_d = \frac{V_o}{V_d} = \frac{120\text{ mV}}{1\text{ mV}} = 120$

$A_c = \frac{V_o}{V_c} = \frac{20\ \mu\text{V}}{1\text{ mV}} = 20 \times 10^{-3}$

Gain (dB) $= 20\log\frac{A_d}{A_c} = 20\log\frac{120}{20\times10^{-3}}$

$$= 20\log(6 \times 10^3) = \mathbf{75.56\text{ dB}}$$

24. $V_d = V_{i1} - V_{i2} = 200\ \mu\text{V} - 140\ \mu\text{V} = 60\ \mu\text{V}$

$$V_c = \frac{V_{i1} + V_{i2}}{2} = \frac{(200\ \mu\text{V} + 140\ \mu\text{V})}{2} = 170\ \mu\text{V}$$

(a) $\text{CMRR} = \dfrac{A_d}{A_c} = 200$

$$A_c = \frac{A_d}{200} = \frac{6000}{200} = \mathbf{30}$$

(b) $\text{CMRR} = \dfrac{A_d}{A_c} = 10^5$

$$A_c = \frac{A_d}{10^5} = \frac{6000}{10^5} = 0.06 = \mathbf{60 \times 10^{-3}}$$

Using $V_o = A_d V_d \left[1 + \dfrac{1}{CMRR}\dfrac{V_c}{V_d}\right]$

(a) $V_o = 6000(60\ \mu\text{V})\left[1 + \dfrac{1}{200}\dfrac{170\ \mu\text{V}}{60\ \mu\text{V}}\right] = \mathbf{365.1\ mV}$

(b) $V_o = 6000(60\ \mu\text{V})\left[1 + \dfrac{1}{10^5}\dfrac{170\ \mu\text{V}}{60\ \mu\text{V}}\right] = \mathbf{360.01\ mV}$

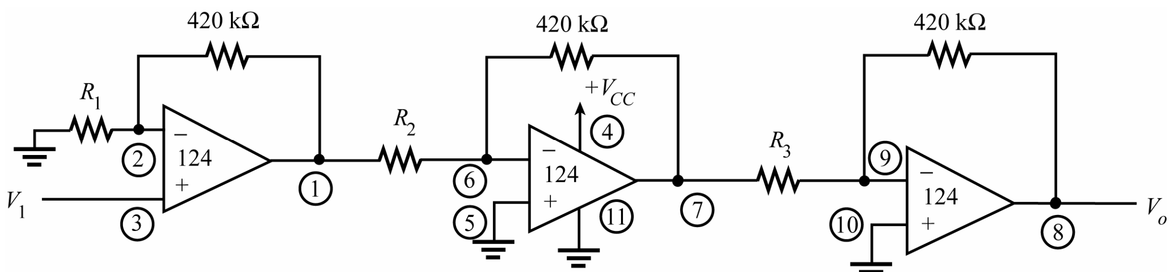
Chapter 11

1. $$V_o = -\frac{R_F}{R_1}V_1 = -\frac{180\text{ k}\Omega}{3.6\text{ k}\Omega}(3.5\text{ mV}) = \mathbf{-175\text{ mV}}$$

2. $$V_o = \left(1+\frac{R_F}{R_1}\right)V_1 = \left(1+\frac{750\text{ k}\Omega}{36\text{ k}\Omega}\right)(150\text{ mV, rms})$$
$$= \mathbf{3.275\text{ V}}\text{, rms } \angle 0°$$

3. $$V_o = \left(1+\frac{510\text{ k}\Omega}{18\text{ k}\Omega}\right)(20\ \mu\text{V})\left[-\frac{680\text{ k}\Omega}{22\text{ k}\Omega}\right]\left[-\frac{750\text{ k}\Omega}{33\text{ k}\Omega}\right]$$
$$= (29.33)(-30.91)(-22.73)(20\ \mu\text{V})$$
$$= \mathbf{412\text{ mV}}$$

4.



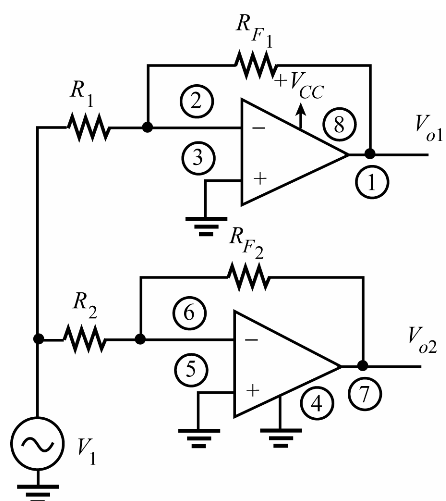
$$\left(1+\frac{420\text{ k}\Omega}{R_1}\right) = +15 \qquad -\frac{420\text{ k}\Omega}{R_2} = -22 \qquad \frac{420\text{ k}\Omega}{R_2} = -30$$

$$R_1 = \frac{420\text{ k}\Omega}{14} \qquad R_2 = \frac{420\text{ k}\Omega}{22} \qquad R_3 = \frac{420\text{ k}\Omega}{30}$$

$\boldsymbol{R_1 = 71.4\text{ k}\Omega}$ $\qquad$ $\boldsymbol{R_2 = 19.1\text{ k}\Omega}$ $\qquad$ $\boldsymbol{R_3 = 14\text{ k}\Omega}$

$$V_o = (+15)(-22)(-30)V_1 = 9000(80\ \mu\text{V}) = 792\text{ mV}$$
$$= \mathbf{0.792\text{ V}}$$

5.



$$V_{o1} = -\frac{R_{F1}}{R_1}V_1 = -\frac{150\text{ k}\Omega}{R_1}V_1$$
$$\frac{V_{o1}}{V_1} = A_{v_1} = -15 = -\frac{150\text{ k}\Omega}{R_1}$$
$$R_1 = \frac{150\text{ k}\Omega}{15} = \mathbf{10\text{ k}\Omega}$$

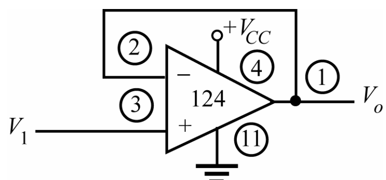
$$V_{o2} = -\frac{R_{F2}}{R_2}V_1 = -\frac{150\text{ k}\Omega}{R_2}V_1$$
$$\frac{V_{o2}}{V_1} = A_{v_2} = -30 = -\frac{150\text{ k}\Omega}{R_2}$$
$$R_2 = \frac{150\text{ k}\Omega}{30} = \mathbf{5\text{ k}\Omega}$$

6. $$V_o = -\left[\frac{R_F}{R_1}V_1 + \frac{R_F}{R_2}V_2\right] = -\left[\frac{470\text{ k}\Omega}{47\text{ k}\Omega}(40\text{ mV}) + \frac{470\text{ k}\Omega}{12\text{ k}\Omega}(20\text{ mV})\right]$$
$= -[400\text{ mV} + 783.3\text{ mV}] = \mathbf{-1.18\ V}$

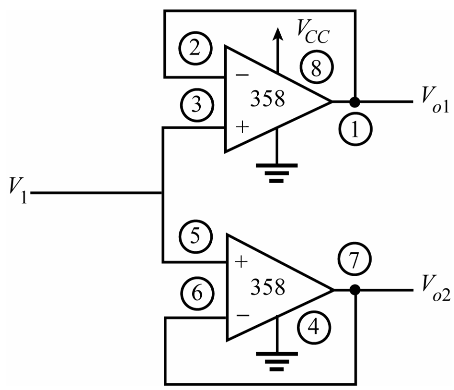
7. $$V_o = \left(\frac{10\text{ k}\Omega}{10\text{ k}\Omega + 10\text{ k}\Omega}\right)\left(\frac{150\text{ k}\Omega + 300\text{ k}\Omega}{150\text{ k}\Omega}\right)V_1 - \frac{300\text{ k}\Omega}{150\text{ k}\Omega}V_2$$
$= 0.5(3)(1\text{ V}) - 2(2\text{ V}) = 1.5\text{ V} - 4\text{ V} = \mathbf{-2.5\ V}$

8. $$V_o = -\left\{\left[\frac{330\text{ k}\Omega}{33\text{ k}\Omega}(12\text{ mV})\right]\left(\frac{470\text{ k}\Omega}{47\text{ k}\Omega}\right) + \frac{470\text{ k}\Omega}{47\text{ k}\Omega}(18\text{ mV})\right\}$$
$= -[(-120\text{ mV})(10) + 180\text{ mV}] = -[-1.2\text{ V} + 0.18\text{ V}]$
$= \mathbf{+1.02\ V}$

9.



10.



11. $$I_L = \frac{V_1}{R_1} = \frac{12\text{ V}}{2\text{ k}\Omega} = \mathbf{6\ mA}$$

12. $V_o = -I_1R_1 = -(2.5\text{ mA})(10\text{ k}\Omega) = \mathbf{-25\ V}$

13. $$\frac{I_o}{V_1} = \frac{R_F}{R_1}\left(\frac{1}{R_s}\right)$$
$$I_o = \frac{100\text{ k}\Omega}{200\text{ k}\Omega}\left(\frac{1}{10\ \Omega}\right)(10\text{ mV}) = \mathbf{0.5\ mA}$$

14. $$V_o = \left(1 + \frac{2R}{R_p}\right)[V_2 - V_1]$$
$$= \left(1 + \frac{2(5000)}{1000}\right)[1\text{ V} - 3\text{ V}] = \mathbf{-22\ V}$$

15. $$f_{OH} = \frac{1}{2\pi R_1 C_1} = \frac{1}{2\pi(2.2\text{ k}\Omega)(0.05\ \mu\text{F})}$$
$$= \mathbf{1.45\ kHz}$$

16. $$f_{OL} = \frac{1}{2\pi R_1 C_1} = \frac{1}{2\pi(20\text{ k}\Omega)(0.02\ \mu\text{F})}$$
$$= \mathbf{397.9\ Hz}$$

17. $$f_{OL} = \frac{1}{2\pi R_1 C_1} = \frac{1}{2\pi(10\text{ k}\Omega)(0.05\ \mu\text{F})} = \mathbf{318.3\ Hz}$$
$$f_{OH} = \frac{1}{2\pi R_2 C_2} = \frac{1}{2\pi(20\text{ k}\Omega)(0.02\ \mu\text{F})}$$
$$= \mathbf{397.9\ Hz}$$

Chapter 12

1. $I_{B_Q} = \dfrac{V_{CC} - V_{BE}}{R_B} = \dfrac{18\text{ V} - 0.7\text{ V}}{1.2\text{ k}\Omega}$ = 14.42 mA

$I_{C_Q} = \beta I_{B_Q}$ = 40(14.42 mA) = 576.67 mA

$P_i = V_{CC} I_{\text{dc}} \cong V_{CC} I_{C_Q}$ = (18 V)(576.67 mA)

$\cong$ **10.4 W**

I_C(rms) = βI_B(rms)

= 40(5 mA) = 200 mA

$P_o = I_C^2(\text{rms}) R_C$ = (200 mA)^2(16 Ω) = **640 mW**

2. $I_{B_Q} = \dfrac{V_{CC} - V_{BE}}{R_B} = \dfrac{18\text{ V} - 0.7\text{ V}}{1.5\text{ k}\Omega}$ = 11.5 mA

$I_{C_Q} = \beta I_{B_Q}$ = 40(11.5 mA) = 460 mA

P_i(dc) = $V_{CC} I_{\text{dc}} = V_{CC}\left(I_{C_Q} + I_{B_Q}\right)$

= 18 V(460 mA + 11.5 mA)

= **8.5 W**

$\left[P_i \approx V_{CC} I_{C_Q} = 18\text{ V}(460\text{ mA}) = 8.3\text{ W}\right]$

3. From problem 2: I_{C_Q} = 460 mA, P_i = 8.3 W.

For maximum efficiency of 25%:

$\%\eta = 100\% \times \dfrac{P_o}{P_i} = \dfrac{P_o}{8.3\text{ W}} \times 100\% = 25\%$

P_o = 0.25(8.3 W) = **21 W**

[If dc bias condition also is considered:

$V_C = V_{CC} - I_{C_Q} R_C$ = 18 V − (460 mA)(16 Ω) = 10.64 V

collector may vary ±7.36 V about Q-point, resulting in maximum output power:

$P_o = \dfrac{V_{CE}^2(P)}{2R_C} = \dfrac{(7.36\text{ V})^2}{2(16)} = \mathbf{1.69\ W}$

4. Assuming maximum efficiency of 25%
with P_o(max) = 1.5 W

$$\%\eta = \frac{P_o}{P_i} \times 100\%$$

$$P_i = \frac{1.5\text{ W}}{0.25} = 6\text{ W}$$

Assuming dc bias at mid-point, $V_C = 9$ V

$$I_{C_Q} = \frac{V_{CC} - V_C}{R_C} = \frac{18\text{ V} - 9\text{ V}}{16\ \Omega} = 0.5625\text{ A}$$

$$P_i(\text{dc}) = V_{CC} I_{C_Q} = (18\text{ V})(0.5625\text{ A})$$

$$= \mathbf{10.38\ W}$$

at this input:

$$\%\eta = \frac{P_o}{P_i} \times 100\% = \frac{1.5\text{ W}}{10.38\text{ W}} \times 100\% = \mathbf{14.45\%}$$

5. $$R_p = \left(\frac{N_1}{N_2}\right)^2 R_s = \left(\frac{25}{1}\right)^2 (4\ \Omega) = \mathbf{2.5\ k\Omega}$$

6. $R_2 = a^2 R_1$

$$a^2 = \frac{R_2}{R_1} = \frac{8\text{ k}\Omega}{8\ \Omega} = 1000$$

$$a = \sqrt{1000} = \mathbf{31.6}$$

7. $R_2 = a^2 R_1$
$8\text{ k}\Omega = a^2(4\ \Omega)$

$$a^2 = \frac{8\text{ k}\Omega}{4\ \Omega} = 2000$$

$$a = \sqrt{2000} = \mathbf{44.7}$$

8. (a) $P_{pri} = P_L = \mathbf{2\ W}$

(b) $P_L = \dfrac{V_L^2}{R_L}$

$$V_L = \sqrt{P_L R_L} = \sqrt{(2\text{ W})(16\ \Omega)}$$

$$= \sqrt{32} = \mathbf{5.66\ V}$$

(c) $R_2 = a^2 R_1 = (3.87)^2(16\ \Omega) = \mathbf{239.6\ \Omega}$

$$P_{pri} = \frac{V_{pri}^2}{R_{pri}} = 2\text{ W}$$

$$V_{pri}^2 = (2\text{ W})(239.6\ \Omega)$$

$$V_{pri} = \sqrt{479.2} = \mathbf{21.89\ V}$$

[or, $V_{pri} = aV_L = (3.87)(5.66\text{ V}) = 21.9$ V]

(d) $P_L = I_L^2 R_L$

$$I_L = \sqrt{\frac{P_L}{R_L}} = \sqrt{\frac{2\text{ W}}{16\ \Omega}} = \mathbf{353.55\ mA}$$

$$P_{pri} = 2\text{ W} = I_{pri}^2 R_{pri} = (239.6\ \Omega)\, I_{pri}^2$$

$$I_{pri} = \sqrt{\frac{2\text{ W}}{239.6\ \Omega}} = \mathbf{91.36\ mA}$$

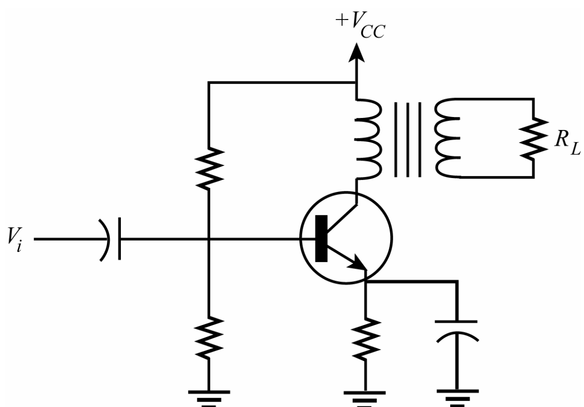
$$\text{or, } I_{pri} = \frac{I_L}{a} = \frac{353.55\text{ mA}}{3.87} = \mathbf{91.36\ mA}$$

9. $I_{dc} = I_{C_Q} = 150\text{ mA}$

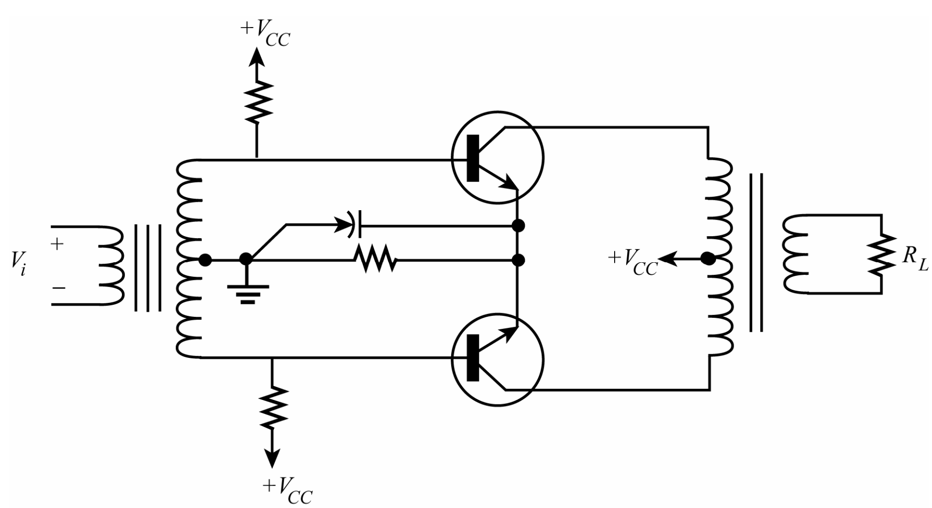
$$P_i = V_{CC} I_{C_Q} = (36\text{ V})(150\text{ mA}) = 5.4\text{ W}$$

$$\%\eta = \frac{P_o}{P_i} \times 100\% = \frac{2\text{ W}}{5.4\text{ W}} \times 100\% = \mathbf{37\%}$$

10.



11.



12. (a) $P_i = V_{CC}I_{dc} = (25\text{ V})(1.75\text{ A}) = \mathbf{43.77\ W}$

Where, $I_{dc} = \dfrac{2}{\pi}I_p = \dfrac{2}{\pi}\dfrac{V_p}{R_L} = \dfrac{2}{\pi}\cdot\dfrac{22\text{ V}}{8\ \Omega} = 1.75\text{ A}$

(b) $P_o = \dfrac{V_p^2}{2R_L} = \dfrac{(22\text{ V})^2}{2(8\ \Omega)} = \mathbf{30.25\ W}$

(c) $\%\eta = \dfrac{P_o}{P_i} \times 100\% = \dfrac{30.75\text{ W}}{43.77\text{ W}} \times 100\% = \mathbf{69\%}$

13. (a) $\max P_i = V_{CC}I_{dc}$

$= V_{CC}\cdot\left(\dfrac{2}{\pi}\cdot\dfrac{V_{CC}}{R_L}\right) = (25\text{ V})\left[\dfrac{2}{\pi}\cdot\dfrac{25\text{ V}}{8\ \Omega}\right]$

$= \mathbf{49.74\ W}$

(b) $\max P_o = \dfrac{V_{CC}^2}{2R_L} = \dfrac{(25\text{ V})^2}{2(8\ \Omega)} = \mathbf{39.06\ W}$

(c) $\max \%\eta = \dfrac{\max P_o}{\max P_i}\times 100\% = \dfrac{39.06\text{ W}}{49.74\text{ W}} \times 100\%$

$= \mathbf{78.5\%}$

14. (a) $V_{L_{\text{(peak)}}} = 20\text{ V}$

$P_i = V_{CC}I_{dc} = V_{CC}\left[\dfrac{2}{\pi}\cdot\dfrac{V_L}{R_L}\right]$

$= (22\text{ V})\left[\dfrac{2}{\pi}\cdot\dfrac{20\text{ V}}{4\ \Omega}\right] = 70\text{ W}$

$P_o = \dfrac{V_L^2}{2R_L} = \dfrac{(20\text{ V})^2}{2(4\ \Omega)} = 50\text{ W}$

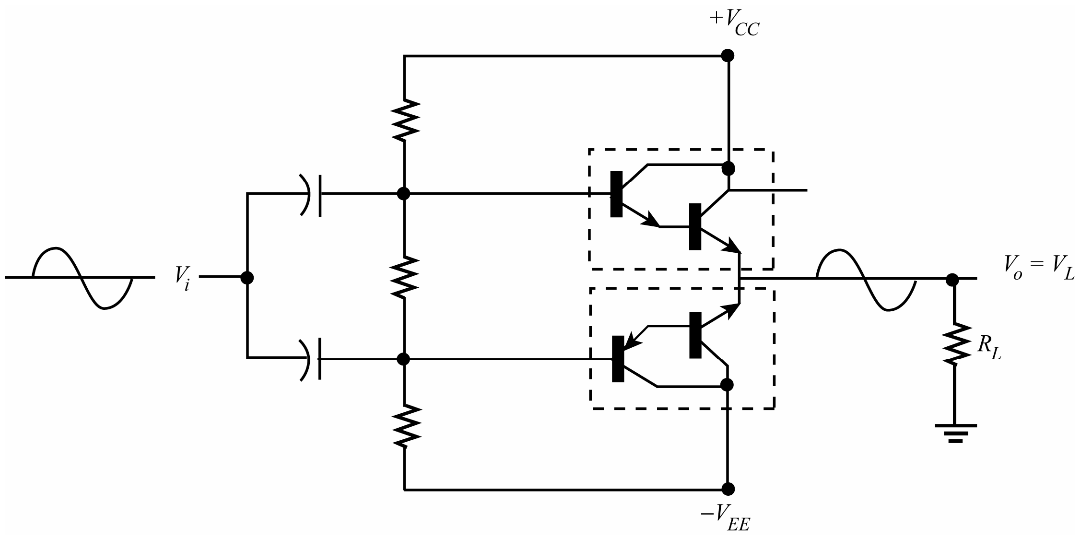
$\%\eta = \dfrac{P_o}{P_i} \times 100\% = \dfrac{50\text{ W}}{70\text{ W}} \times 100\% = \mathbf{71.4\%}$

(b) $P_i = (22\text{ V})\left[\dfrac{2}{\pi}\cdot\dfrac{4\text{ V}}{4\ \Omega}\right] = 14\text{ W}$

$P_o = \dfrac{(4)^2}{2(4)} = 2\text{ W}$

$\%\eta = \dfrac{P_o}{P_i} \times 100\% = \dfrac{2\text{ W}}{14\text{ W}} \times 100\% = \mathbf{14.3\%}$

15.



16. (a) max P_o(ac) for $V_{L_{\text{peak}}} = 30$ V:

$$\max P_o(\text{ac}) = \frac{V_L^2}{2R_L} = \frac{(30\text{ V})^2}{2(8\ \Omega)} = \mathbf{56.25\ W}$$

(b) $$\max P_i(\text{dc}) = V_{CC}I_{\text{dc}} = V_{CC}\left[\frac{2}{\pi}\cdot\frac{V_o}{R_L}\right] = V_{CC}\left[\frac{2}{\pi}\cdot\frac{30\text{ V}}{8\ \Omega}\right] = \mathbf{71.62\ W}$$

(c) $$\max \%\eta = \frac{\max P_o}{\max P_i} \times 100\% = \frac{56.25\text{ W}}{71.62\text{ W}} \times 100\%$$
$$= \mathbf{78.54\%}$$

(d) $$\max P_{Z_Q} = \frac{2}{\pi^2}\cdot\frac{V_{CC}^2}{R_L} = \frac{2}{\pi^2}\cdot\frac{(30)^2}{8} = \mathbf{22.8\ W}$$

17. (a) $$P_i(\text{dc}) = V_{CC}I_{\text{dc}} = V_{CC}\cdot\frac{2}{\pi}\left(\frac{V_o}{R_L}\right)$$
$$= 30\text{ V}\cdot\frac{2}{\pi}\left[\frac{\sqrt{2}\cdot 8}{8}\right] = \mathbf{27\ W}$$

(b) $$P_o(\text{ac}) = \frac{V_L^2(\text{rms})}{R_L} = \frac{(8\text{ V})^2}{8\ \Omega} = \mathbf{8\ W}$$

(c) $$\%\eta = \frac{P_o}{P_i}\times 100\% = \frac{8\text{ W}}{27\text{ W}} \times 100\% = \mathbf{29.6\%}$$

(d) $P_{2Q} = P_i - P_o = 27\text{ W} - 8\text{ W} = \mathbf{19\ W}$

18. (a) $P_o(\text{ac}) = \dfrac{V_L^2(\text{rms})}{R_L} = \dfrac{(18\text{ V})^2}{8\ \Omega} = \mathbf{40.5\ W}$

(b) $P_i(\text{dc}) = V_{CC}I_{\text{dc}} = V_{CC}\left[\dfrac{2}{\pi}\cdot\dfrac{V_{L_{\text{peak}}}}{R_L}\right]$

$$= (40\text{ V})\left[\frac{2}{\pi}\cdot\frac{18\sqrt{2}\text{ V}}{8\ \Omega}\right] = \mathbf{81\ W}$$

(c) $\%\eta = \dfrac{P_o}{P_i} \times 100\% = \dfrac{40.5\text{ W}}{81\text{ W}} \times 100\% = \mathbf{50\%}$

(d) $P_{2_Q} = P_i - P_o = 81\text{ W} - 40.5\text{ W} = \mathbf{40.5\ W}$

19. $\%D_2 = \left|\dfrac{A_2}{A_1}\right| \times 100\% = \left|\dfrac{0.3\text{ V}}{2.1\text{ V}}\right| \times 100\% \cong \mathbf{14.3\%}$

$\%D_3 = \left|\dfrac{A_3}{A_1}\right| \times 100\% = \dfrac{0.1\text{ V}}{2.1\text{ V}} \times 100\% \cong \mathbf{4.8\%}$

$\%D_4 = \left|\dfrac{A_4}{A_1}\right| \times 100\% = \dfrac{0.05\text{ V}}{2.1\text{ V}} \times 100\% \cong \mathbf{2.4\%}$

20. $\%THD = \sqrt{D_2^2 + D_3^2 + D_4^2} \times 100\%$

$= \sqrt{(0.143)^2 + (0.048)^2 + (0.024)^2} \times 100\%$

$= \mathbf{15.3\%}$

21. $$D_2 = \left|\frac{\frac{1}{2}\left(V_{CE_{\max}} + V_{CE_{\min}}\right)}{V_{CE_{\max}} - V_{CE_{\min}}}\right| \times 100\%$$

$$= \left|\frac{\frac{1}{2}(20\text{ V} + 2.4\text{ V}) - 10\text{ V}}{20\text{ V} - 2.4\text{ V}}\right| \times 100\%$$

$$= \frac{1.2\text{ V}}{17.6\text{ V}} \times 100\% = \mathbf{6.8\%}$$

22. $THD = \sqrt{D_2^2 + D_3^2 + D_4^2} = \sqrt{(0.15)^2 + (0.01)^2 + (0.05)^2}$

$\cong 0.16$

$P_1 = \dfrac{I_1^2 R_C}{2} = \dfrac{(3.3\text{ A})^2(4\ \Omega)}{2} = \mathbf{21.8\ W}$

$P = (1 + THD^2)P_1 = [1 + (0.16)^2)]21.8\text{ W}$

$= \mathbf{22.36\ W}$

23. $P_D\,(150°\text{C}) = P_D(25°\text{C}) - (T_{150} - T_{25})\text{ (Derating Factor)}$

$= 100\text{ W} - (150°\text{C} - 25°\text{C})(0.6\text{ W/°C})$

$= 100\text{ W} - 125(0.6) = 100 - 75$

$=$ **25 W**

24. $$P_D = \frac{T_J - T_A}{\theta_{JC} + \theta_{CS} + \theta_{SA}} = \frac{200°\text{C} - 80°\text{C}}{0.5\text{ °C/W} + 0.8\text{ °C/W} + 1.5\text{ °C/W}}$$

$$= \frac{120°\text{C}}{2.8\text{ °C/W}} = \mathbf{42.9\text{ W}}$$

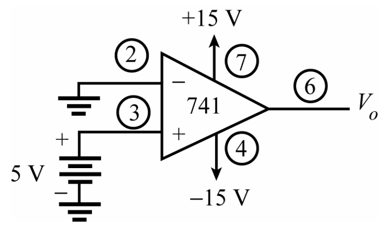
25. $$P_D = \frac{T_J - T_A}{\theta_{JA}}$$

$$= \frac{200°\text{C} - 80°\text{C}}{(40°\text{C/W})} = \frac{120°\text{C}}{40°\text{C/W}}$$

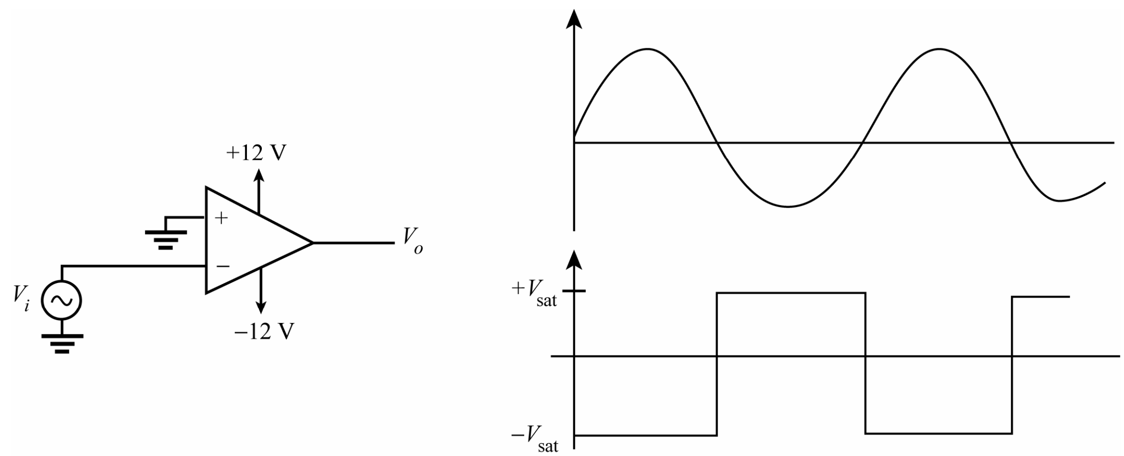
$=$ **3 W**

Chapter 13

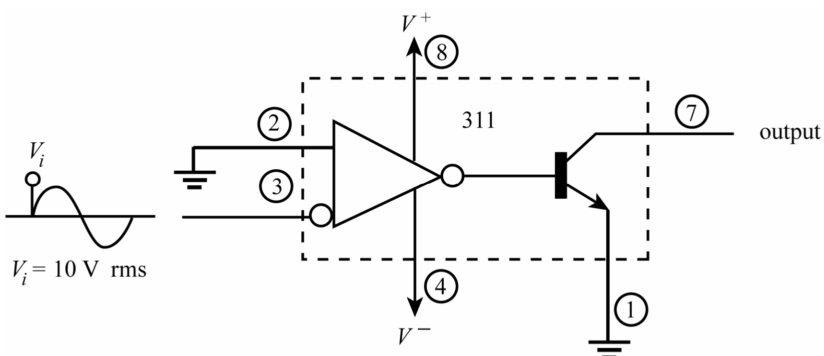
1.



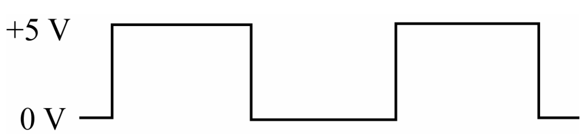
2.



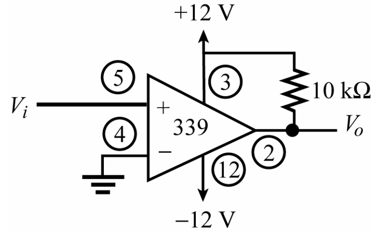
3.

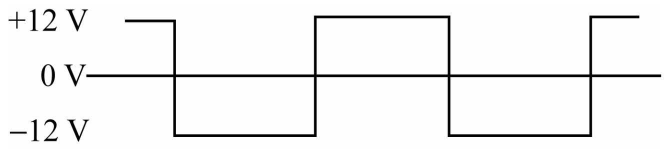


4.



5.



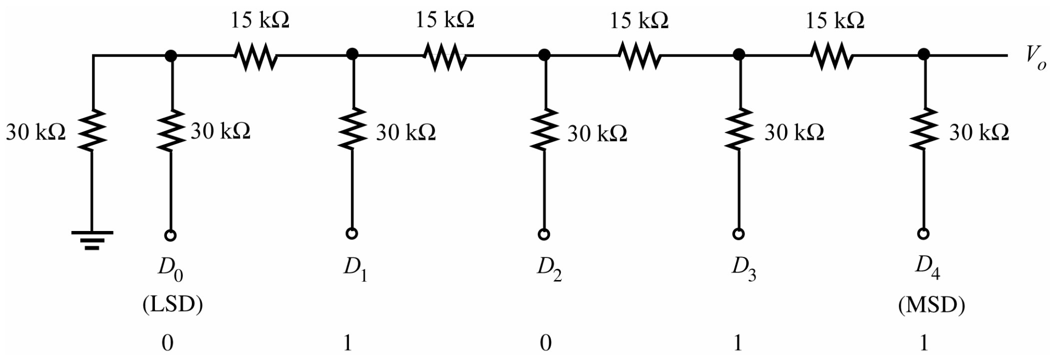
6. 

7. Circuit operates as a window detector.

Output goes *low* for input *above* $\dfrac{9.1\text{ k}\Omega}{9.1\text{ k}\Omega + 6.2\text{ k}\Omega}(+12\text{ V}) = \mathbf{7.1\ V}$

Output goes *low* for input *below* $\dfrac{1\text{ k}\Omega}{1\text{ k}\Omega + 6.2\text{ k}\Omega}(+12\text{ V}) = \mathbf{1.7\ V}$

Output is *high* for input between +1.7 V and +7.1 V.

8. 

9. $$\frac{11010}{2^5}(16\text{ V}) = \frac{26}{32}(16\text{ V}) = \mathbf{13\ V}$$

10. Resolution $= \dfrac{V_{REF}}{2^n} = \dfrac{10\text{ V}}{2^{12}} = \dfrac{10\text{ V}}{4096} = \mathbf{2.4\ mV/count}$

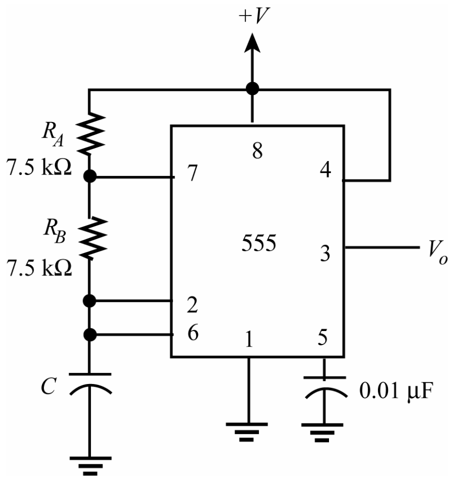
11. See section 13.3.

12. Maximum number of count steps = 2^{12} = **4096**

13. $2^{12} = 4096$ steps at $T = \dfrac{1}{f} = \dfrac{1}{20\text{ MHz}} = 50\text{ ns/count}$

Period = 4096 counts × $50\dfrac{\text{ns}}{\text{count}} = \mathbf{204.8\ \mu s}$

14.

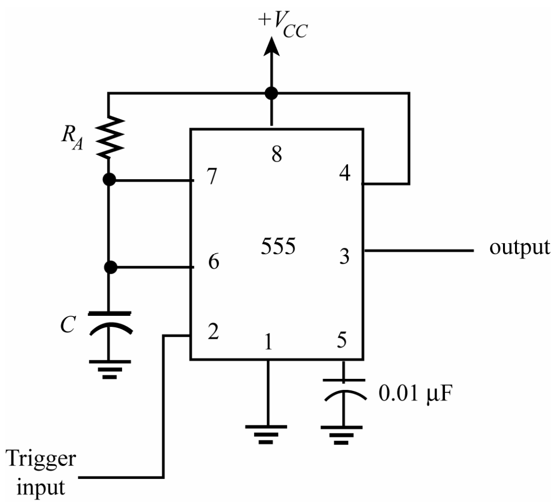


$$f = \frac{1.44}{(R_A + 2R_B)C} = 350 \text{ kHz}$$

$$C = \frac{1.44}{7.5 \text{ k}\Omega + 2(7.5 \text{ k}\Omega)(350 \text{ kHz})}$$

$\cong$ **183 pF**

15.



$T = 1.1\, R_A C$

$20\ \mu s = 1.1(7.5 \text{ k}\Omega)C$

$$C = \frac{20 \times 10^{-6}}{1.1(7.5 \times 10^{3})}$$

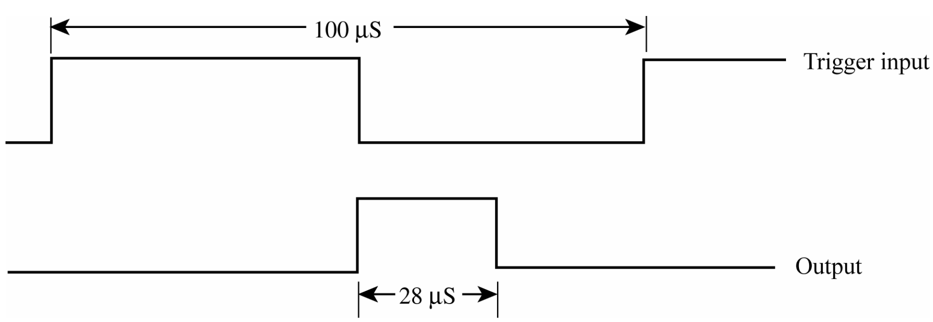
$= 2.4 \times 10^{-9}$

$= 2400 \times 10^{-12}$

$=$ **2400 pF**

16. $$T = \frac{1}{f} = \frac{1}{10 \text{ kHz}} = 100\ \mu s$$

$T = 1.1\, R_A C = 1.1(5.1 \text{ k}\Omega)(5 \text{ nF}) =$ **28 μs**



17. $f_o = \dfrac{2}{R_1C_1}\left(\dfrac{V^+ - V_C}{V^+}\right)$

$V^+ = 12\text{ V}$

$V_C = \dfrac{R_3}{R_2 + R_3}(V^+) = \dfrac{11\text{ k}\Omega}{1.8\text{ k}\Omega + 11\text{ k}\Omega}(+12\text{ V}) = 10.3\text{ V}$

$f_o = \dfrac{2}{(4.7\text{ k}\Omega)(0.001\ \mu\text{F})}\left[\dfrac{12\text{ V} - 10.3\text{ V}}{12\text{ V}}\right]$

$= 60.3 \times 10^3 \cong$ **60 kHz**

18. With potentiometer set at top:

$V_C = \dfrac{R_3 + R_4}{R_2 + R_3 + R_4}V^+ = \dfrac{5\text{ k}\Omega + 18\text{ k}\Omega}{510\ \Omega + 5\text{ k}\Omega + 18\text{ k}\Omega}(12\text{ V}) = 11.74\text{ V}$

resulting in a lower cutoff frequency of

$f_o = \dfrac{2}{R_1C_1}\left(\dfrac{V^+ - V_C}{V^+}\right) = \dfrac{2}{(10\times 10^3)(0.001\ \mu\text{F})}\left(\dfrac{12\text{ V} - 11.74\text{ V}}{12\text{ V}}\right)$

$=$ **4.3 kHz**

With potentiometer set at bottom:

$V_C = \dfrac{R_4}{R_2 + R_3 + R_4}V^+ = \dfrac{18\text{ k}\Omega}{510\ \Omega + 5\text{ k}\Omega + 18\text{ k}\Omega}(12\text{ V})$

$= 9.19\text{ V}$

resulting in a higher cutoff frequency of

$f_o = \dfrac{2}{R_1C_1}\left(\dfrac{V^+ - V_C}{V^+}\right) = \dfrac{2}{(10\text{ k}\Omega)(0.001\ \mu\text{F})}\left[\dfrac{12\text{ V} - 9.19\text{ V}}{12\text{ V}}\right]$

$=$ **61.2 kHz**

19. $V^+ = 12\text{ V}$

$V_C = \dfrac{R_3}{R_2 + R_3}V^+ = \dfrac{10\text{ k}\Omega}{1.5\text{ k}\Omega + 10\text{ k}\Omega}(12\text{ V}) = 10.4\text{ V}$

$f_o = \dfrac{2}{R_1C_1}\left(\dfrac{V^+ - V_C}{V^+}\right) = \dfrac{2}{10\text{ k}\Omega(C_1)}\left(\dfrac{12\text{ V} - 10.4\text{ V}}{12\text{ V}}\right)$

$= 200\text{ kHz}$

$C_1 = \dfrac{2}{10\text{ k}\Omega(200\text{ kHz})}(0.133)$

$= 133 \times 10^{-12} =$ **133 pF**

20. $f_o = \dfrac{0.3}{R_1C_1} = \dfrac{0.3}{(4.7\text{ k}\Omega)(0.001\ \mu\text{F})}$

$=$ **63.8 kHz**

21. $C_1 = \dfrac{0.3}{R_1 f} = \dfrac{0.3}{(10\text{ k}\Omega)(100\text{ kHz})} =$ **300 pF**

22. $f_L = \pm\frac{8f_o}{V}$

$= \pm\frac{8(63.8\times10^3)}{6\text{ V}}$ $\left[f_o = \frac{0.3}{R_1C_1} = \frac{0.3}{4.7\text{ k}\Omega(0.001\ \mu\text{F})}\right]$

= **85.1 kHz** $= 63.8$ kHz

23. For current loop: mark = 20 mA
space = 0 mA

For $RS-232\ C$: mark = −12 V
space = +12 V

24. A line (or lines) onto which data bits are connected.

25. Open-collector is active-LOW only.
Tri-state is active-HIGH or active-LOW.

Chapter 14

1. $$A_f = \frac{A}{1+\beta A} = \frac{-2000}{1+\left(-\frac{1}{10}\right)(-2000)} = \frac{-2000}{201} = \mathbf{-9.95}$$

2. $$\frac{dA_f}{A_f} = \frac{1}{\beta A}\frac{dA}{A} = \frac{1}{\left(-\frac{1}{20}\right)(-1000)}(10\%) = \mathbf{0.2\%}$$

3. $$A_f = \frac{A}{1+\beta A} = \frac{-300}{1+\left(-\frac{1}{15}\right)(-300)} = \frac{-300}{21} = \mathbf{-14.3}$$

$R_{if} = (1 + \beta A)R_i = 21(1.5\ \text{k}\Omega) = \mathbf{31.5\ k\Omega}$

$$R_{of} = \frac{R_o}{1+\beta A} = \frac{50\ \text{k}\Omega}{21} = \mathbf{2.4\ k\Omega}$$

4. $$R_L = \frac{R_o R_D}{R_o + R_D} = 40\ \text{k}\Omega \parallel 8\ \text{k}\Omega = 6.7\ \text{k}\Omega$$

$A = -g_m R_L = -(5000 \times 10^{-6})(6.7 \times 10^3) = \mathbf{-33.5}$

$$\beta = \frac{-R_2}{R_1 + R_2} = \frac{-200\ \text{k}\Omega}{200\ \text{k}\Omega + 800\ \text{k}\Omega} = \mathbf{-0.2}$$

$$A_f = \frac{A}{1+\beta A} = \frac{-33.5}{1+(-0.2)(-33.5)} = \frac{-33.5}{7.7}$$

$= \mathbf{-4.4}$

5. DC bias:

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta+1)R_E} = \frac{16\ \text{V} - 0.7\ \text{V}}{600\ \text{k}\Omega + 76(1.2\ \text{k}\Omega)}$$

$$= \frac{15.3\ \text{V}}{691.2\ \text{k}\Omega} = 22.1\ \mu\text{A}$$

$I_E = (1 + \beta)I_B$

$= 76(22.1\ \mu\text{A}) = 1.68\ \text{mA}$

$[V_{CE} = V_{CC} - I_C(R_C + R_E) = 16\ \text{V} - 1.68\ \text{mA}(4.7\ \text{k}\Omega + 1.2\ \text{k}\Omega) \cong 6.1\ \text{V}]$

$$r_e = \frac{26\ \text{mV}}{I_E(\text{mA})} = \frac{26\ \text{mV}}{1.68\ \text{mA}} \cong 15.5\ \Omega$$

$h_{ie} = (1 + \beta)r_e = 76(15.5\ \Omega) = \mathbf{1.18\ k\Omega} = Z_i$

$Z_o = R_C = \mathbf{4.7\ k\Omega}$

$$A_v = \frac{-h_{fe}}{h_{ie} + R_E} = \frac{-75}{1.18\ \text{k}\Omega + 1.2\ \text{k}\Omega} = -31.5 \times 10^{-3}$$

$\beta = R_E = -1.2 \times 10^3$

$(1 + \beta A) = 1 + (-1.2 \times 10^3)(-31.5 \times 10^{-3})$

$= 38.8$

$$A_f = \frac{A_v}{1 + \beta A_v} = \frac{-31.5 \times 10^{-3}}{38.8} = 811.86 \times 10^{-6}$$

$A_{v_f} = -A_f R_C = -(811.86 \times 10^{-6})(4.7 \times 10^3) = \mathbf{-3.82}$

$Z_{i_f} = (1 + \beta A_v)Z_i = (38.8)(1.18\ \text{k}\Omega) = \mathbf{45.8\ k\Omega}$

$Z_{o_f} = (1 + \beta A_v)Z_o = (38.8)(4.7\ \text{k}\Omega) = \mathbf{182.4\ k\Omega}$

without feedback (R_E bypassed):

$$A_v = \frac{-R_C}{r_e} = -\frac{4.7\ \text{k}\Omega}{15.5\ \Omega} = \mathbf{-303.2}$$

6. $$C = \frac{1}{2\pi Rf\sqrt{6}} = \frac{1}{2\pi(10 \times 10^3)(2.5 \times 10^3)\sqrt{6}}$$

$= 2.6 \times 10^{-9} = \mathbf{2600\ pF} = 0.0026\ \mu\text{F}$

7. $$f_o = \frac{1}{2\pi RC} \cdot \frac{1}{\sqrt{6 + 4\left(\frac{R_c}{R}\right)}}$$

$$= \frac{1}{2\pi(6 \times 10^3)(1500 \times 10^{-12})} \cdot \frac{1}{\sqrt{6 + 4(18 \times 10^3 / 6 \times 10^3)}}$$

$= 4.17\ \text{kHz} \cong \mathbf{4.2\ kHz}$

8. $$f_o = \frac{1}{2\pi RC} = \frac{1}{2\pi(10 \times 10^3)(2400 \times 10^{-12})}$$

$= \mathbf{6.6\ kHz}$

9. $$C_{\text{eq}} = \frac{C_1 C_2}{C_1 + C_2} = \frac{(750\ \text{pF})(2000\ \text{pF})}{750\ \text{pF} + 2000\ \text{pF}} = 577\ \text{pF}$$

$$f_o = \frac{1}{2\pi\sqrt{LC_{\text{eq}}}} = \frac{1}{2\pi\sqrt{40 \times 10^{-6})(577 \times 10^{-12})}}$$

$= \mathbf{1.05\ MHz}$

10. $$f_o = \frac{1}{2\pi\sqrt{LC_{\text{eq}}}},$$

$$= \frac{1}{2\pi\sqrt{(100\mu\text{H})(3300\ \text{pF})}}$$

$= \mathbf{277\ kHz}$

where $$C_{\text{eq}} = \frac{C_1 C_2}{C_1 + C_2}$$

$$= \frac{(0.005\ \mu\text{F})(0.01\ \mu\text{F})}{0.005\ \mu\text{F} + 0.01\ \mu\text{F}}$$

$= 3300\ \text{pF}$

11. $f_o = \dfrac{1}{2\pi\sqrt{L_{eq}C}}$,

$= \dfrac{1}{2\pi\sqrt{(4\times10^{-3})(250\times10^{-12})}}$

$=$ **159.2 kHz**

$L_{eq} = L_1 + L_2 + 2\text{ M}$
$= 1.5\text{ mH} + 1.5\text{ mH} + 2(0.5\text{ mH})$
$= 4\text{ mH}$

12. $f_o = \dfrac{1}{2\pi\sqrt{LC_{eq}}}$,

$= \dfrac{1}{2\pi\sqrt{(1800\,\mu\text{H})(150\text{ pF})}}$

$= 306.3\text{ kHz}$

where $L_{eq} = L_1 + L_2 + 2\text{ M}$
$= 750\ \mu\text{H} + 750\ \mu\text{H} + 2(150\ \mu\text{H})$
$= 1800\ \mu\text{H}$

13. See Fig. 14.33a and Fig. 14.34.

14. $f_o = \dfrac{1}{R_T C_T \ln(1/(1-\eta))}$

for $\eta = 0.5$:

$f_o \cong \dfrac{1.5}{R_T C_T}$

(a) Using $R_T = 1\text{ k}\Omega$

$C_T = \dfrac{1.5}{R_T f_o} = \dfrac{1.5}{(1\text{ k}\Omega)(1\text{ kHz})}$ = **1.5 μF**

(b) Using $R_T = 10\text{ k}\Omega$

$C_T = \dfrac{1.5}{R_T f_o} = \dfrac{1.5}{(10\text{ k}\Omega)(150\text{ kHz})}$ = **1000 pF**

Chapter 15

1. ripple factor = $\dfrac{V_r(\text{rms})}{V_{\text{dc}}} = \dfrac{2\text{ V}/\sqrt{2}}{50\text{ V}}$ = **0.028**

2. $\%VR = \dfrac{V_{NL} - V_{FL}}{V_{FL}} \times 100\% = \dfrac{28\text{ V} - 25\text{ V}}{25\text{ V}} \times 100\%$ = **12%**

3. $V_{\text{dc}} = 0.318V_m$
   $V_m = \dfrac{V_{\text{dc}}}{0.318} = \dfrac{20\text{ V}}{0.318} = 62.89\text{ V}$
   $V_r = 0.385V_m = 0.385(62.89\text{ V})$ = **24.2 V**

4. $V_{\text{dc}} = 0.636V_m$
   $V_m = \dfrac{V_{\text{dc}}}{0.636} = \dfrac{8\text{ V}}{0.636} = 12.6\text{ V}$
   $V_r = 0.308V_m = 0.308(12.6\text{ V})$ = **3.88 V**

5. $\%r = \dfrac{V_r(\text{rms})}{V_{\text{dc}}} \times 100\%$

   $V_r(\text{rms}) = rV_{\text{dc}} = \dfrac{8.5}{100} \times 14.5\text{ V}$ = **1.2 V**

6. $V_{NL} = V_m = 18\text{ V}$
   $V_{FL} = 17\text{ V}$
   $$\%VR = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\% = \frac{18\text{ V} - 17\text{ V}}{17\text{ V}} \times 100\%$$
   = **5.88%**

7. $V_m = 18\text{ V}$
   $C = 400\ \mu\text{F}$
   $I_L = 100\text{ mA}$

   $V_r = \dfrac{2.4I_{\text{dc}}}{C} = \dfrac{2.4(100)}{400} = 0.6\text{ V, rms}$

   $V_{\text{dc}} = V_m - \dfrac{4.17I_{\text{dc}}}{C}$

   $= 18\text{ V} - \dfrac{4.17(100)}{400}$ = **16.96 V**

   ≅ **17 V**

8. $V_r = \dfrac{2.4I_{\text{dc}}}{C} = \dfrac{2.4(120)}{200}$ = **1.44 V**

9. $\left.\begin{array}{l} C = 100\ \mu\text{F} \\ V_{\text{dc}} = 12\text{ V} \\ R_L = 2.4\text{ k}\Omega \end{array}\right\} I_{\text{dc}} = \dfrac{V_{\text{dc}}}{R_L} = \dfrac{12\text{ V}}{2.4\text{ k}\Omega} = 5\text{ mA}$

   $V_r(\text{rms}) = \dfrac{2.4I_{\text{dc}}}{C} = \dfrac{2.4(5)}{100}$ = **0.12 V**

10. $C = \dfrac{2.4 I_{dc}}{r V_{dc}} = \dfrac{2.4(150)}{(0.15)(24)}$ = **100 μF**

11. $C = 500\ \mu$F
$I_{dc} = 200$ mA
$R = 8\% = 0.08$

Using $r = \dfrac{2.4 I_{dc}}{C V_{dc}}$

$$V_{dc} = \frac{2.4 I_{dc}}{rC} = \frac{2.4(200)}{0.08(500)} = 12\text{ V}$$

$$V_m = V_{dc} + \frac{4.17 I_{dc}}{C} = 12\text{ V} + \frac{(200)(4.17)}{500}$$
$$= 12\text{ V} + 1.7\text{ V} = \mathbf{13.7\ V}$$

12. $C = \dfrac{2.4 I_{dc}}{V_r} = \dfrac{2.4(200)}{(0.07)}$ = **6857 μF**

13. $C = 120\ \mu$F
$I_{dc} = 80$ mA
$V_m = 25$ V

$$V_{dc} = V_m - \frac{4.17 I_{dc}}{C} = 25\text{ V} - \frac{4.17(80)}{120}$$
$$= 22.2\text{ V}$$

$$\%r = \frac{2.4 I_{dc}}{C V_{dc}} \times 100\% = \frac{2.4(80)}{(120)(22.2)} \times 100\%$$
$$= \mathbf{7.2\%}$$

14. $V_r' = \dfrac{r \cdot V_{dc}'}{100} = \dfrac{2(80)}{100}$ = **1.6 V, rms**

15. $V_r = 2$ V
$V_{dc} = 24$ V
***R* = 33 Ω, *C* = 120 μF**

$$\%r = \frac{V_r}{V_{dc}} \times 100\% = \frac{2\text{ V}}{24\text{ V}} \times 100\%$$
$$= \mathbf{8.3\%}$$

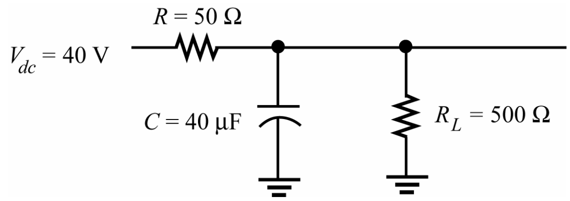
$$X_C = \frac{1.3}{C} = \frac{1.3}{120} = 10.8\ \Omega$$

$$V_r' = \frac{X_C}{R} V_r = \frac{10.8}{33}(2\text{ V}) = 0.65\text{ V}$$

$$V_{dc}' = V_{dc} - I_{dc}R = 24\text{ V} - 33\ \Omega\ (100\ \text{mA})$$
$$= 20.7\text{ V}$$

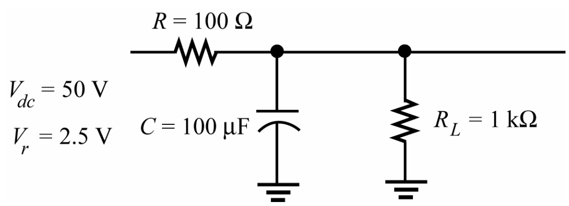
$$\%r' = \frac{V_r'}{V_{dc}'} \times 100\% = \frac{0.65\text{ V}}{20.7\text{ V}} \times 100\% = \mathbf{3.1\%}$$

16.



$$V'_{\text{dc}} = \frac{R_L}{R + R_L} V_{\text{dc}}$$
$$= \frac{500}{50 + 500}(40\text{ V})$$
$$= 36.4\text{ V}$$
$$I_{\text{dc}} = \frac{V'_{\text{dc}}}{R_L} = \frac{36.4\text{ V}}{500\ \Omega} = \mathbf{72.8\text{ mA}}$$

17.



$$X_C = \frac{1.3}{C} = \frac{1.3}{100} = 13\ \Omega$$
$$V'_r = \frac{X_C}{R} V_r = \frac{13}{100}(2.5\text{ V})$$
$$= \mathbf{0.325\text{ V, rms}}$$

18. $V_{NL} = 60\text{ V}$

$$V_{FL} = \frac{R_L}{R + R_L} V_{\text{dc}} = \frac{1\text{ k}\Omega}{100\ \Omega + 1\text{ k}\Omega}(50\text{ V}) = 45.46\text{ V}$$
$$\%VR = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\% = \frac{50\text{ V} - 45.46\text{ V}}{45.46\text{ V}} \times 100\%$$
$$= \mathbf{10\ \%}$$

19. $V_o = V_Z - V_{BE} = 8.3\text{ V} - 0.7\text{ V} = \mathbf{7.6\text{ V}}$

$V_{CE} = V_i - V_o = 15\text{ V} - 7.6\text{ V} = 7.4\text{ V}$

$$I_R = \frac{V_i - V_Z}{R} = \frac{15\text{ V} - 8.3\text{ V}}{1.8\text{ k}\Omega} = 3.7\text{ mA}$$
$$I_L = \frac{V_o}{R_L} = \frac{7.6\text{ V}}{2\text{ k}\Omega} = 3.8\text{ mA}$$
$$I_B = \frac{I_C}{\beta} = \frac{3.8\text{ mA}}{100} = 38\ \mu\text{A}$$

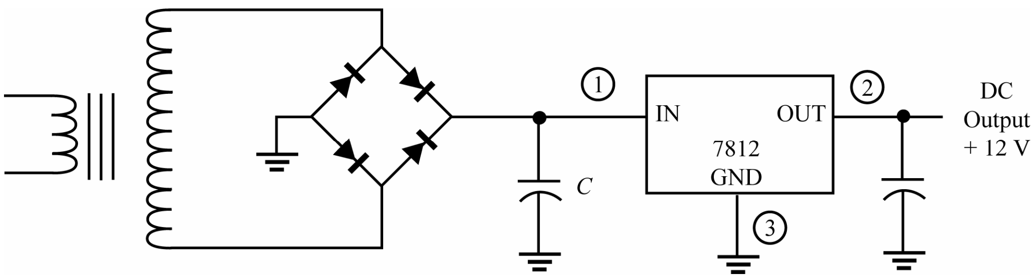
$I_Z = I_R - I_B = 3.7\text{ mA} - 38\ \mu\text{A} = \mathbf{3.66\text{ mA}}$

20. $$V_o = \frac{R_1 + R_2}{R_2}(V_z + V_{BE_2})$$
$$= \frac{33\text{ k}\Omega + 22\text{ k}\Omega}{22\text{ k}\Omega}(10\text{ V} + 0.7\text{ V})$$
$$= \mathbf{26.75\text{ V}}$$

21. $$V_o = \left(1 + \frac{R_1}{R_2}\right)V_Z = \left(1 + \frac{12\text{ k}\Omega}{8.2\text{ k}\Omega}\right)10\text{ V}$$
$$= \mathbf{24.6\text{ V}}$$

22. $V_o = V_L = 10\text{ V} + 0.7\text{ V} = \mathbf{10.7\text{ V}}$

23.



24. $I_L = 250\text{ mA}$
$V_m = V_r(\text{rms}) \cdot \sqrt{2} = \sqrt{2}\,(20\text{ V}) = 28.3\text{ V}$
$$V_{r_{\text{peak}}} = \sqrt{3}\,V_r(\text{rms}) = \sqrt{3}\left(\frac{2.4 I_{\text{dc}}}{C}\right)$$
$$= \sqrt{3}\left(\frac{2.4(250)}{500}\right) = 2.1\text{ V}$$
$V_{\text{dc}} = V_m - V_{r_{\text{peak}}} = 28.3\text{ V} - 2.1\text{ V} = 26.2\text{ V}$
$V_i(\text{low}) = V_{\text{dc}} - V_{r_{\text{peak}}} = 26.2\text{ V} - 2.1\text{ V} = \mathbf{24.1\text{ V}}$

25. To maintain $V_i(\text{min}) \geq 7.3\text{ V}$ (see Table 15.1)
$V_{r_{\text{peak}}} \leq V_m - V_i(\text{min}) = 12\text{ V} - 7.3\text{ V} = 4.7\text{ V}$
so that
$$V_r(\text{rms}) = \frac{V_{r_{\text{peak}}}}{\sqrt{3}} = \frac{4.7\text{ V}}{1.73} = 2.7\text{ V}$$
The maximum value of load current is then

$$I_{\text{dc}} = \frac{V_r(\text{rms})C}{2.4} = \frac{(2.7\text{ V})(200)}{2.4} = \mathbf{225\text{ mA}}$$

26. $V_o = V_{\text{ref}}\left(1+\dfrac{R_2}{R_1}\right) + I_{\text{adj}}R_L$

$= 1.25\text{ V}\left(1+\dfrac{1.8\text{ k}\Omega}{240\ \Omega}\right) + 100\ \mu\text{A}(2.4\text{ k}\Omega)$

$= 1.25\text{ V}(8.5) + 0.24\text{ V}$

$=$ **10.87 V**

27. $V_o = V_{\text{ref}}\left(1+\dfrac{R_2}{R_1}\right) + I_{\text{adj}}\,R_2$

$= 1.25\text{ V}\left(1+\dfrac{1.5\text{ k}\Omega}{220\ \Omega}\right) + 100\ \mu\text{A}(1.5\text{ k}\Omega)$

$=$ **9.9 V**

Chapter 16

1. (a) The Schottky Barrier diode is constructed using an *n*-type semiconductor material and a metal contact to form the diode junction, while the conventional *p-n* junction diode uses both *p*- and *n*-type semiconductor materials to form the junction.

   (b) –

2. (a) In the forward-biased region the dynamic resistance is about the same as that for a *p-n* junction diode. Note that the slope of the curves in the forward-biased region is about the same at different levels of diode current.

   (b) In the reverse-biased region the reverse saturation current is larger in magnitude than for a *p-n* junction diode, and the Zener breakdown voltage is lower for the Schottky diode than for the conventional *p-n* junction diode.

3. $$\frac{\Delta I_R}{\Delta°C} = \frac{100\ \mu\text{A} - 0.5\ \mu\text{A}}{75°\ \text{C}} = 1.33\ \mu\text{A/°C}$$

   $$\Delta I_R = (1.33\ \mu\text{A/°C})\Delta\text{C} = (1.33\ \mu\text{A/°C})(25°\text{C}) = 33.25\mu\text{A}$$
   $$I_R = 0.5\mu\text{A} + 33.25\mu\text{A} = \mathbf{33.75\mu A}$$

4. $$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(1\ \text{MHz})(7\ \text{pF})} = \mathbf{22.7\ k\Omega}$$

   $$R_{DC} = \frac{V_F}{I_F} = \frac{400\ \text{mV}}{10\ \text{mA}} = \mathbf{40\ \Omega}$$

5. Temperature on linear scale
   T(1/2 power level of 100 mW) ≅ **95°C**

6. V_F a linear scale $\quad V_F$ (25°C) ≅ 380 mV = **0.38 V**

   At 125°C, V_F ≅ 280 mV

   $$\frac{\Delta V_F}{\Delta_T} = \frac{100\ \text{mV}}{100°\text{C}} = 1\ \text{mV/°C}$$

   ∴ At 100°C $\quad V_F$ = 280 mV + (1 mV/°C)(25°C)
   = 280 mV + 25 mV
   = 305 mV

   Increase temperature and V_F drops.

7. (a) $C_T(V_R) = \dfrac{C(0)}{\left(1+|V_R/V_T|\right)^n} = \dfrac{80 \text{ pF}}{\left(1+\dfrac{4.2 \text{ V}}{0.7 \text{ V}}\right)^{1/3}}$

$= \dfrac{80 \text{ pF}}{1.912} = \mathbf{41.85\ pF}$

(b) $k = C_T(V_T + V_R)^n$

$= 41.85 \text{ pF}(\underbrace{0.7 \text{ V} + 4.2 \text{ V})^{1/3}}_{1.698}$

$\cong \mathbf{71 \times 10^{-12}}$

8. (a) At –3 V, C = **40 pF**

At –12 V, C = **20 pF**

ΔC = 40 pF – 20 pF = **20 pF**

(b) At –8 V, $\dfrac{\Delta C}{\Delta V_R} = \dfrac{40 \text{ pF}}{20 \text{ V}}$ = **2 pF/V**

At –2 V, $\dfrac{\Delta C}{\Delta V_R} = \dfrac{60 \text{ pF}}{9 \text{ V}}$ = **6.67 pF/V**

$\dfrac{\Delta C}{\Delta V_R}$ increases at less negative values of V_R.

9. Ratio = $\dfrac{C_t(-1 \text{ V})}{C_t(-8 \text{ V})} = \dfrac{92 \text{ pF}}{5.5 \text{ pF}}$ = **16.73**

$\dfrac{C_t(-1.25 \text{ V})}{C_t(-7 \text{ V})}$ = **13**

10. $C_t \cong 15$ pF

$Q = \dfrac{1}{2\pi f R_s C_t} = \dfrac{1}{2\pi(10 \text{ MHz})(3\ \Omega)(15 \text{ pF})}$

= **354.61** vs **350** on chart

11. $TC_C = \dfrac{\Delta C}{C_o(T_1 - T_0)} \times 100\% \Rightarrow T_1 = \dfrac{\Delta C \times 100\%}{TC_C(C_o)} + T_o$

$= \dfrac{(0.11 \text{ pF})(100)}{(0.02)(22 \text{ pF})} + 25$

= **50°C**

12. V_R from –2 V to –8 V

$C_t(-2 \text{ V}) = 60$ pF, $C_t(-8 \text{ V}) = 6$ pF

Ratio = $\dfrac{C_t(-2 \text{ V})}{C_t(-8 \text{ V})} = \dfrac{60 \text{ pF}}{6 \text{ pF}}$ = **10**

13. $Q(-1\text{ V}) = 82$, $Q(-10\text{ V}) = 5000$

$$\text{Ratio} = \frac{Q(-10\text{ V})}{Q(-1\text{ V})} = \frac{5000}{82} = 60.98$$

$$BW = \frac{f_o}{Q} = \frac{10\times10^6\text{ Hz}}{82} = \mathbf{121.95\text{ kHz}}$$

$$BW = \frac{f_o}{Q} = \frac{10\times10^6\text{ Hz}}{5000} = \mathbf{2\text{ kHz}}$$

14. High-power diodes have a higher forward voltage drop than low-current devices due to larger *IR* drops across the bulk and contact resistances of the diode. The higher voltage drops result in higher power dissipation levels for the diodes, which in turn may require the use of heat sinks to draw the heat away from the body of the structure.

15. The primary difference between the standard *p-n* junction diode and the tunnel diode is that the tunnel diode is doped at a level from 100 to several thousand times the doping level of a *p-n* junction diode, thus producing a diode with a "negative resistance" region in its characteristic curve.

16. At 1 MHz: $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(1\times10^6\text{ Hz})(5\times10^{-12}\text{ F})}$

$= \mathbf{31.83\text{ k}\Omega}$

At 100 MHz: $X_C = \dfrac{1}{2\pi(100\times10^6\text{ Hz})(5\times10^{-12}\text{F})}$

$= \mathbf{318.3\ \Omega}$

At 1 MHz: $X_{L_s} = 2\pi fL = 2\pi(1\times10^6\text{ Hz})(6\times10^{-9}\text{ H})$

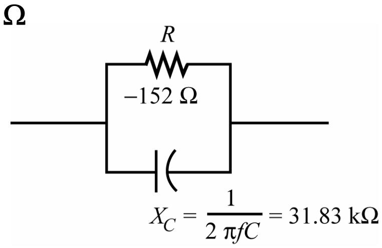
$= \mathbf{0.0337\ \Omega}$

At 100 MHz: $X_{L_s} = 2\pi(100\times10^6\text{ Hz})(6\times10^{-9}\text{ H})$

$= \mathbf{3.769\ \Omega}$

L_s effect is negligible!

R and *C* in parallel:
$f = 1$ MHz



$$Z_T = \frac{(152\ \Omega\angle180°)(31.83\text{ k}\Omega\angle-90°)}{-152\ \Omega - j31.83\text{ k}\Omega}$$

$$= -152.05\ \Omega\angle0.27° \cong -152\ \Omega\angle0°$$

$f = 100$ MHz

$$Z_T = \frac{(152\ \Omega\angle180°)(318.3\angle-90°)}{-152\ \Omega - j318.3}$$

$$= -137.16\ \Omega\angle25.52 \neq -152\ \Omega\angle0°$$

At very high frequencies X_C has some impact!

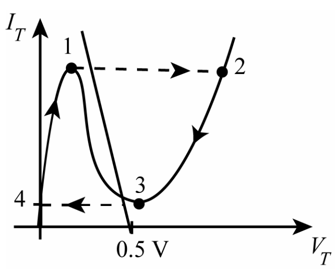
17. The heavy doping greatly reduces the width of the depletion region resulting in lower levels of Zener voltage. Consequently, small levels of reverse voltage can result in a significant current levels.

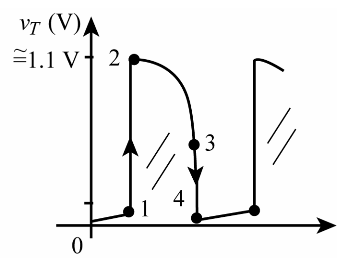
18. At $V_T = 0.1$ V,
$I_F \cong 5.5$ mA
At $V_T = 0.3$ V
$I_F \cong 2.3$ mA

$$R = \frac{\Delta V}{\Delta I} = \frac{0.3\text{ V} - 0.1\text{ V}}{2.3\text{ mA} - 5.5\text{ mA}}$$
$$= \frac{0.2\text{ V}}{-3.2\text{ mA}} = \mathbf{-62.5\ \Omega}$$

19. $$I_{\text{sat}} = \frac{E}{R} = \frac{2\text{ V}}{0.39\text{ k}\Omega} \cong 5.13\text{ mA}$$
From graph: Stable operating points: $I_T \cong$ **5 mA**, $V_T \cong$ **60 mV**
$I_T \cong$ **2.8 mA**, $V_T =$ **900 mV**

20. $$I_{\text{sat}} = \frac{E}{R} = \frac{0.5\text{ V}}{51\ \Omega} = 9.8\text{ mA}$$
Draw load line on characteristics.





21. $$f_s = \left(\frac{1}{2\pi\sqrt{LC}}\right)\sqrt{1 - \frac{R_l^2 C}{L}}$$
$$= \left(\frac{1}{2\pi\sqrt{(5\times10^{-3}\text{ H})(1\times10^{-6}\text{ F})}}\right)\sqrt{1 - \frac{(10\ \Omega)^2(1\times10^{-6}\text{ F})}{5\times10^{-3}\text{ H}}}$$
$= (2250.79$ Hz$)(0.9899)$
$\cong$ **2228 Hz**

22. $$W = \cancel{h}f = \cancel{h}\frac{v}{\lambda} = \frac{(6.624\times10^{-34}\text{ J}\cdot\text{s})(3\times10^{8}\text{ m/s})}{(5000)(10^{-10}\text{ m})}$$
$= \mathbf{3.97\times10^{-19}\ J}$
$$3.97\times10^{-19}\cancel{\text{J}}\left[\frac{1\text{ eV}}{1.6\times10^{-19}\cancel{\text{J}}}\right] = \mathbf{2.48\ eV}$$

23. (a) Visible spectrum: **3750 A → 7500**
(b) Silicon, peak relative response ≅ **8400 Å**
(c) BW = 10,300 Å − 6100 Å = **4200 Å**

24. $\dfrac{4\times10^{-9}\ \text{W/m}^2}{1.609\times10^{-12}} = 2{,}486\,f_c$
From the intersection of V_A = 30 V and 2,486 f_c we find
$I_\lambda \cong$ **440 μA**

25. (a) Silicon
(b) $1\ \text{Å} = 10^{-10}\ \text{m},\ \dfrac{6\times10^{-7}\,\text{m}}{10^{-10}\,\text{m/Å}} \Rightarrow 6000\ \text{Å} \rightarrow$ **orange**

26. Note that V_λ is given and not V.
At the intersection of V_λ = 25 V and 3000f_c we find $I_\lambda \cong$ 500 μA and
$V_R = I_\lambda R = (500\times10^{-6}\ \text{A})(100\times10^3\ \Omega)$ = **50 V**

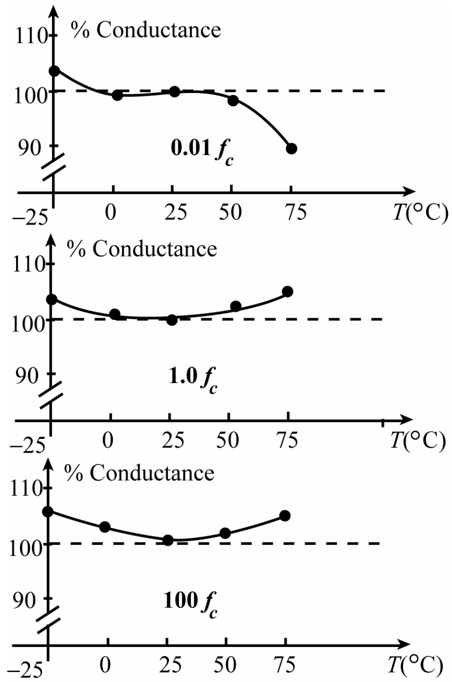
27. (a) Extending the curve:
0.1 kΩ → 1000f_c, 1 kΩ → 25f_c
$$\frac{\Delta R}{\Delta f_c} = \frac{(1-0.1)\times10^3\ \Omega}{(1000-25)f_c} = \mathbf{0.92\ \Omega/f_c \cong 0.9\ \Omega/f_c}$$

(b) 1 kΩ → 25f_c, 10 kΩ → 1.3f_c
$$\frac{\Delta R}{\Delta f_c} = \frac{(10-1)\times10^3\ \Omega}{(25-1.3)f_c} = \mathbf{379.75\ \Omega/f_c \cong 380\ \Omega/f_c}$$

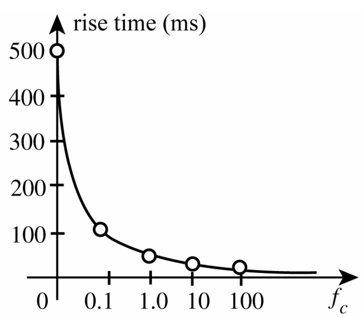
(c) 10 kΩ → 1.3f_c, 100 kΩ → 0.15f_c
$$\frac{\Delta R}{\Delta f_c} = \frac{(100-10)\times10^3}{(1.3-0.15)f_c} = \mathbf{78{,}260.87\ \Omega/f_c \cong 78\times10^3\ \Omega/f_c}$$
The greatest rate of change in resistance occurs in the low illumination region.

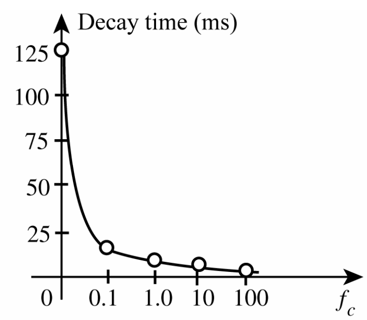
28. The "dark current" of a photodiode is the diode current level when no light is striking the diode. It is essentially the reverse saturation leakage current of the diode, comprised mainly of minority carriers.

29. 10f_c → $R \cong 2$ kΩ
$$V_o = 6\ \text{V} = \frac{(2\times10^3\ \Omega)V_i}{2\times10^3\ \Omega + 5\times10^3\ \Omega}$$
V_i = **21 V**

30. 

Except for low illumination levels ($0.01f_c$) the % conductance curves appear above the 100% level for the range of temperature. In addition, it is interesting to note that for other than the low illumination levels the % conductance is higher above and below room temperature (25°C). In general, the % conductance level is not adversely affected by temperature for the illumination levels examined.

31. (a) 

(b) 

(c) Increased levels of illumination result in reduced rise and decay times.

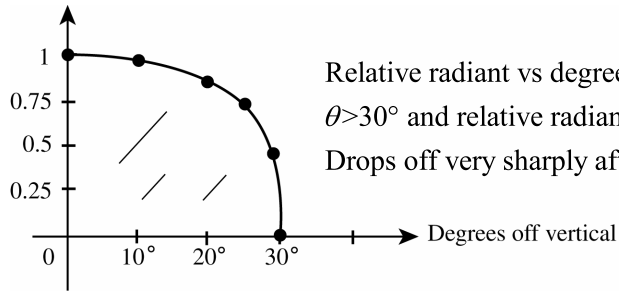
32. The highest % sensitivity occurs between 5250A and 5750A. Fig 16.20 reveals that the CdS unit would be most sensitive to *yellow*. The % sensitivity of the CdS unit of Fig. 16.30 is at the 30% level for the range 4800Å → 7000Å. This range includes green, yellow, and orange in Fig. 16.20.

33. (a) ≅ **5 mW** radiant flux

(b) ≅ 3.5 mW $\quad \dfrac{3.5 \text{ mW}}{1.496\times10^{-13}\text{ W/lm}} = \mathbf{2.34 \times 10^{10}\ lms}$

34. (a) Relative radiant intensity $\cong$ **0.8**.

(b)



Relative radiant vs degrees off vertical
θ>30° and relative radiant intensity essentially zero-
Drops off very sharply after 25°!

35. At $I_F = 60$ mA, $\Phi \cong 4.4$ mW
At 5°, relative radiant intensity = 0.8
(0.8)(4.4 mW) = **3.52 mW**

36. 6, 7, 8

37. –

38. The LED generates a light source in response to the application of an electric voltage. The LCD depends on ambient light to utilize the change in either reflectivity or transmissivity caused by the application of an electric voltage.

39. The LCD display has the advantage of using approximately 1000 times less power than the LED for the same display, since much of the power in the LED is used to produce the light, while the LCD utilizes ambient light to see the display. The LCD is usually more visible in daylight than the LED since the sun's brightness makes the LCD easier to see. The LCD, however, requires a light source, either internal or external, and the temperature range of the LCD is limited to temperatures above freezing.

40. $$\eta\% = \frac{P_{\max}}{(A_{\text{cm}^2})(100\text{ mW/cm}^2)} \times 100\%$$

$$9\% = \frac{P_{\max}}{(2\text{ cm}^2)(100\text{ mW/cm}^2)} \times 100\%$$

$P_{\max}$ = **18 mW**

41. The greatest rate of increase in power will occur at low illumination levels. At higher illumination levels, the change in V_{OC} drops to nearly zero, while the current continues to rise linearly. At low illumination levels the voltage increases logarithmically with the linear increase in current.

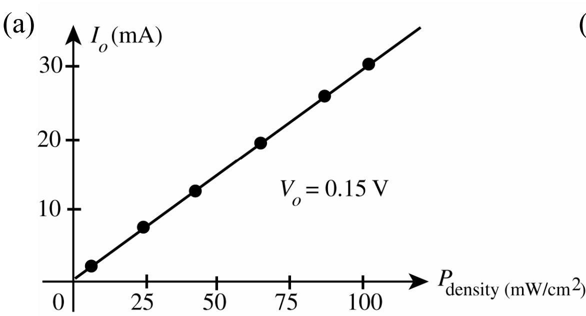
42. (a) Fig. 16.48 $\Rightarrow$ **79 mW/cm²**

(b) It is the maximum power density available at sea level.

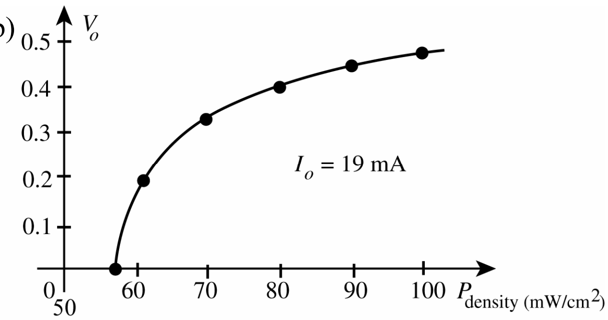
(c) Fig. 16.48 $\cong$ **12.7 mA**

(b)

43. (a)

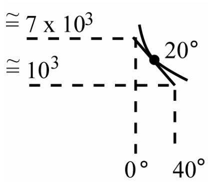


(b)

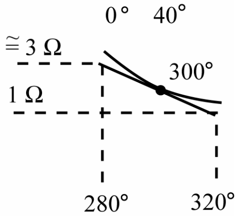


(c) The curve of I_o vs P_{density} is quite linear while the curve of V_o vs P_{density} is only linear in the region near the optimum power locus (Fig 16.48).

44. Since log scales are present, the differentials must be as small as possible.



$$\frac{\Delta R}{\Delta T} = \frac{(7000 - 1000)\Omega}{(40 - 0)°} = \frac{6000\ \Omega}{40°} = 150\ \Omega/°\text{C}$$



$$\frac{\Delta R}{\Delta T} = \frac{(3 - 1)\Omega}{40°} = \frac{2\ \Omega}{40°} = 0.05\ \Omega/°\text{C}$$

From the above 150 Ω/°C: 0.05 Ω/°C = 3000:1
Therefore, the highest rate of change occurs at lower temperatures such as 20°C.

45. No. 1 Fenwall Electronics Thermistor material.
Specific resistance ≅ 10^4 = 10,000 Ω cm

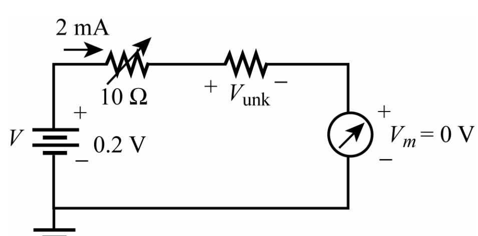
$$R = \frac{\rho \ell}{A} \quad \underbrace{2x}_{\text{twice}} \qquad \therefore R = 2 \times (10{,}000\ \Omega) = \mathbf{20\ k\Omega}$$

46. (a) ≅ 10^{-5} A = **10 μA**

(b) Power ≅ **0.1 mW**, $R \cong 10^7\ \Omega$ = **10 MΩ**

(c) Log scale ≅ **0.3 mW**

47.



$$V = IR + IR_{\text{unk}} + V_m$$
$$V = I(R + R_{\text{unk}}) + 0\ \text{V}$$
$$R_{\text{unk}} = \frac{V}{I} - R$$
$$= \frac{0.2\ \text{V}}{2\ \text{mA}} - 10\ \Omega$$
$$= 100\ \Omega - 10\ \Omega$$
$$= \mathbf{90\ \Omega}$$

Chapter 17

1. –

2. –

3. –

4. (a) *p-n* junction diode

   (b) The SCR will not fire once the gate current is reduced to a level that will cause the forward blocking region to extend beyond the chosen anode-to-cathode voltage. In general, as I_G decreases, the blocking voltage required for conduction increases.

   (c) The SCR will fire once the anode-to-cathode voltage is less than the forward blocking region determined by the gate current chosen.

   (d) The holding current increases with decreasing levels of gate current.

5. (a) Yes

   (b) No

   (c) No. As noted in Fig. 17.8b the minimum gate voltage required to trigger all units is 3 V.

   (d) $V_G = 6$ V, $I_G = 800$ mA is a good choice (center of preferred firing area).
   $V_G = 4$ V, $I_G = 1.6$ A is less preferable due to higher power dissipation in the gate. Not in preferred firing area.

6. In the conduction state, the SCR has characteristics very similar to those of a *p-n* junction diode (where $V_T = 0.7$ V).

7. The smaller the level of R_1, the higher the peak value of the gate current. The higher the peak value of the gate current the sooner the triggering level will be reached and conduction initiated.

8. (a) $V_P = \left(\dfrac{V_{\text{sec}}(\text{rms})}{2}\right)\sqrt{2}$

   $= \dfrac{117\text{ V}}{2}\left(\sqrt{2}\right) = 82.78\text{ V}$

   $V_{DC} = 0.636(82.78\text{ V})$

   $= \mathbf{52.65\ V}$

   (b) $V_{AK} = V_{DC} - V_{Batt} = 52.65\text{ V} - 11\text{ V} = \mathbf{41.65\ \ V}$

(c) $V_R = V_Z + V_{GK}$
$= 11\text{ V} + 3\text{ V}$
$= 14\text{ V}$
At 14 V, SCR_2 conducts and stops the charging process.

(d) At least 3 V to turn on SCR_2.

(e) $V_2 \cong \frac{1}{2}V_P = \frac{1}{2}(82.78\text{ V}) = \mathbf{41.39\text{ V}}$

9. –

10. (a) Charge toward 200 V but will be limited by the development of a negative voltage $V_{GK}\left(= V_Z - V_{C_1}\right)$ that will eventually turn the GTO off.

(b) $\tau = R_3C_1 = (20\text{ k}\Omega)(0.1\ \mu\text{F})$
$= 2\text{ ms}$
$5\tau = \mathbf{10\text{ ms}}$

(c) $5\tau' = \frac{1}{2}(5\tau) = 5\text{ ms} = 5R_{GTO}C_1$

$$R_{GTO} = \frac{5\text{ ms}}{5C_1} = \frac{5\text{ ms}}{5(0.1\times 10^{-6}\text{ F})} = \mathbf{10\text{ k}\Omega}\left(= \frac{1}{2}(20\text{ k}\Omega - \text{ above})\right)$$

11. (a) $\cong \mathbf{0.7\text{ mW/cm}^2}$

(b) $0°\text{C} \rightarrow 0.82\text{ mW/cm}^2$
$100°\text{C} \rightarrow 0.16\text{ mW/cm}^2$
$$\frac{0.82 - 0.16}{0.82} \times 100\% \cong \mathbf{80.5\%}$$

12. $V_C = V_{BR} + V_{GK} = 6\text{ V} + 3\text{ V} = 9\text{ V}$
$V_C = 40(1 - e^{-t/RC}) = 9$
$40 - 40e^{-t/RC} = 9$
$40e^{-t/RC} = 31$
$e^{-t/RC} = 31/40 = 0.775$
$RC = (10 \times 10^3\ \Omega)(0.2 \times 10^{-6}\text{ F}) = 2 \times 10^{-3}\text{ s}$
$\log_e(e^{-t/RC}) = \log_e 0.775$
$-t/RC = -t/2 \times 10^{-3} = -0.255$
and $t = 0.255(2 \times 10^{-3}) = \mathbf{0.51\text{ ms}}$

13. –

14. $V_{BR_1} = V_{BR_2} \pm 10\%\ V_{BR_2}$
$= 6.4\text{ V} \pm 0.64\text{ V} \Rightarrow \mathbf{5.76\text{ V} \rightarrow 7.04\text{ V}}$

15. –

16. $\dfrac{V - V_P}{I_P} > R_1$

$\dfrac{40\text{ V} - [0.6(40\text{ V}) + 0.7\text{ V}]}{10\times10^{-6}} = \mathbf{1.53\ M\Omega} > R_1$

$\dfrac{V - V_V}{I_V} < R_1 \Rightarrow \dfrac{40\text{ V} - 1\text{ V}}{8\text{ mA}} = 4.875\text{ k}\Omega < R_1$

$\therefore \mathbf{1.53\ M\Omega > \boldsymbol{R_1} > 4.875\ k\Omega}$

17. (a) $\eta = \dfrac{R_{B_1}}{R_{B_1} + R_{B_2}\big|_{I_E=0}} \Rightarrow 0.65 = \dfrac{2\text{ k}\Omega}{2\text{ k}\Omega + R_{B_2}}$ $\quad R_{B_2} = \mathbf{1.08\ k\Omega}$

(b) $R_{BB} = \left(R_{B_1} + R_{B_2}\right)\Big|_{I_E=0} = 2\text{ k}\Omega + 1.08\text{ k}\Omega = \mathbf{3.08\ k\Omega}$

(c) $V_{R_{B_1}} = \eta V_{BB} = 0.65(20\text{ V}) = \mathbf{13\ V}$

(d) $V_P = \eta V_{BB} + V_D = 13\text{ V} + 0.7\text{ V} = \mathbf{13.7\ V}$

18. (a) $\eta = \dfrac{R_{B_1}}{R_{BB}}\Bigg|_{I_E=0}$

$0.55 = \dfrac{R_{B_1}}{10\text{ k}\Omega}$

$R_{B_1} = \mathbf{5.5\ k\Omega}$

$R_{BB} = R_{B_1} + R_{B_2}$

$10\text{ k}\Omega = 5.5\text{ k}\Omega + R_{B_2}$

$R_{B_2} = \mathbf{4.5\ k\Omega}$

(b) $V_P = \eta V_{BB} + V_D = (0.55)(20\text{ V}) + 0.7\text{ V} = \mathbf{11.7\ V}$

(c) $R_1 < \dfrac{V - V_P}{I_p} = \dfrac{20\text{ V} - 11.7\text{ V}}{50\ \mu\text{A}} = 166\text{ k}\Omega$

ok: $68\text{ k}\Omega < 166\text{ k}\Omega$

(d) $t_1 = R_1 C \log_e \dfrac{V - V_V}{V - V_P} = (68 \times 10^3)(0.1 \times 10^{-6}) \log_e \dfrac{18.8}{8.3} = 5.56 \text{ ms}$

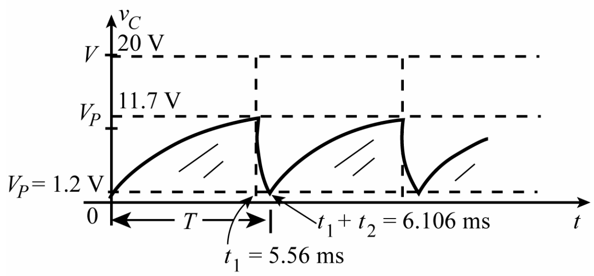
$t_2 = (R_{B_1} + R_2)\, C \log_e \dfrac{V_P}{V_V} = (0.2\text{ k}\Omega + 2.2\text{ k}\Omega)(0.1 \times 10^{-6}) \log_e \dfrac{11.7}{1.2}$

$= 0.546 \text{ ms}$

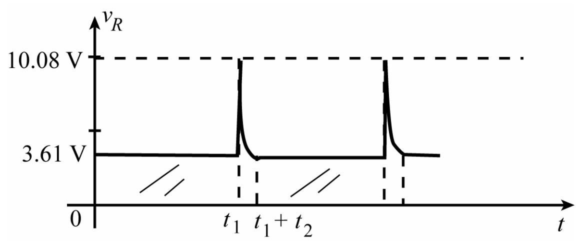
$T = t_1 + t_2 = 6.106 \text{ ms}$

$f = \dfrac{1}{T} = \dfrac{1}{6.106 \text{ ms}} = \mathbf{163.77\ Hz}$

(e)



(f)



$V_{R_2} = \dfrac{R_2 V}{R_2 + R_{BB}} = \dfrac{2.2\text{ k}\Omega(20\text{ V})}{2.2\text{ k}\Omega + 10\text{ k}\Omega}$

$= \mathbf{3.61\ V}$

$V_{R_2} \cong \dfrac{R_2(V_P - 0.7\text{ V})}{R_2 + R_{B_1}}$

$= \dfrac{2.2\text{ k}\Omega(11.7\text{ V} - 0.7\text{ V})}{2.2\text{ k}\Omega + 0.2\text{ k}\Omega}$

$= \mathbf{10.08\ V}$

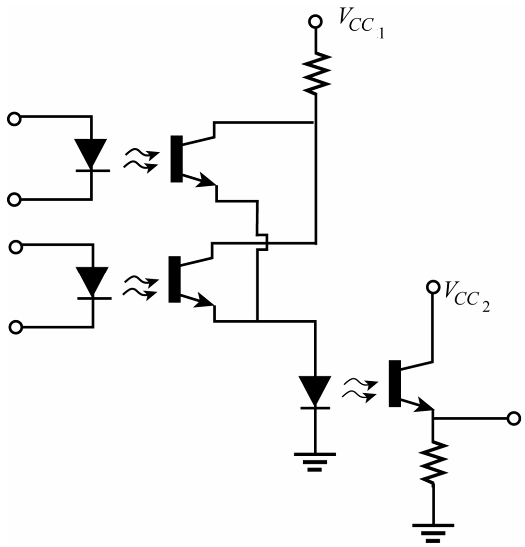
(g) $f \cong \dfrac{1}{R_1 C \log_e(1/(1-\eta))} = \dfrac{1}{(6.8\text{ k}\Omega)(0.1\ \mu\text{F})\log_e 2.22} = \mathbf{184.16\ Hz}$

difference in frequency levels is partly due to the fact that $t_2 \cong 10\%$ of t_1.

19. $I_B = \mathbf{25\ \mu A}$

$I_C = h_{f_e} I_B = (40)(25\ \mu\text{A}) = \mathbf{1\ mA}$

20.



21. (a) $D_F = \dfrac{\Delta I}{\Delta T}$

$$= \frac{0.95 - 0}{25 - (-50)} = \frac{0.95}{75} = \mathbf{1.26\%/°C}$$

(b) Yes, curve flattens after 25°C.

22. (a) At 25°C, $I_{CEO} \cong 2$ nA
At 50°C, $I_{CEO} \cong 30$ nA

$$\frac{\Delta I_{CEO}}{\Delta T} = \frac{(30-2)\times 10^{-9}\,\text{A}}{(50-25)°\text{C}} = \frac{28\text{ nA}}{25°\text{C}} = \mathbf{1.12\ nA/°C}$$

I_{CEO} (35°C) = I_{CEO}(25°C) + (1.12 nA/°C)(35°C − 25°C)
= 2 nA + 11.2 nA
= **13.2 nA**

From Fig. 17.55 I_{CEO} (35°C) ≅ **4 nA**

Derating factors, therefore, cannot be defined for large regions of non-linear curves. Although the curve of Fig. 17.55 appears to be linear, the fact that the vertical axis is a log scale reveals that I_{CEO} and T(°C) have a non-linear relationship.

23. $\dfrac{I_o}{I_i} = \dfrac{I_C}{I_F} = \dfrac{20\text{ mA}}{\cong 45\text{ mA}} = \mathbf{0.44}$

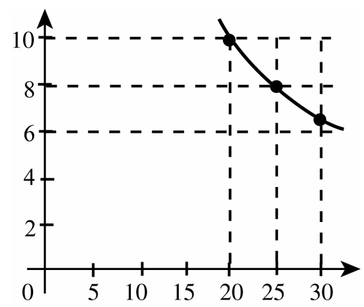
Yes, relatively efficient.

24. (a) $P_D = V_{CE}I_C = 200$ mW

$$I_C = \frac{P_D}{V_{CE_{\max}}} = \frac{200 \text{ mW}}{30 \text{ V}} = 6.67 \text{ mA @ } V_{CE} = 30 \text{ V}$$

$$V_{CE} = \frac{P_D}{I_C} = \frac{200 \text{ mW}}{10 \text{ mA}} = 20 \text{ V @ } I_C = 10 \text{ mA}$$

$$I_C = \frac{P_D}{V_{CE}} = \frac{200 \text{ mW}}{25 \text{ V}} = 8.0 \text{ mA @ } V_{CE} = 25 \text{ V}$$



Almost the entire area of Fig. 17.57 falls within the power limits.

(b) $\beta_{\text{dc}} = \frac{I_C}{I_F} = \frac{4 \text{ mA}}{10 \text{ mA}} = \mathbf{0.4}$, Fig. 17.56 $\frac{I_C}{I_F} \cong \frac{4 \text{ mA}}{10 \text{ mA}} = \mathbf{0.4}$

The fact that the I_F characteristics of Fig. 17.57 are fairly horizontal reveals that the level of I_C is somewhat unaffected by the level of V_{CE} except for very low or high values. Therefore, a plot of I_C vs. I_F as shown in Fig. 17.56 can be provided without any reference to the value of V_{CE}. As noted above, the results are essentially the same.

25. (a) $I_C \geq$ **3 mA**

(b) At $I_C = 6$ mA; $R_L = 1$ kΩ, $t = 8.6$ μs
$R_L = 100$ Ω; $t = 2$ μs
1 kΩ:100 Ω = 10:1
8.6 μs:2 μs = 4.3:1
ΔR:$\Delta t \cong$ **2.3:1**

26. $$\eta = \frac{3R_{B_2}}{3R_{B_2} + R_{B_2}} = \frac{3}{4} = \mathbf{0.75}, \quad V_G = \eta V_{BB} = 0.75(20 \text{ V}) = \mathbf{15\ V}$$

27. $V_P = 8.7$ V, $I_P = 100$ μA $\qquad Z_P = \frac{V_P}{I_P} = \frac{8.7 \text{ V}}{100\ \mu\text{A}} = \mathbf{87\ k\Omega}$ ($\cong$ open)

$V_V = 1$ V, $I_V = 5.5$ mA $\qquad Z_V = \frac{V_V}{I_V} = \frac{1 \text{ V}}{5.5 \text{ mA}} = \mathbf{181.8\ \Omega}$ (relatively low)

87 kΩ: 181.8 Ω = 478.55:1 ≅ **500:1**

28. Eq. 17.23: $T = RC\log_e\left(\dfrac{V_{BB}}{V_{BB}-V_P}\right) = RC\log_e\left(\dfrac{V_{BB}}{V_{BB}-(\eta V_{BB}+V_D)}\right)$

Assuming $\eta V_{BB} \gg V_D$, $T = RC\log_e\left(\dfrac{V_{BB}}{V_{BB}(1-\eta)}\right) = RC\log_e(1/1-\eta) = RC\log_e\left(\dfrac{1}{1-\dfrac{R_{B_1}}{R_{B_1}+R_{B_2}}}\right)$

$= RC\log_e\left(\dfrac{R_{B_1}+R_{B_2}}{R_{B_2}}\right) = RC\log_e\left(1+\dfrac{R_{B_1}}{R_{B_2}}\right)$ Eq. 17.24

29. (a) Minimum V_{BB}:

$$R_{\max} = \frac{V_{BB}-V_P}{I_P} \geq 20\text{ k}\Omega$$

$$\frac{V_{BB}-(\eta V_{BB}+V_D)}{I_P} = 20\text{ k}\Omega$$

$$V_{BB} - \eta V_{BB} - V_D = I_P\,20\text{ k}\Omega$$

$$V_{BB}(1-\eta) = I_P\,20\text{ k}\Omega + V_D$$

$$V_{BB} = \frac{I_P\,20\text{ k}\Omega + V_D}{1-\eta}$$

$$= \frac{(100\ \mu\text{A})(20\text{ k}\Omega)+0.7\text{ V}}{1-0.67}$$

$$= \mathbf{8.18\ V}$$

10 V OK

(b) $R < \dfrac{V_{BB}-V_V}{I_V} = \dfrac{12\text{ V}-1\text{ V}}{5.5\text{ mA}} = 2\text{ k}\Omega$

$R <$ **2 kΩ**

(c) $T \cong RC\log_e\left(1+\dfrac{R_{B_1}}{R_{B_2}}\right)$

$$2\times10^{-3} = R(1\times10^{-6})\underbrace{\log_e\left(1+\frac{10\text{ k}\Omega}{5\text{ k}\Omega}\right)}_{\log_e 3\, =\, 1.0986}$$

$$R = \frac{2\times10^{-3}}{(1\times10^{-6})(1.0986)}$$

$R =$ **1.82 kΩ**