Online Instructor's Manual
for

Electronic Devices and Circuit Theory

Eleventh Edition

Robert L. Boylestad

Louis Nashelsky

PEARSON

Boston Columbus Indianapolis New York San Francisco Upper Saddle River

Amsterdam Cape Town Dubai London Madrid Milan Munich Paris Montreal Toronto

Delhi Mexico City Sao Paulo Sydney Hong Kong Seoul Singapore Taipei Tokyo

10 9 8 7 6 5 4 3 2 1

ISBN10: 0-13-278373-8

PEARSON

ISBN13: 978-0-13-278373-6

Contents

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. a. $W = QV = (12\ \mu C)(6\ \text{V}) = \mathbf{72\ \mu J}$

   b. $72 \times 10^{-6}\ \text{J} = \left[\dfrac{1\ \text{eV}}{1.6 \times 10^{-19}\ \text{J}}\right] = \mathbf{2.625 \times 10^{14}\ eV}$

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

   $Q = \dfrac{W}{V} = \dfrac{76.8 \times 10^{-19}\ \text{J}}{3.2\ \text{V}} = \mathbf{2.40 \times 10^{-18}\ C}$

   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. a. $V_T = \dfrac{kT_K}{q} = \dfrac{(1.38\times10^{-23}\text{ J/K})(20°\text{C} + 273°\text{C})}{1.6\times10^{-19}\text{ C}}$
$= \mathbf{25.27\ mV}$

b. $I_D = I_s(e^{V_D/nV_T} - 1)$
$= 40\text{ nA}(e^{(0.5\text{ V})/(2)(25.27\text{mV})} - 1)$
$= 40\text{ nA}(e^{9.89} - 1) = \mathbf{0.789\ mA}$

16. a. $V_T = \dfrac{k(T_K)}{q} = \dfrac{(1.38\times10^{-23}\text{ J/K})(100°\text{C} + 273°\text{C})}{1.6\times10^{-19}}$
$= \mathbf{32.17\ mV}$

b. $I_D = I_s(e^{V_D/nV_T} - 1)$
$= 40\text{ nA}(e^{(0.5\text{ V})/(2)(32.17\text{ mV})} - 1)$
$= 40\text{ nA}(e^{7.77} - 1) = \mathbf{11.84\ mA}$

17. a. $T_K = 20 + 273 = 293$
$V_T = \dfrac{kT_K}{q} = \dfrac{(1.38\times10^{-23}\text{ J/K})(293°)}{1.6\times10^{-19}\text{ C}}$
$= \mathbf{25.27\ mV}$

b. $I_D = I_s(e^{V_D/nV_T} - 1)$
$= 0.1\ \mu\text{A}\left(e^{-10/(2)(25.27\text{ mV})} - 1\right)$
$= 0.1\ \mu\text{A}(e^{-197.86} - 1)$
$\cong \mathbf{0.1\ \mu A}$

18. $V_T = \frac{kT_K}{q} = \frac{(1.38 \times 10^{-23} \text{ J/K})(25°\text{C} + 273°\text{C})}{1.6 \times 10^{-19} \text{ C}}$

$= 25.70 \text{ mV}$

$I_D = I_s(e^{V_D/nV_T} - 1)$

$8\text{mA} = I_s(e^{(0.5\text{V})/(1)(25.70 \text{ mV})} - 1) = I_s(28 \times 10^8)$

$I_s = \frac{8 \text{ mA}}{2.8 \times 10^8}$ = **28.57 pA**

19. $I_D = I_s(e^{V_D/nV_T} - 1)$

$6 \text{ mA} = 1 \text{ nA}(e^{V_D/(1)(26 \text{ mV})} - 1)$

$6 \times 10^6 = e^{V_D/26 \text{ mV}} - 1$

$e^{V_D/26 \text{ mV}} = 6 \times 10^6 - 1 \cong 6 \times 10^6$

$\log_e e^{V_D/26\text{mV}} = \log_e 6 \times 10^6$

$\frac{V_D}{26 \text{ mV}} = 15.61$

$V_D = 15.61(26 \text{ mV}) \cong$ **0.41 V**

20. (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 $x = 0$, $e^0 = 1$ and $I = I_s(1 - 1) =$ **0 mA**

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

$1.6\ \mu\text{A} : 0.1\ \mu\text{A} \Rightarrow 16:1$ increase due to rise in temperature of 40°C.

22. 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.

23. From 1.19:

	−75°C	25°C	100°C	200°C
V_F @ 10 mA	1.1 V	0.85 V	1.0 V	0.6 V
I_s	0.01 pA	1 pA	1 μA	1.05 μA

V_F decreased with increase in temperature

1.7 V: 0.65 V ≅ **2.6:1**

I_s increased with increase in temperature

2 μA: 0.1 μA = **20:1**

24. 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.

25. 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.

26. 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).

27. $V_D \cong 0.7$ V, $I_D = 4$ mA

$$R_{DC} = \frac{V_D}{I_D} = \frac{0.7\text{ V}}{4\text{ mA}} = \mathbf{175\ \Omega}$$

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

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

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

29. $V_D = -10$ V, $I_D = I_s =$ **$-0.1\ \mu$A**

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

$V_D = -30$ V, $I_D = I_s =$ **$-0.1\ \mu$A**

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

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

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

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

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

$R_{DC} >> r_d$

31. (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

32. $I_D = 1$ 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, $r_d = \dfrac{\Delta V_d}{\Delta I_d} = \dfrac{0.8\text{ V} - 0.78\text{ V}}{20\text{ mA} - 10\text{ mA}} = \mathbf{2\ \Omega}$

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

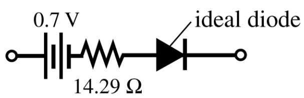
$I_D = 15$ mA, $r_d = \dfrac{26\text{ mV}}{I_D} = \dfrac{26\text{ mV}}{15\text{ mA}} = \mathbf{1.73\ \Omega}$ vs $2\ \Omega$ (#30)

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

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

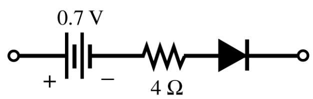
(relatively close to average value of 24.4 Ω (#32))

36. $r_{av} = \dfrac{\Delta V_d}{\Delta I_d} = \dfrac{0.9 \text{ V} - 0.7 \text{ V}}{14 \text{ mA} - 0 \text{ mA}} = \dfrac{0.2 \text{ V}}{14 \text{ mA}}$ = **14.29 Ω**



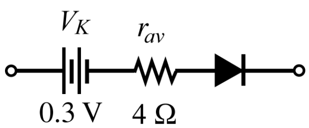
37. Using the best approximation to the curve beyond V_D = 0.7 V:

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



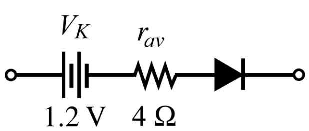
38. Germanium:

$$r_{av} = \frac{0.42 \text{ V} - 0.3 \text{ V}}{30 \text{ mA} - 0 \text{ mA}} = 4\ \Omega$$



GaAa:

$$r_{av} = \frac{1.32 \text{ V} - 1.2 \text{ V}}{30 \text{ mA} - 0 \text{ mA}} = 4\ \Omega$$



39. (a) $V_R = -25$ V: $C_T \cong$ **0.75 pF**
$V_R = -10$ V: $C_T \cong$ **1.25 pF**

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

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

$\left|\dfrac{\Delta C_T}{\Delta V_R}\right| = \left|\dfrac{1.25 \text{ pF} - 3 \text{ pF}}{10 \text{ V} - 1 \text{ V}}\right| = \dfrac{1.75 \text{ pF}}{9 \text{ V}}$ = **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

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

41. 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.

42. $V_D = 0.2$ 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

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

43. $$C_T = \frac{C(0)}{\left(1+|V_R/V_K|\right)^n} = \frac{8\text{ pF}}{\left(1+|5\text{ V}/0.7\text{ V}|\right)^{1/2}}$$

$$= \frac{8\text{pF}}{(1+7.14)^{1/2}} = \frac{8\text{ pF}}{\sqrt{8.14}} = \frac{8\text{ pF}}{2.85}$$

$$= \mathbf{2.81\,pF}$$

44. $$C_T = \frac{C(0)}{\left(1+|V_R/V_k|\right)^{\mu}}$$

$$4\text{ pF} = \frac{10\text{ pF}}{\left(1+|V_R/0.7\text{ V}|\right)^{1/3}}$$

$$= (1+V_R/0.7\text{ V})^{1/3} = 2.5$$

$$1+V_R/0.7\text{ V} = (2.5)^3 = 15.63$$

$$V_R/0.7\ V = 15.63 - 1 = 14.63$$

$$V_R = (0.7)(14.63) = \mathbf{10.24\ V}$$

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

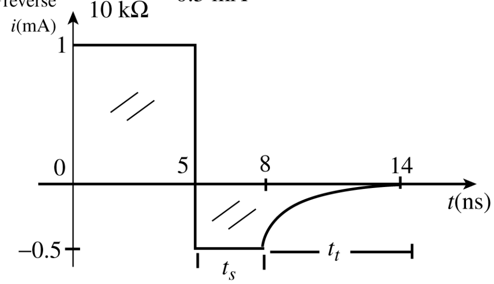
$t_s + t_t = t_{rr} = 9$ ns

$t_s + 2t_s = 9$ ns

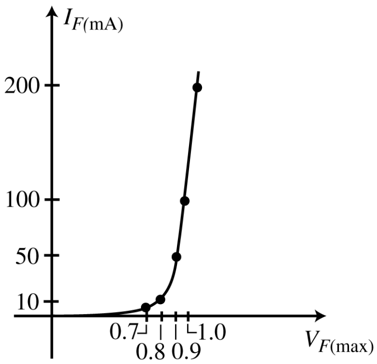
$t_s =$ **3 ns**

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

$I_{reverse} = \dfrac{5\text{ V}}{10\text{ k}\Omega} = 0.5$ mA



46.



47. a. 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.

b. 6 pF

c. At $V_R = -4$ V, $C_T = 2$ pF

$$C_T = \frac{C(0)}{\left(1 + \left|V_R / V_k\right|\right)^n}$$

$$2 \text{ pF} = \frac{6 \text{ pF}}{\left(1 + |4\text{V}/0.7 \text{ V}|\right)^n}$$

$$\left(1 + |4 \text{ V} + 0.7 \text{ V}|^n\right) = 3$$

$$(6.71)^n = 3$$

$$n \log_{10} 6.71 = \log_{10} 3$$

$$n(0.827) = 0.477$$

$$n = \frac{0.477}{0.827} \cong \mathbf{0.58}$$

48. 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.

49. 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).

50. $I_F = 0.1$ 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.

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

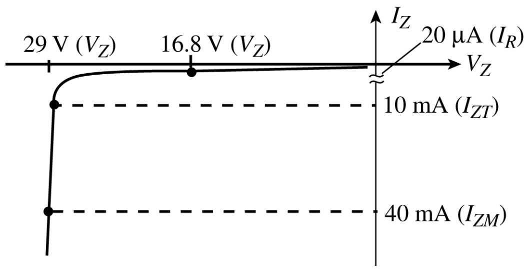
$$I_F = \frac{P_{max}}{V_F} = \frac{500\text{ mW}}{0.7\text{ V}} = \mathbf{714.29\text{ mA}}$$

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

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

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

53.



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

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

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

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

$T_1 = 104.17° + 25° =$ **129.17°**

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

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

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

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

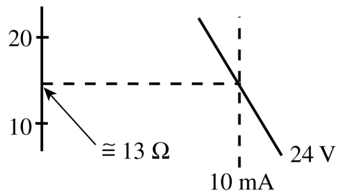
At $I_Z = 0.1$ mA, $T_C \cong 0.06\%/°C$

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

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**

57.



58. 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.

59. $V_K \cong 2.0$ 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.

60. $$0.67\ \cancel{eV}\left[\frac{1.6\times10^{-19}\text{ J}}{1\ \cancel{eV}}\right] = 1.072\times10^{-19}\text{ J}$$

$$E_g = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{E_g} = \frac{(6.626\times10^{-34}\text{ Js})(3\times10^{8})\text{ m/s}}{1.072\times10^{-19}\text{ J}}$$

$$= \mathbf{1850\ nm}$$

Very low energy level.

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

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

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

@ 10 mA ≅ **1.02**

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

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

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

@ 35 mA ≅ **1.42**

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

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

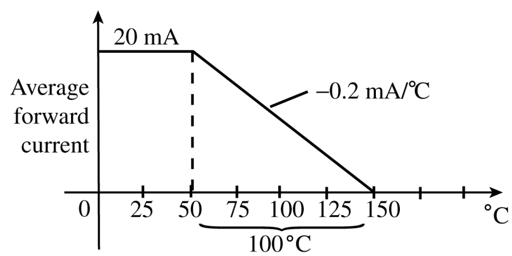
(c) For currents greater than about 30 mA the percent increase is significantly less than for increasing currents of lesser magnitude.

63. (a) $\frac{0.75}{3.0} = 0.25$

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

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

64. 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 $I_D = \dfrac{E}{R} = \dfrac{12\text{ V}}{750\ \Omega}$ = 16 mA and V_D = 12 V.

   (a) $V_{D_Q} \cong$ **0.85 V**
   $I_{D_Q} \cong$ **15 mA**
   $V_R = E - V_{D_Q}$ = 12 V − 0.85 V = **11.15 V**

   (b) $V_{D_Q} \cong$ **0.7 V**
   $I_{D_Q} \cong$ **15 mA**
   $V_R = E - V_{D_Q}$ = 12 V − 0.7 V = **11.3 V**

   (c) $V_{D_Q} \cong$ **0 V**
   $I_{D_Q} \cong$ **16 mA**
   $V_R = E - V_{D_Q}$ = 12 V − 0 V = **12 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) $I_D = \dfrac{E}{R} = \dfrac{6\text{ V}}{0.2\text{ k}\Omega}$ = 30 mA
   The load line extends from I_D = 30 mA to V_D = 6 V.
   $V_{D_Q} \cong$ **0.95 V**, $I_{D_Q} \cong$ **25.3 mA**

   (b) $I_D = \dfrac{E}{R} = \dfrac{6\text{ V}}{0.47\text{ k}\Omega}$ = 12.77 mA
   The load line extends from I_D = 12.77 mA to V_D = 6 V.
   $V_{D_Q} \cong$ **0.8 V**, $I_{D_Q} \cong$ **11 mA**

   (c) $I_D = \dfrac{E}{R} = \dfrac{6\text{ V}}{0.68\text{ k}\Omega}$ = 8.82 mA
   The load line extends from I_D = 8.82 mA to V_D = 6 V.
   $V_{D_Q} \cong$ **0.78 V**, $I_{D_Q} \cong$ **78 mA**

   The resulting values of V_{D_Q} are quite close, while I_{D_Q} extends from 7.8 mA to 25.3 mA.

3. Load line through I_{D_Q} = 10 mA of characteristics and V_D = 7 V will intersect I_D axis as 11.3 mA.
   $I_D = 11.3\text{ mA} = \dfrac{E}{R} = \dfrac{7\text{ V}}{R}$
   with $R = \dfrac{7\text{ V}}{11.3\text{ mA}}$ = 619.47 kΩ ≅ **0.62 kΩ** standard resistor

4. (a) $I_D = I_R = \dfrac{E - V_D}{R} = \dfrac{30\text{ V} - 0.7\text{ V}}{1.5\text{ k}\Omega} = \mathbf{19.53\ mA}$

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

(b) $I_D = \dfrac{E - V_D}{R} = \dfrac{30\text{ V} - 0\text{ V}}{1.5\text{ k}\Omega} = \mathbf{20\ mA}$

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

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)

$I(20\ \Omega) = \dfrac{19.3\text{ V}}{20\ \Omega} = 0.965\text{ A}$

$V(10\ \Omega) = 20\text{ V} - 0.7\text{ V} = 19.3\text{ V}$

$I(10\ \Omega) = \dfrac{19.3\text{ V}}{10\ \Omega} = 1.93\text{ A}$

$I = I(10\ \Omega) + I(20\ \Omega)$

$= \mathbf{2.895\ A}$

(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,

$I_D = \dfrac{8\text{ V} + 6\text{ V} - 0.7\text{ V}}{1.2\text{ k}\Omega + 4.7\text{ k}\Omega} = \mathbf{2.25\ mA}$

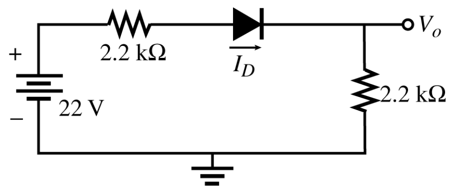
$V_o = 8\text{ V} - (2.25\text{ mA})(1.2\text{ k}\Omega) = \mathbf{5.3\ V}$

7. (a) $V_o = \dfrac{10\text{ k}\Omega(12\text{ V} - 0.7\text{ V} - 0.3\text{ V})}{2\text{ k}\Omega + 10\text{ k}\Omega} = \mathbf{9.17\ V}$

(b) $V_o = \mathbf{10\ V}$

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

$$I_D = \frac{22 \text{ V} - 0.7 \text{ V}}{2.2 \text{ k}\Omega + 2.2 \text{ k}\Omega} = \mathbf{4.84 \text{ mA}}$$

$V_o = I_D(1.2 \text{ k}\Omega)$
$= (4.84 \text{ mA})(1.2 \text{ k}\Omega)$
$= \mathbf{5.81 \text{ V}}$

(b) Diode forward-biased

$$I_D = \frac{20 \text{ V} + 20 \text{ V} - 0.7 \text{ V}}{6.8 \text{ k}\Omega} = \mathbf{5.78 \text{ mA}}$$

Kirchhoff's voltage law (CW):
$+V_o - 0.7 \text{ V} + 20 \text{ V} = 0$
$V_o = \mathbf{-19.3 \text{ V}}$

9. (a) $V_{o_1} = 12 \text{ V} - 0.7 \text{ V} = \mathbf{11.3 \text{ V}}$
$V_{o_2} = \mathbf{1.2 \text{ V}}$

(b) $V_{o_1} = \mathbf{0 \text{ V}}$
$V_{o_2} = \mathbf{0 \text{ V}}$

10. (a) Both diodes forward-biased
Si diode turns on first and locks in 0.7 V drop.

$$I_R = \frac{12 \text{ V} - 0.7 \text{ V}}{4.7 \text{ k}\Omega} = 2.4 \text{ mA}$$

$I_D = I_R = \mathbf{2.4 \text{ mA}}$
$V_o = 12 \text{ V} - 0.7 \text{ V} = \mathbf{11.3 \text{ V}}$

(b) Right diode forward-biased:

$$I_D = \frac{20 \text{ V} + 4 \text{ V} - 0.7 \text{ V}}{2.2 \text{ k}\Omega} = \mathbf{10.59 \text{ mA}}$$

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

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

$$I = \frac{1 \text{ V} - 0.7 \text{ V}}{1 \text{ k}\Omega} = \frac{0.3 \text{ V}}{1 \text{ k}\Omega} = \mathbf{0.3 \text{ mA}}$$

$V_o = 1 \text{ V} - 0.7 \text{ V} = \mathbf{0.3 \text{ V}}$

(b) $$I = \frac{16 \text{ V} - 0.7 \text{ V} - 0.7 \text{ V} + 4 \text{ V}}{4.7 \text{ k}\Omega} = \frac{18.6 \text{ V}}{4.7 \text{ k}\Omega} = \mathbf{3.96 \text{ mA}}$$

$V_o = 16 \text{ V} - 0.7 \text{ V} - 0.7 \text{ V} = \mathbf{14.6 \text{ V}}$

12. Both diodes forward-biased:

$V_{o_1} = \mathbf{0.7\ V}$, $V_{o_2} = \mathbf{0.7\ V}$

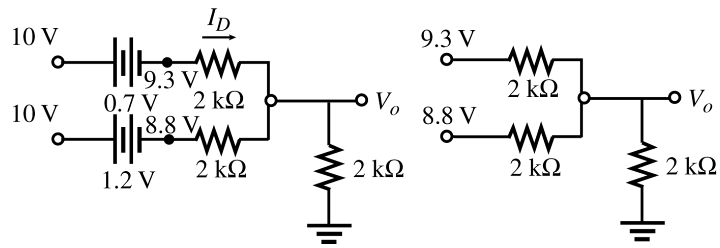
$$I_{1\,k\Omega} = \frac{20\ V - 0.7\ V}{1\ k\Omega} = \frac{19.3\ V}{1\ k\Omega} = 19.3\ mA$$

$I_{0.47\,k\Omega} = 0$ mA

$I = I_{1\,k\Omega} - I_{0.47\,k\Omega} = 19.3\ mA - 0\ mA$

$= \mathbf{19.3\ mA}$

13.



Superposition: $V_{o_1}(9.3\ V) = \dfrac{1\ k\Omega(9.3\ V)}{1\ k\Omega + 2\ k\Omega} = 3.1\ V$

$$V_{o_2}(8.8\ V) = \frac{16\ k\Omega(8.8\ V)}{1\ k\Omega + 2\ k\Omega} = 2.93\ V$$

$$V_o = V_{o_1} + V_{o_2} = \mathbf{6.03\ V}$$

$$I_D = \frac{9.3\ V - 6.03\ V}{2\ k\Omega} = \mathbf{1.635\ mA}$$

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

$V_o = \mathbf{0\ V}$

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

16. Both diodes "on".

$V_o = \mathbf{0.7\ V}$

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

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

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

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:

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

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

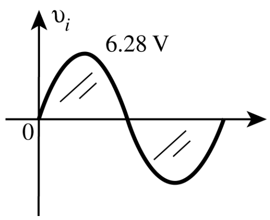
$V_o = \mathbf{+10\ V}$

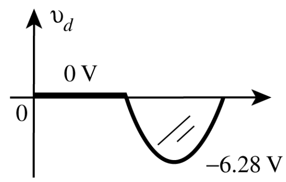
as established by 10 V supply connected to 1 kΩ resistor.

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".

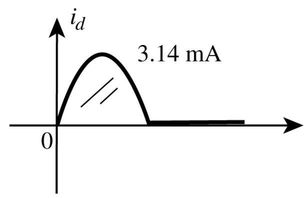
The result: $V_o = 5\text{ V} - 0.3\text{ V} = \mathbf{4.7\ V}$
The result supports the above assumptions.

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

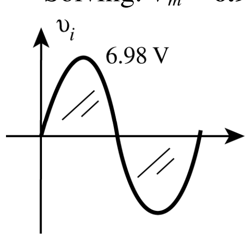


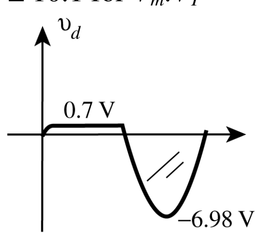


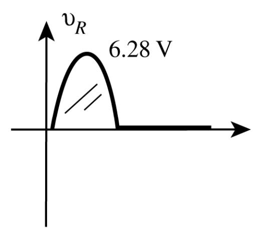
$I_m = \dfrac{V_m}{R} = \dfrac{6.28\text{ V}}{2\text{ k}\Omega} = \mathbf{3.14\ mA}$

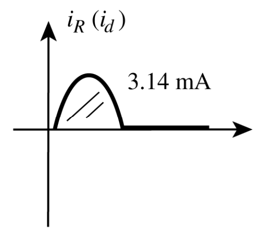


23. Using $V_{dc} \cong 0.318(V_m - V_T)$
$2\text{ V} = 0.318(V_m - 0.7\text{ V})$
Solving: $V_m = \mathbf{6.98\ V} \cong 10{:}1$ for $V_m{:}V_T$

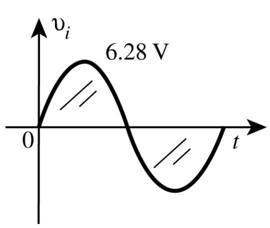


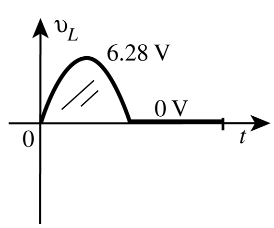




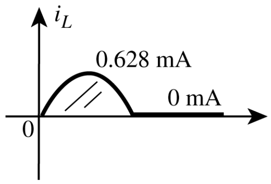


24. $V_m = \dfrac{V_{dc}}{0.318} = \dfrac{2\text{ V}}{0.318} = \mathbf{6.28\ V}$



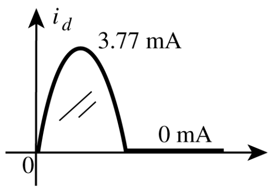


$I_{L_{max}} = \dfrac{6.28\text{ V}}{10\text{ k}\Omega} = \mathbf{0.628\ mA}$

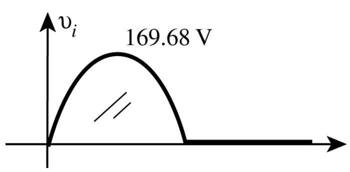


$I_{max}(2\text{ k}\Omega) = \dfrac{6.28\text{ V}}{2\text{ k}\Omega} = \mathbf{3.14\text{ mA}}$

$I_{D_{max}} = I_{L_{max}} + I_{max}(2\text{ k}\Omega) = 0.678\text{ mA} + 3.14\text{ mA} = \mathbf{3.77\text{ mA}}$



25. $V_m = \sqrt{2}\,(120\text{ V}) = 169.68\text{ V}$
$V_{dc} = 0.318V_m = 0.318(169.68\text{ V}) = \mathbf{53.96\text{ V}}$



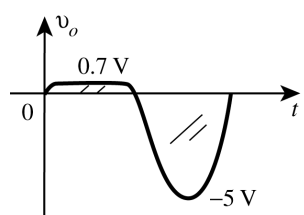
26. Diode will conduct when $v_o = 0.7$ V; that is,

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

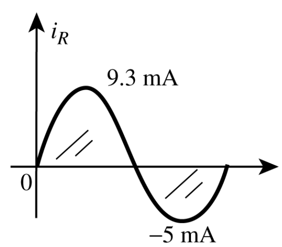
Solving: $v_i = \mathbf{1.4\text{ V}}$

For $v_i \geq 1.4$ V Si diode is "on" and $v_o = \mathbf{0.7\text{ V}}$.
For $v_i < 1.4$ V Si diode is open and level of v_o is determined by voltage divider rule:

$$v_o = \frac{1\text{ k}\Omega(v_i)}{1\text{ k}\Omega + 1\text{ k}\Omega} = 0.5\,v_i$$



For $v_i = -10$ V:
$v_o = 0.5(-10\text{ V})$
$= \mathbf{-5\text{ V}}$



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

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

$I_{max}(\text{reverse}) = \dfrac{10\text{ V}}{1\text{ k}\Omega + 1\text{ k}\Omega} = \mathbf{0.5\text{ mA}}$

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) $I_{\max} = 2 \times 20 \text{ mA} = \mathbf{40 \text{ mA}}$

(c) $4.7 \text{ k}\Omega \,||\, 68 \text{ k}\Omega = 4.4 \text{ k}\Omega$

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

$$I_{\max} = \frac{159.3 \text{ V}}{4.4 \text{ k}\Omega} = 36.2 \text{ mA}$$

$$I_d = \frac{I_{\max}}{2} = \mathbf{18.1 \text{ mA}}$$

(d) Total damage, **36.2 mA > 20 mA**

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

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

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

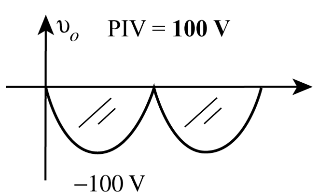
(b) $\text{PIV} = V_m(\text{load}) + V_D = 168.3 \text{ V} + 0.7 \text{ V} = \mathbf{169 \text{ V}}$

(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) $P_{\max} = V_D I_D = (0.7 \text{ V})I_{\max}$

$= (0.7 \text{ V})(168.3 \text{ mA})$

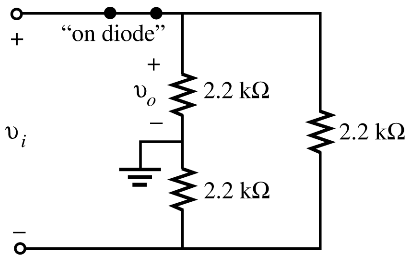
$= \mathbf{117.81 \text{ mW}}$

29. 

$$I_{\max} = \frac{100 \text{ V}}{2.2 \text{ k}\Omega} = \mathbf{45.45 \text{ mA}}$$

30. Positive half-cycle of v_i:

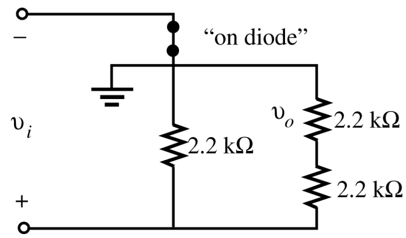
Network redrawn:



Voltage-divider rule:

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

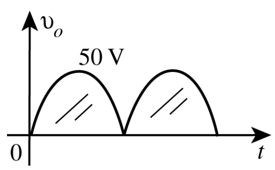
Negative half-cycle of υ_i:



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

Voltage-divider rule:

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



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

31. Positive pulse of v_i:

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

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

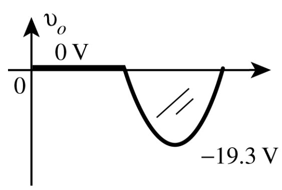
Negative pulse of v_i:

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

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

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

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



(b) For $v_i \le 8$ V the 8 V battery will ensure the diode is forward-biased and $v_o = v_i - 8$ V.

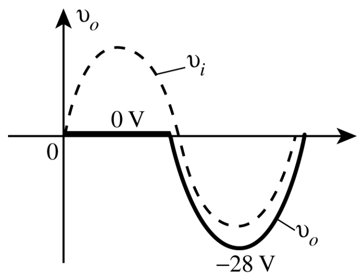
At $v_i = 8$ V

$v_o = 8\text{ V} - 8\text{ V} = \mathbf{0\ V}$

At $v_i = -20$ V

$v_o = -20\text{ V} - 8\text{ V} = \mathbf{-28\ V}$

For $v_i > 8$ V the diode is reverse-biased and $v_o = \mathbf{0\ V}$.

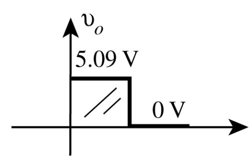


33. (a) Positive pulse of v_i:

$$V_o = \frac{1.8\text{ k}\Omega(12\text{ V} - 0.7\text{ V})}{1.8\text{ k}\Omega + 2.2\text{ k}\Omega} = \mathbf{5.09\ V}$$

Negative pulse of v_i:

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

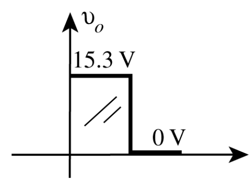


(b) Positive pulse of v_i:

$V_o = 12\text{ V} - 0.7\text{ V} + 4\text{ V} = \mathbf{15.3\ V}$

Negative pulse of v_i:

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

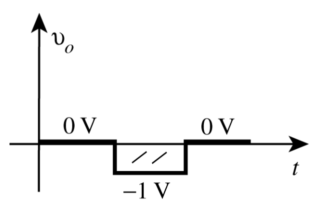


34. (a) For $v_i = 20$ V the diode is reverse-biased and $v_o = \mathbf{0\ V}$.

For $v_i = -5$ V, v_i overpowers the 4 V battery and the diode is "on".

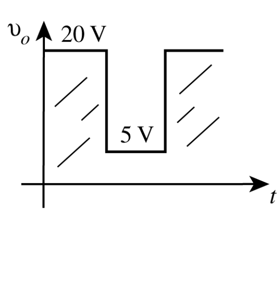
Applying Kirchhoff's voltage law in the clockwise direction:

$$-5\text{ V} + 4\text{ V} - v_o = 0$$
$$v_o = \mathbf{-1\ V}$$



(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 $v_o = v_i = \mathbf{20\ V}$.

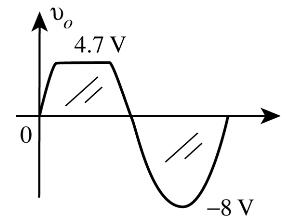
For $v_i = -5$ V, both v_i and the 5 V supply reverse-bias the diode and separate v_i from v_o. However, v_o is connected directly through the 2.2 kΩ resistor to the 5 V supply and $v_o = \mathbf{5\ V}$.



35. (a) Diode "on" for $v_i \geq 4.7$ V

For $v_i > 4.7$ V, $V_o = 4 \text{ V} + 0.7 \text{ V} = \mathbf{4.7\ V}$

For $v_i < 4.7$ V, diode "off" and $v_o = \boldsymbol{v_i}$



(b) Again, diode "on" for $v_i \geq 3.7$ V but v_o now defined as the voltage across the diode

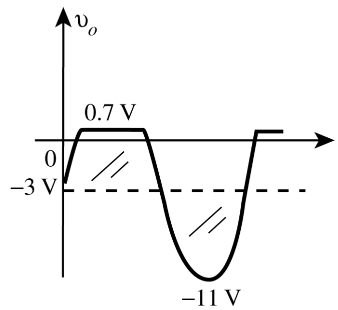
For $v_i \geq 3.7$ V, $v_o = \mathbf{0.7\ V}$

For $v_i < 3.7$ V, diode "off", $I_D = I_R = 0$ mA and $V_{2.2\text{ k}\Omega} = IR = (0\text{ mA})R = 0$ V

Therefore, $v_o = v_i - 3$ V

At $v_i = 0$ V, $v_o = \mathbf{-3\ V}$

$v_i = -8$ V, $v_o = -8 \text{ V} - 3 \text{ V} = \mathbf{-11\ V}$



36. For the positive region of v_i:

The right Si diode is reverse-biased.

The left Si diode is "on" for levels of v_i greater than 5.3 V + 0.7 V = 6 V. In fact, $v_o = \mathbf{6\ V}$ for $v_i \geq 6$ V.

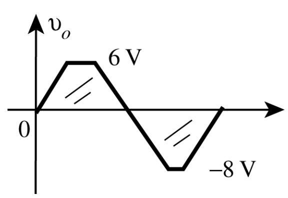
For $v_i < 6$ V both diodes are reverse-biased and $v_o = \boldsymbol{v_i}$.

For the negative region of v_i:

The left Si diode is reverse-biased.

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

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



i_R: For $-8 \text{ V} < v_i < 6$ 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, $v_R = 10 \text{ V} - 6 \text{ V} = 4$ V

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

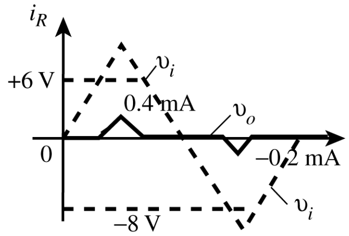
For $v_i \leq -8$ V

$v_R = v_i - v_o = v_i + 8$ V

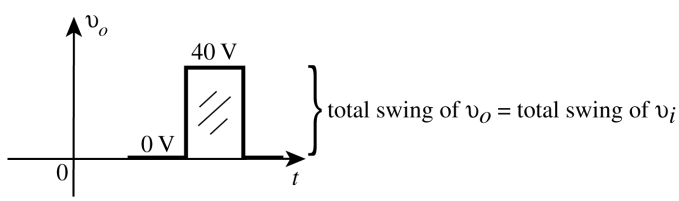
For $v_i = -10$ V

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

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

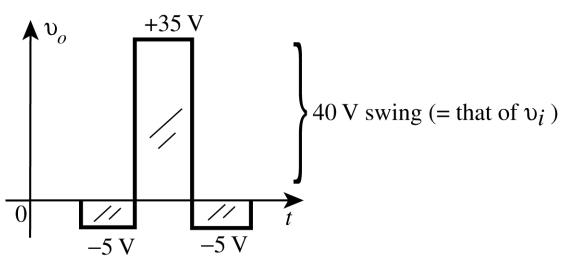


37. (a) Starting with $v_i = -20$ V, the diode is in the "on" state and the capacitor quickly charges to −20 V+. During this interval of time v_o is across the "on" diode (short-current equivalent) and $v_o = 0$ V.
When v_i switches to the +20 V level the diode enters the "off" state (open-circuit equivalent)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

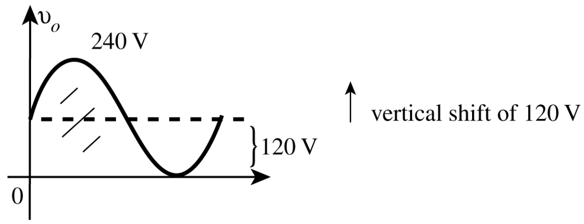


(b) Starting with $v_i = -20$ V, the diode is in the "on" state and the capacitor quickly charges up to −15 V+. Note that $v_i = +20$ V and the 5 V supply are additive across the capacitor. During this time interval v_o is across "on" diode and 5 V supply and $v_o = -5$ V.

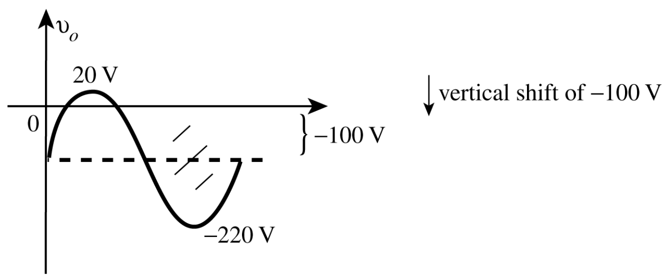
When v_i switches to the +20 V level the diode enters the "off" state and $v_o = v_i + v_C = 20\text{ V} + 15\text{ V} = 35\text{ V}$.



38. (a) For negative half cycle capacitor charges to peak value of 120 V = 120 V with polarity (− –|(– +). The output v_o is directly across the "on" diode resulting in v_o = **0 V** as a negative peak value.
For next positive half cycle $v_o = v_i + 120$ V with peak value of
v_o = 120 V + 120 V = **240 V**.



(b) For positive half cycle capacitor charges to peak value of 120 V − 20 V = 100 V with polarity (+ –|(– −). The output v_o = 20 V = **20 V**
For next negative half cycle $v_o = v_i - 100$ V with negative peak value of
v_o = −120 V − 100 V = **−220 V**.

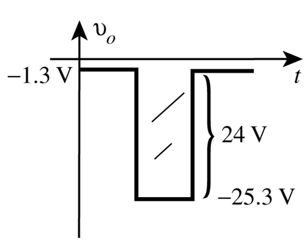


39. (a) $\tau = RC$ = (56 kΩ)(0.1 μF) = 5.6 ms
5τ = **28 ms**

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

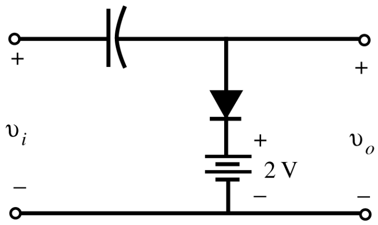
(c) Positive pulse of v_i:
Diode "on" and v_o = −2 V + 0.7 V = −1.3 V
Capacitor charges to 12 V + 2 V − 0.7 V = 13.3 V

Negative pulse of v_i:
Diode "off" and v_o = −12 V − 13.3 V = −25.3 V



40. Solution is network of Fig. 2.181(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

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

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

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

with I_Z = **0 mA**
and V_L = **9 V**

(b) In the absence of the Zener diode

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

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

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

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

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

and $I_Z = I_{R_s} - I_L = 45.45\text{ mA} - 21.28\text{ mA}$ = **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 = **220 Ω**

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

$I_{ZM} = I_{R_S} - I_L = 60\text{ mA} - 20\text{ mA} =$ **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.

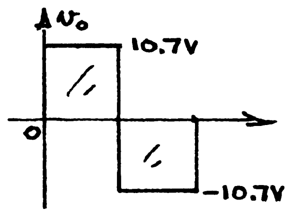
Therefore, $V_o = V_{Z_1} + V_{Z_2} = 0.7\text{ V} + 10\text{ V} =$ **10.7 V**

For $v_i = -50$ V:

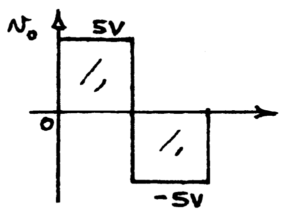
Z_1 reverse-biased at the Zener potential and $V_{Z_1} = -10$ V.

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 $\mathbf{2V_m}$

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

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

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

13. (a) $I_C \cong I_E =$ **3.5 mA**

(b) $I_C \cong I_E =$ **3.5 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, $I_E \cong 2$ mA
Then Fig. 3.8 results in $I_C \cong$ **2 mA**

(b) Using Fig. 3.8 first, $I_E \cong 5$ mA
Then Fig. 3.7 results in $V_{BE} \cong$ **0.77 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) $I_C = \alpha I_E = (0.998)(4\text{ mA}) = \mathbf{3.992\ mA}$

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

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

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

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

16. –

17. –

18. (a) Fig. 3.13(b): $I_B \cong \mathbf{35\mu A}$
Fig. 3.13(a): $I_C \cong$ **3.6 mA**

(b) Fig. 3.14(a): $V_{CE} \cong$ **12 V**
Fig. 3.14(b): $V_{BE} \cong$ **0.75 V**

19. (a) $\beta_{\text{dc}} = \dfrac{I_C}{I_B} = \dfrac{2\text{ mA}}{18\ \mu\text{A}} = \mathbf{111.11}$

(b) $\alpha = \dfrac{\beta}{\beta+1} = \dfrac{111.11}{111.11+1} = \mathbf{0.991}$

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

(d) $I_{CBO} = (1-\alpha)I_{CEO}$
$= (1 - 0.991)(0.3\text{ mA}) = \mathbf{2.7\ \mu A}$

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

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

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

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

$I_{CBO} \cong (1 - \alpha)I_{CEO}$
$= (1 - 0.9926)(0.3 \text{ mA})$
$=$ **2.2 μA**

21. (a) $\beta_{\text{dc}} = \dfrac{I_C}{I_B} = \dfrac{5.25 \text{ mA}}{60\ \mu\text{A}}$ = **87.5**

(b) $\beta_{\text{dc}} = \dfrac{I_C}{I_B} = \dfrac{3.25 \text{ mA}}{30\ \mu\text{A}}$ = **108.3**

(c) $\beta_{\text{dc}} = \dfrac{I_C}{I_B} = \dfrac{1.35 \text{ mA}}{10\ \mu\text{A}}$ = **135**

(d) Yes, highest at lowest levels of I_C.

22. (a) $\beta_{\text{ac}} = \dfrac{\Delta I_C}{\Delta I_B} = \dfrac{5.9 \text{ mA} - 4.6 \text{ mA}}{70\ \mu\text{A} - 50\ \mu\text{A}}$ = **65**

(b) $\beta_{\text{ac}} = \dfrac{\Delta I_C}{\Delta I_B} = \dfrac{4.1 \text{ mA} - 2.3 \text{ mA}}{40\ \mu\text{A} - 20\ \mu\text{A}}$ = **90**

(c) $\beta_{\text{ac}} = \dfrac{\Delta I_C}{\Delta I_B} = \dfrac{2.4 \text{ mA} - 0.3 \text{ mA}}{20\ \mu\text{A} - 0\ \mu\text{A}}$ = **105**

(d) Yes, highest at lowest levels of I_C.

(e)

	I_C	β_{dc}	β_{ac}	V_{CE}	$\beta_{dc}/\beta_{\text{ac}}$
a.	5.25 mA	87.5	65	4 V	1.35
b.	3.25 mA	108.3	90	7 V	1.20
c.	1.35 mA	135	105	10 V	1.29

$\beta_{dc} > \beta_{\text{ac}}$ although ratio consistent over scope of characteristics.

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

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

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

24. (a) $\beta = \dfrac{\alpha}{1-\alpha} = \dfrac{0.980}{1-0.980}$ = **49**

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

(c) $I_B = \frac{I_C}{\beta} = \frac{2\text{ mA}}{120}$ = **16.66 μA**

$I_E = I_C + I_B = 2\text{ mA} + 16.66\ \mu\text{A} \cong$ **2.017 mA**

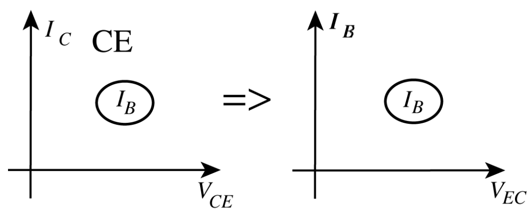
25. –

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

$A_v = \frac{V_o}{V_i} = \frac{1.9\text{ V}}{2\text{ V}}$ = **0.95** ≅ 1

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

27. 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.

28. $P_{C_{\max}} = 35\text{ mW} = V_{CE}I_C$

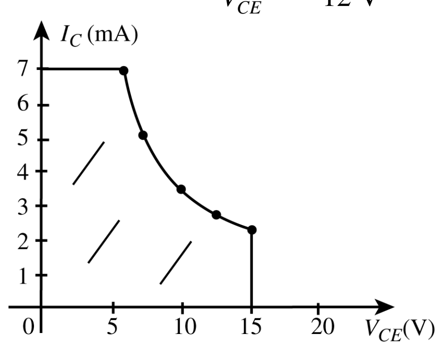
$I_C = I_{C_{\max}}$, $V_{CE} = \frac{P_{C_{\max}}}{I_{C_{\max}}} = \frac{35\text{ mW}}{6\text{ mA}} = 5.83\text{ V}$

$V_{CE} = V_{CE_{\max}}$, $I_C = \frac{P_{C_{\max}}}{V_{CE_{\max}}} = \frac{35\text{ mW}}{20\text{ V}} = 2.33\text{ mA}$

$V_{CE} = 10\text{ V}$, $I_C = \frac{P_{C_{\max}}}{V_{CE}} = \frac{35\text{ mW}}{10\text{ V}} = 3.5\text{ mA}$

$I_C = 5\text{ mA}$, $V_{CE} = \frac{P_{C_{\max}}}{I_C} = \frac{35\text{ mW}}{5\text{ mA}} = 7.00\text{ V}$

$V_{CE} = 15\text{ V}$, $I_C = \frac{P_{C_{\max}}}{V_{CE}} = \frac{35\text{ mW}}{12\text{ V}} = 2.91\text{ mA}$

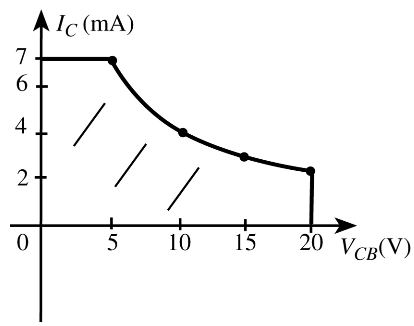


29. $I_C = I_{C_{max}}$, $V_{CE} = \dfrac{P_{C_{max}}}{I_{C_{max}}} = \dfrac{42 \text{ mW}}{7 \text{ mA}}$ $= \mathbf{6\ V}$

$V_{CB} = V_{CB_{max}}$, $I_C = \dfrac{P_{C_{max}}}{V_{CB_{max}}} = \dfrac{42 \text{ mW}}{20 \text{ V}}$ $= \mathbf{2.1\ mA}$

$I_C = 4$ mA, $V_{CB} = \dfrac{P_{C_{max}}}{I_C} = \dfrac{42 \text{ mW}}{4 \text{ mA}}$ $= \mathbf{10.5\ V}$

$V_{CB} = 10$ V, $I_C = \dfrac{P_{C_{max}}}{V_{CB}} = \dfrac{42 \text{ mW}}{15 \text{ V}}$ $= \mathbf{2.8\ mA}$



30. The operating temperature range is $-55°C \le T_J \le 150°C$

$$°F = \frac{9}{5}°C + 32°$$

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

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

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

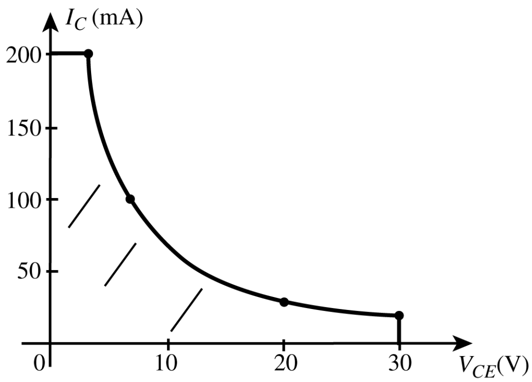
31. $I_{C_{max}} = 200$ mA, $V_{CE_{max}} = 30$ V, $P_{D_{max}} = 625$ mW

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

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

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

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



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

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

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

33. 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.

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

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

(b) The results confirm the conclusions of problems 21 and 22 that beta tends to increase with increasing collector current.

36. $T_j = +125°\text{C}$: $1.45(\beta_{\text{norm}})$
$T_j = +25°\text{C}$: $0.95(\beta_{\text{norm}})$
$T_j = -55°\text{C}$: $0.5(\beta_{\text{norm}})$
Yes, 34% drop between +125°C and 25°C. 65.5% drop between +125°C and −55°C.

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

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

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

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

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

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

Chapter 4

1. (a) $I_{B_Q} = \dfrac{V_{CC} - V_{BE}}{R_B} = \dfrac{16\text{ V} - 0.7\text{ V}}{510\text{ k}\Omega} = \dfrac{15.3\text{ V}}{510\text{ k}\Omega} = \mathbf{30\ \mu A}$

(b) $I_{C_Q} = \beta I_{B_Q}$ = (120)(30 μA) = **3.6 mA**

(c) $V_{CE_Q} = V_{CC} - I_{C_Q} R_C$ = 16 V − (3.6 mA)(1.8 kΩ) = **9.52 V**

(d) $V_C = V_{CE_Q}$ = **6.48 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) $R_C = \dfrac{V_{R_C}}{I_C} = \dfrac{V_{CC} - V_C}{I_C} = \dfrac{12\text{ V} - 6\text{ V}}{3.2\text{ mA}} = \dfrac{6\text{ V}}{3.2\text{ mA}} = \mathbf{1.875\ k\Omega}$

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

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

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

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: $R_B = \dfrac{V_{CC} - V_{BE}}{I_B} = \dfrac{21\text{ V} - 0.7\text{ V}}{25\ \mu\text{A}} = \mathbf{812\ k\Omega}$

(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) $I_{C_{sat}} = \dfrac{V_{CC}}{R_C} = \dfrac{21 \text{ V}}{3 \text{ k}\Omega}$ = **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. (b) $I_{B_Q} = \dfrac{V_{CC} - V_{BE}}{R_B} = \dfrac{16 \text{ V} - 0.7 \text{ V}}{510 \text{ k}\Omega}$ = 30 μA

V_{CE_Q} = **8.5 V**, I_{C_Q} = **4.1 mA**

(c) $\beta = \dfrac{I_C}{I_B} = \dfrac{4.1 \text{ mA}}{30\ \mu\text{A}}$ = **136.67**

7. $I_{B_Q} = \dfrac{16 \text{ V} - 0.7 \text{ V}}{910 \text{ k}\Omega}$ = 16.81 μA

$I_{C_Q} = \beta I_{B_Q}$ = (120)(16.81 μA) = **2.017 mA**

(from characteristics) V_{E_Q} = **11.5 V**, I_{C_Q} = **2.4 mA**

8. (a) $I_{B_Q} = \dfrac{V_{CC} - V_{BE}}{R_B + (\beta+1)R_E} = \dfrac{20 \text{ V} - 0.7 \text{ V}}{270 \text{ k}\Omega + (126)2.2 \text{ k}\Omega} = \dfrac{19.3 \text{ V}}{547.2 \text{ k}\Omega}$

= **35.27 μA**

(b) $I_{C_Q} = \beta I_{B_Q}$ = (125)(35.27 μA) = **4.41 mA**

(c) $V_{CE_Q} = V_{CC} - I_C(R_C + R_E)$ = 20 V − (4.41 mA)(470 kΩ + 2.2 kΩ)

= 20 V − 11.77 V

= **8.23 V**

(d) $V_C = V_{CC} - I_C R_C$ = 20 V − (4.41 mA)(470 kΩ) = 20 V − 2.07 V

= **17.93 V**

(e) $V_B = V_{CC} - I_B R_B$ = 20 V − (35.27 μA)(270 kΩ)

= 20 V − 9.52 V = **10.48 V**

(f) $V_E = V_C - V_{CE}$ = 17.93 V − 8.23 V = **9.7 V**

9. (a) $I_{B_Q} = 35.27\ \mu\text{A}$ using β from problem 8.

$$I_{\text{sat}} = \frac{20\text{ V}}{2.2\text{ k}\Omega + 470\ \Omega} = 7.49\text{ mA}$$

(b) I_{C_Q} **= 4.7 mA**, V_{CE_Q} **= 7.5 V**

(c) $\beta = \dfrac{I_C}{I_B} = \dfrac{4.7\text{ mA}}{35.27\ \mu\text{A}}$ **= 133.25**

(d) reasonably close

(e) different β and Q pt.

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

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

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

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

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

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

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

(b) $V_{CC} = V_{R_C} + V_{CE} + V_E$

$= (3.09\text{ mA})(2.7\text{ k}\Omega) + 7.3\text{ V} + 2.1\text{ V} = 8.34\text{ V} + 7.3\text{ V} + 2.1\text{ V}$
= 17.74 V

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

$= \dfrac{14.94\text{ V}}{20\ \mu\text{A}}$ **= 747 kΩ**

12. $I_{C_{\text{sot}}} = \dfrac{V_{CC}}{R_C + R_E} = \dfrac{20\text{ V}}{470\ \Omega + 2.2\text{ k}\Omega} = \dfrac{20\text{ V}}{2.67\text{ k}\Omega}$ **= 7.49 mA**

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

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

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

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

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

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

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

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

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

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

14. (a) Problem 1: $I_{C_Q} = \mathbf{3.6 \text{ mA}}$, $V_{CE_Q} = \mathbf{6.48 \text{ V}}$

(b) $I_{B_Q} = 30 \ \mu\text{A}$ (the same)

$I_{C_Q} = \beta I_{B_Q} = (180)(30 \ \mu\text{A}) = 5.4 \text{ mA}$

$V_{CE_Q} = V_{CC} - I_{C_Q} R_C = 16 \text{ V} - (5.4 \text{ mA})(1.8 \text{ k}\Omega) = \mathbf{6.28 \text{ V}}$

(c) $\% \Delta I_C = \left| \dfrac{5.4 \text{ mA} - 3.6 \text{ mA}}{3.6 \text{ mA}} \right| \times 100\% = \mathbf{50\%}$

$\% \Delta V_{CE} = \left| \dfrac{9.52 \text{ V} - 6.28 \text{ V}}{6.28 \text{ V}} \right| \times 100\% = \mathbf{51.6\%}$

About 50% change for each.

(d) Problem 8: $I_{C_Q} = \mathbf{4.41 \text{ mA}}$, $V_{CE_Q} = \mathbf{8.23 \text{ V}}$ ($I_{B_Q} = 35.27 \ \mu\text{A}$)

(e) $I_{B_Q} = \dfrac{V_{CC} - V_{BE}}{R_B + (\beta + 1) R_E} = \dfrac{20 \text{ V} - 0.7 \text{ V}}{270 \text{ k}\Omega + (187.5 + 1)(2.2 \text{ k}\Omega)} = 28.19 \ \mu\text{A}$

$I_{C_Q} = \beta I_{B_Q} = (187.5)(28.19 \ \mu\text{A}) = \mathbf{5.29 \text{ mA}}$

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

$= 20 \text{ V} - (5.29 \text{ mA})(470 \text{ k}\Omega + 2.2 \text{ k}\Omega) = \mathbf{5.88 \text{ V}}$

(f) $\%\Delta I_C = \left|\dfrac{5.29\text{ mA} - 4.41\text{ mA}}{4.41\text{ mA}}\right| \times 100\% = \mathbf{20\%}$

$\%\Delta V_{CE} = \left|\dfrac{5.88\text{ V} - 8.23\text{ V}}{8.23\text{ V}}\right| \times 100\% = \mathbf{28.6\%}$

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

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

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

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

(a) Use exact approach:

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

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

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

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

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

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

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

$= \mathbf{8.17\ V}$

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

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

$= \mathbf{9.33\ V}$

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

$= \mathbf{1.16\ V}$

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

$= \mathbf{1.86\ V}$

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

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

$$I_{B_Q} = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta+1)R_E} = \frac{2.05\text{ V} - 0.7\text{ V}}{7.94\text{ k}\Omega + (140+1)(0.68\text{ k}\Omega)}$$

$= \mathbf{13\ \mu A\ (vs.\ 21.42\ \mu A)}$

$I_{C_Q} = \beta I_{B_Q} = (140)(13\ \mu\text{A}) = \mathbf{1.82\ mA}$ (vs. 1.71 mA)

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

$= 16\text{ V} - (1.82\text{ mA})(3.9\text{ k}\Omega + 0.68\text{ k}\Omega)$

$= \mathbf{7.66\ V}$ (vs. 8.17 V)

$V_C = V_{CC} - I_C R_C$
$= 16 \text{ V} - (1.82 \text{ mA})(3.9 \text{ k}\Omega)$
$= \mathbf{8.9 \text{ V}}$ (vs. 9.33 V)
$V_E = I_E R_E \cong I_C R_E = (1.82 \text{ mA})(0.68 \text{ k}\Omega)$
$= \mathbf{1.24 \text{ V}}$ (vs. 1.16 V)
$V_B = V_E + V_{BE} = 1.24 \text{ V} + 0.7 \text{ V}$
$= \mathbf{1.94 \text{ V}}$ (vs. 1.86 V)

(b) I_{B_Q} affected the most

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

(b) $V_E = I_E R_E \cong I_C R_E = (1.28 \text{ mA})(1.2 \text{ k}\Omega) = \mathbf{1.54 \text{ V}}$
(c) $V_B = V_{BE} + V_E = 0.7 \text{ V} + 1.54 \text{ V} = \mathbf{2.24 \text{ V}}$

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

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

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

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

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

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

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

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

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

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

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

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

20. (a) Testing $\beta R_E \geq 10R_z$

$(140)(0.68\text{ k}\Omega) \geq 10(9.1\text{ k}\Omega)$

$95.2\text{ k}\Omega \geq 91\text{ k}\Omega$ satisfied (barely)

Applying the approximation approved:

$V_B = \dfrac{R_2V_{CC}}{R_1 + R_2} = \dfrac{(9.1\text{ k}\Omega)(16\text{ V})}{62\text{ k}\Omega + 9.1\text{ k}\Omega}$ = **2.05 V** (vs. 1.95 V)

$V_E = V_B - V_{BE} = 2.05\text{ V} - 0.7\text{ V}$ = **1.35 V** (vs. 1.24 V)

$I_C \cong I_E = \dfrac{V_E}{R_E} = \dfrac{1.35\text{ V}}{0.68\text{ k}\Omega}$ = **1.99 mA** (vs. 1.82 mA)

$V_C = V_{CC} - I_CR_C = 16\text{ V} - (1.99\text{ mA})(3.9\text{ k}\Omega)$ = **8.24 V** (vs 8.9 V)

$V_{CE} = V_C - V_E = 8.24\text{ V} - 1.35\text{ V}$ = **6.89 V** (vs 7.66 V)

21. (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)

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

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

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

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

$= 18\text{ V} - (2.43\text{ mA})(3.3\text{ k}\Omega + 1\text{ k}\Omega)$

= **7.55 V**

(c) $I_B = \dfrac{I_C}{\beta} = \dfrac{2.43\text{ mA}}{120}$ = **20.25 μA**

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

(e) V_B = **3.13 V**

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

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

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

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

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

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

(c) **19.02 μA** (vs. 20.25 μA #16)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

25. (a) From problem 12b, I_C = **1.71 mA**
From problem 12c, V_{CE} = **8.17 V**

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

$$I_B = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta+1)R_E} = \frac{2.05\text{ V} - 0.7\text{ V}}{7.94\text{ k}\Omega + (121)(0.68\text{ k}\Omega)}$$
$$= 14.96\ \mu\text{A}$$

$I_C = \beta I_B = (120)(14.96\ \mu\text{A})$ = **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)
$$\%\Delta I_C = \left|\frac{1.8\text{ mA} - 1.71\text{ mA}}{1.71\text{ mA}}\right| \times 100\% = \mathbf{5.26\%}$$
$$\%\Delta V_{CE} = \left|\frac{7.76\text{ V} - 8.17\text{ V}}{8.17\text{ V}}\right| \times 100\% = \mathbf{5.02\%}$$

(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.

26. (a) Problem 21: Approximation approach: I_{C_Q} = **2.43 mA**, V_{CE_Q} = **7.55 V**

Problem 22: Exact analysis: I_{C_Q} = **2.28 mA**, V_{CE_Q} = **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 $\%\Delta V_{CE} = 0\%$.

Problem 22: $E_{Th} = 3.13\text{ V}$, $R_{Th} = 6.78\text{ k}\Omega$

$$I_B = \frac{E_{TH} - V_{BE}}{R_{Th} + (\beta+1)R_E} = \frac{3.13\text{ V} - 0.7\text{ V}}{6.78\text{ k}\Omega + (180+1)1\text{ k}\Omega} = \frac{2.43\text{ V}}{187.78\text{ k}\Omega}$$
$$= 12.94\ \mu\text{A}$$

$I_C = \beta I_B = (180)(12.94\ \mu\text{A})$ = **2.33 mA**

$$V_{CE} = V_{CC} - I_C(R_C + R_E) = 18\text{ V} - (2.33\text{ mA})(3.3\text{ k}\Omega + 1\text{ k}\Omega)$$
$$= \mathbf{7.98\ V}$$

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

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

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

$\%\Delta I_C = 2.19\%$ vs. 49.83% for problem 14.
$\%\Delta V_{CE} = 2.68\%$ vs. 48.70% for problem 14.

Voltage-divider configuration considerably less sensitive.

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

27. (a) $I_B = \dfrac{V_{CC} - V_{BE}}{R_B + \beta(R_C + R_E)} = \dfrac{16\text{ V} - 0.7\text{ V}}{270\text{ k}\Omega + (120)(3.6\text{ k}\Omega + 1.2\text{ k}\Omega)}$
$= \mathbf{18.09\ \mu A}$

(b) $I_C = \beta I_B = (120)(18.09\ \mu\text{A})$
$= \mathbf{2.17\ mA}$

(c) $V_C = V_{CC} - I_C R_C$
$= 16\text{ V} - (2.17\text{ mA})(3.6\text{ k}\Omega)$
$= \mathbf{8.19\ V}$

28. (a) $I_{C_Q} \cong \dfrac{V_{CC} - V_{BE}}{R_C + R_E} = \dfrac{16\text{ V} - 0.7\text{ V}}{3.6\text{ k}\Omega + 1.2\text{ k}\Omega} = \mathbf{3.19\ mA}$

(b) $I_{C_Q} = \mathbf{3.19\ mA}$ vs 2.17 mA (not too close)

(c) $R' = R_C + R_E = 4.8\text{ k}\Omega$, $R_F/\beta = 270\text{ k}\Omega/120 = 2.25\text{ k}\Omega$
$\therefore R' \cong \mathbf{2(R_F/\beta)}$

(d) Yes, $I_{C_Q} = \beta I_{B_Q} = \dfrac{\beta(V_{CC} - V_{BE})}{R_F + \beta(R_C + R_E)} = \dfrac{V_{CC} - V_{BE}}{R_F/\beta + R_C + R_E}$

For $R_C + R_E >> R_F/\beta$, $\boldsymbol{I_{C_Q} \cong \dfrac{V_{CC} - V_{BE}}{R_C + R_E}}$

(e) $I_{C_Q} = \dfrac{16\text{ V} - 0.7\text{ V}}{\dfrac{270\text{ k}\Omega}{240} + 3.6\text{ k}\Omega + 1.2\text{ k}\Omega} = \mathbf{2.58\ mA}$ vs. 3.19 mA (much closer)

29. (a) $I_B = \dfrac{V_{CC} - V_{BE}}{R_B + \beta(R_C + R_E)} = \dfrac{30 \text{ V} - 0.7 \text{ V}}{550 \text{ k}\Omega + 180(8.2 \text{ k}\Omega + 1.8 \text{ k}\Omega)} = 12.47\ \mu\text{A}$

$I_C = \beta I_B = (180)(12.47\ \mu\text{A}) = \mathbf{2.24\ mA}$

(b) $V_C = V_{CC} - I_C R_C$
$= 30 \text{ V} - (2.24 \text{ mA})(8.2 \text{ k}\Omega) = 30 \text{ V} - 18.37 \text{ V} = \mathbf{11.63\ V}$

(c) $V_E = I_E R_E \cong I_C R_E = (2.24 \text{ mA})(1.8 \text{ k}\Omega) = \mathbf{4.03\ V}$

(d) $V_{CE} = V_{CC} - I_C(R_C + R_E) = 30 \text{ V} - (2.24 \text{ mA})(8.2 \text{ k}\Omega + 1.8 \text{ k}\Omega)$
$= \mathbf{7.6\ V}$

30. (a) $R' = R_C + R_E = 8.2 \text{ k}\Omega + 1.8 \text{ k}\Omega = 10 \text{ k}\Omega$
$R_F/\beta = 550 \text{ k}\Omega/180 = 3.06 \text{ k}\Omega$
$R' \cong \mathbf{3.27(R_F/\beta)}$ should be close

(b) $I_{C_Q} = \dfrac{V_{CC} - V_{BE}}{R_C + R_E} = \dfrac{30 \text{ V} - 0.7 \text{ V}}{8.2 \text{ k}\Omega + 1.8 \text{ k}\Omega} = \mathbf{2.93\ mA}$
$I_{C_Q} = \mathbf{2.93\ mA}$ relatively close to 2.24 mA

31. (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.

32. 1 MΩ = 0 Ω, R_B = 150 kΩ

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

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

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

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

$=$ **5.98 V**

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

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

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

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

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

$=$ **8.31 V**

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

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

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

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

$=$ **11.95 V**

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

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

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

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

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

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

$=$ **2.88 mA**

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

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

$=$ **−2.54 V**

35. (a) $V_B = \dfrac{82\text{ k}\Omega(12\text{ V})}{82\text{ k}\Omega + 22\text{ k}\Omega} = 9.46\text{ V}$

$V_E = V_B - V_{BE} = 9.46\text{ V} - 0.7\text{ V} = 8.76\text{ V}$

$I_E = \dfrac{V_E}{R_E} = \dfrac{8.76\text{ V}}{1.2\text{ k}\Omega} = \mathbf{7.3\text{ mA}}$

$I_B = \dfrac{I_E}{\beta+1} = \dfrac{7.3\text{ mA}}{111} = \mathbf{65.77\ \mu A}$

$I_C = \beta I_B = (110)(65.77\ \mu\text{A}) = \mathbf{7.23\text{ mA}}$

(b) $V_B =$ **9.46 V**, $V_C =$ **12 V**, $V_E =$ **8.76 V**

(c) $V_{BC} = V_B - V_C = 9.46\text{ V} - 12\text{ V} = \mathbf{-2.54\text{ V}}$

$V_{CE} = V_C - V_E = 12\text{ V} - 8.76\text{ V} = \mathbf{3.24\text{ V}}$

36. (a) $I_B = \dfrac{V_{EE} - V_{BE}}{R_B + (\beta+1)R_E} = \dfrac{12\text{ V} - 0.7\text{ V}}{9.1\text{ k}\Omega + (80+1)15\text{ k}\Omega}$

$= \mathbf{9.26\ \mu A}$

(b) $I_C = \beta I_B = (80)(9.26\ \mu\text{A}) = \mathbf{0.741\text{ mA}}$

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

$= 16\text{ V} + 12\text{ V} - (0.741\text{ mA})(27\text{ k}\Omega)$

$= \mathbf{8\text{ V}}$

(d) $V_C = V_{CC} - I_C R_C = 16\text{ V} - (0.741\text{ mA})(12\text{ k}\Omega) = \mathbf{7.11\text{ V}}$

37. (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) $V_{CE} = 10\text{ V} + 8\text{ V} - (3.32\text{ mA})(2.2\text{ k}\Omega + 1.8\text{ k}\Omega)$

$= 18\text{ V} - 13.28\text{ V}$

$= \mathbf{4.72\text{ V}}$

38. (a) $V_E = 4\text{ V} - 0.7\text{ V} = 3.3\text{ V}$

$I_E = \dfrac{V_E}{R_E} = \dfrac{V_E}{R_E} = \dfrac{3.3\text{ V}}{1.1\text{ k}\Omega} = 3\text{ mA}$

$I_C \cong I_E = 3\text{ mA}$

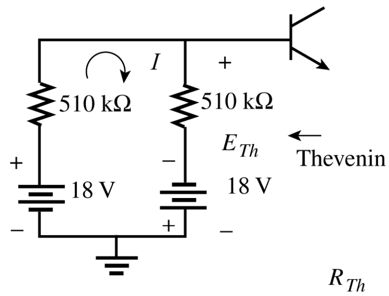
$V_C = 8\text{ V} = V_{CC} - I_C R_C = 14\text{ V} - (3\text{ mA})R_C$

$R_C = \mathbf{2\text{ k}\Omega}$

(b) $I_E = 3\text{ mA},\ I_B = \dfrac{I_E}{\beta+1} = \dfrac{3\text{ mA}}{91} = \mathbf{32.97\ \mu A}$

(c) $V_{BC} = V_B - V_C = 4\text{ V} - 8\text{ V} = \mathbf{-4\ V}$
$V_{CE} = V_C - V_E = 8\text{ V} - 3.3\text{ V} = \mathbf{4.7\ V}$

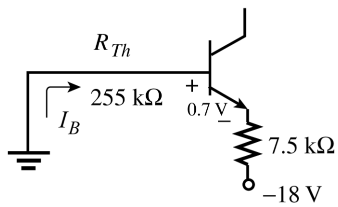
39. (a) $\beta R_E > 10R_2$ not satisfied $\therefore$ Use exact approach:
Network redrawn to determine the Thevenin equivalent:



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

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

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



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

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

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

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

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

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

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

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

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

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

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

Standard values:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Substituting in the above equation:

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

R_1 = **41.15 kΩ**

Standard values:

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

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

$R_E = \frac{V_E}{I_E} = \frac{5.6\text{ V}}{5\text{ mA}}$ = **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)

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

$V_B = \frac{R_2 V_{CC}}{R_2 + R_1} \Rightarrow 6.3\text{ V} = \frac{R_2(28\text{ V})}{R_2 + R_1}$ (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**

45. (a) $V_{B_1} = \frac{4.7\text{ k}\Omega(20\text{ V})}{4.7\text{ k}\Omega + 18\text{ k}\Omega}$ = **4.14 V**

$V_{E_1} = 4.14\text{ V} - 0.7\text{ V}$ = **3.44 V**

$I_{C_1} \cong I_{E_1} = \frac{3.44\text{ V}}{1\text{ k}\Omega} = 3.44\text{ mA}$

$V_{C_1} = 20\text{ V} - (3.44\text{ mA})(2.2\text{ k}\Omega)$ = **12.43 V**

$V_{B_2} = \frac{3.3\text{ k}\Omega(20\text{ V})}{3.3\text{ k}\Omega + 22\text{ k}\Omega}$ = **2.61 V**

$V_{E_2} = 2.61\text{ V} - 0.7\text{ V}$ = **1.91 V**

$$I_{E_2} \cong I_{C_2} = \frac{1.91\text{ V}}{1.2\text{ k}\Omega} = \mathbf{1.59\text{ mA}}$$
$$V_{C_2} = 20\text{ V} - (1.59\text{ mA})(2.2\text{ k}\Omega) = \mathbf{16.5\text{ V}}$$

(b) $$I_{B_1} = \frac{I_{C_1}}{\beta} = \frac{3.44\text{ mA}}{160} = \mathbf{21.5\ \mu A},\ I_{C_1} \cong I_{E_1} = \mathbf{3.44\text{ mA}}$$
$$I_{B_2} = \frac{I_{C_2}}{\beta} = \frac{1.59\text{ mA}}{90} = \mathbf{17.67\ \mu A},\ I_{C_2} \cong I_{E_2} = \mathbf{1.59\text{ mA}}$$

46. (a) $\beta_D = \beta_1\beta_2 = (50)(75) = 3750$

(b) $$I_{B_1} = \frac{V_{CC} - V_{BE_1} - V_{BE_2}}{R_B + (\beta_D + 1)R_E} = \frac{18\text{ V} - 0.7\text{ V} - 0.7\text{ V}}{2.2\text{ M}\Omega + (3750{+}1)470\ \Omega}$$
$$= \mathbf{4.19\ \mu A}$$
$$I_{B_2} = (\beta_1 + 1)I_{B_1} = (50 + 1)(4.19\ \mu\text{A}) = \mathbf{213.69\ \mu A}$$

(c) $$I_{C_1} = \beta_1 I_{B_1} = (50)(4.19\ \mu\text{A}) = \mathbf{0.21\text{ mA}}$$
$$I_{C_2} = \beta_2 I_{B_2} = (75)(213.69\ \mu\text{A}) = \mathbf{16.03\text{ mA}}$$

(d) $$V_{C_1} = \mathbf{18\text{ V}},\ V_{C_2} = \mathbf{18\text{ V}}$$
$$V_{E_2} = I_E R_E \cong I_{C_2} R_E = (16.03\text{ mA})(470\ \Omega)$$
$$= \mathbf{7.53\text{ V}}$$
$$V_{E_1} = V_{E_2} + 0.7\text{ V} = 7.53\text{ V} + 0.7\text{ V} = \mathbf{8.23\text{ V}}$$

47. (a) $$V_{B_1} = \frac{3.3\text{ k}\Omega(22\text{ V})}{3.3\text{ k}\Omega + 4.7\text{ k}\Omega + 8.2\text{ k}\Omega} = 4.48\text{ V}$$
$$V_{E_1} = V_{B_1} - 0.7\text{ V} = 3.78\text{ V}$$
$$I_{E_1} \cong I_{E_2} \cong I_{C_2} \cong I_{C_1} = \frac{V_{E_1}}{R_E} = \frac{3.78\text{ V}}{1.1\text{ k}\Omega} = 3.44\text{ mA}$$
$$I_{B_1} = \frac{I_{C_1}}{60} = \mathbf{57.33\ \mu A},\ I_{C_1} = \mathbf{3.44\text{ mA}}$$
$$I_{B_2} = \frac{I_{C_3}}{120} = \mathbf{28.67\ \mu A},\ I_{C_2} = \mathbf{3.44\text{ mA}}$$

(b) $$V_{B_1} = \mathbf{4.48\text{ V}}$$
$$V_{B_2} = \frac{(4.7\text{ k}\Omega + 3.3\text{ k}\Omega)(22\text{ V})}{3.3\text{ k}\Omega + 4.7\text{ k}\Omega + 8.2\text{ k}\Omega} = \mathbf{10.86\text{ V}}$$
$$V_{E_1} = \mathbf{3.78\text{ V}},\ V_{C_1} = V_{B_2} - 0.7\text{ V} = \mathbf{10.16\text{ V}}$$
$$V_{E_@} = \mathbf{10.16\text{ V}},\ V_{C_2} = 22\text{ V} - (3.44\text{ mA})(2\ 2\text{ k}\Omega) = \mathbf{14.43\text{ V}}$$

48. (a) $I_{B_1} = \frac{V_{CC} - V_{EB_1}}{R_B + \beta_1\beta_2 R_C} = \frac{12\text{ V} - 0.7\text{ V}}{1.8\text{ M}\Omega + (80)(160)(220\ \Omega)}$ = **2.45 μA**

$I_{C_1} = \beta_1 I_{B_1} = (80)(2.45\ \mu\text{A})$ = **196 μA**

$I_{B_2} = I_{C_1}$ = **196 μA**

$I_{C_2} = \beta_2 I_{B_2} = (160)(196\ \mu\text{A})$ = **31.36 mA**

(b) $V_{B_1} = I_{B_1} R_B = (2.45\ \mu\text{A})(1.8\text{ M}\Omega)$ = **4.41 V**

$V_{E_1} = 12\text{ V} - I_C(220\ \Omega) = 12\text{ V} - (31.36\text{ mA})(220\ \Omega)$ = **5.1 V**

$V_{B_2} = V_{BE_2}$ = **0.7 V**, $V_{C_2} = V_{E_1}$ = **5.1 V**, $V_{C_1} = V_{B_2}$ = **0.7 V**, V_{E_2} = **0 V**

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

50. For current mirror:

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

51. $6\text{ V} - I_B R_B - V_{BE} - I_E R_E = 0$

$6\text{ V} - I_B 100\text{ k}\Omega - 0.7\text{ V} - (\beta+1)I_B 1.2\text{ k}\Omega = 0$

$6\text{ V} - 0.7\text{ V} - I_B(100\text{ k}\Omega + (120+1)(1.2\text{ k}\Omega)) = 0$

$I_B = \frac{6\text{ V} - 0.7\text{ V}}{100\text{ k}\Omega + 145\text{ k}\Omega} = 21.61\ \mu\text{A}$

$I = I_C = \beta I_B = (120)(21.61\ \mu\text{A})$ = **2.59 mA**

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

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

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

53. $I_E = \frac{V_Z - V_{BE}}{R_E} = \frac{5.1\text{ V} - 0.7\text{ V}}{1.2\text{ k}\Omega}$ = **3.67 mA**

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

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

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

= **−4.69 V**

$V_{CE} = V_C$ = **−4.69 V**

55. $\beta R_E \geq 10R_2$

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

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

Use approximate approach:

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

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

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

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

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

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

$= \mathbf{-13.53\ V}$

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

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

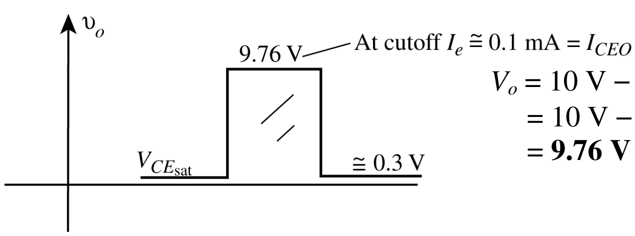
$= \mathbf{-3.37\ V}$

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

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

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

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



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

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

$= \mathbf{9.76\ V}$

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

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

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

Use 1.2 (80 μA) = 96 μA

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

Standard values:

R_B = **43 kΩ**

R_C = **0.62 kΩ**

59. (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

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

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

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

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

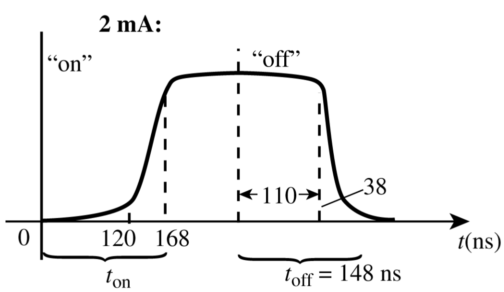
$t_{off} = t_s + t_f = 120 \text{ ns} + 12 \text{ ns} = \mathbf{132\ ns}$

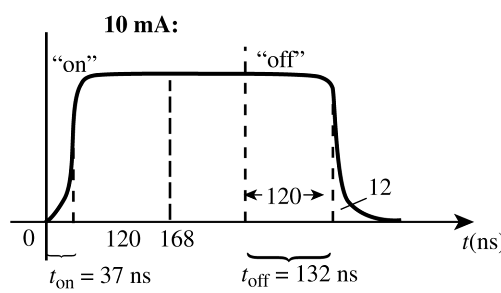
The turn-on time has dropped dramatically

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

while the turn-off time is only slightly smaller

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





60. (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

61. (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:

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

As an emitter feedback bias circuit:

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

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

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

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

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

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

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

As $\beta\uparrow$, $\frac{R_{Th}}{\beta}\downarrow$, $I_C\uparrow$, $V_{R_C}\uparrow$

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

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

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

64. (a) R_B open, $I_B = 0\ \mu\text{A}$, $I_C = I_{CEO} \cong 0$ 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 ≅ 0.06 V

(e) Open in the base circuit

65. (a) $S(I_{CO}) = \beta = \mathbf{120}$

(b) $S(V_{BE}) \cong -\beta/R_B\ -120/510\ \text{k}\Omega\ = \mathbf{-235 \times 10^{-6}\ S}$

(c) $S(\beta) = I_{C_1}/\beta_1 = 3.6\ \text{mA}/120 = \mathbf{30 \times 10^{-6}\ A}$

(d) $$\begin{aligned}\Delta I_C &= S(I_{CO})\Delta I_{CO} + S(V_{BE})\Delta V_{BE} + S(\beta)\Delta\beta \\ &= (120)(10\ \mu\text{A} - 0.2\ \mu\text{A}) + (-2.35\times 10^{-4}\ S)(0.5\ \text{V} - 0.7\ \text{V}) \\ &\quad + (30\times 10^{-6}\ \text{A})(150-120)\end{aligned}$$
$\cong \mathbf{2.12\ mA}$

66. (a) $$S(I_{CO}) \cong \frac{\beta(1+R_B/R_E)}{\beta + R_B/R_E} = \frac{125(1+270\ \text{k}\Omega/2.2\ \text{k}\Omega)}{125+270\ \text{k}\Omega/2.2\ \text{k}\Omega}$$
$= \mathbf{62.44}$

(b) $$S(V_{BE}) \cong \frac{-\beta/R_E}{\beta + R_B/R_E} = \frac{-125/2.2\ \text{k}\Omega}{125+270\,\text{k}\Omega/2.2\ \text{k}\Omega}$$
$= \mathbf{-229.3 \times 10^{-6}\ S}$

(c) $$S(\beta) = \frac{I_{C_1}(1+R_B/R_E)}{\beta_1(\beta_2 + R_B/R_E)} = \frac{4.41\,\text{mA}(1+122.73)}{125(156.25+122.73)}$$
$= \mathbf{15.65 \times 10^{-6}\ A}$

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

$= (62.44)(10\ \mu\text{A} - 0.2\ \mu\text{A}) + (-229.36\times10^{-6}\ \text{S})(0.5\ \text{V} - 0.7\ \text{V})$

$+ 15.65\times10^{-6}\ \text{A}(156.25 - 125)$

$= \mathbf{1.03\ mA}$

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

$= \mathbf{11.06}$

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

$= \mathbf{-1280\times10^{-6}S}$

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

$= \mathbf{2.43\times10^{-6}\ A}$

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

$= (11.06)(10\ \mu\text{A} - 0.2\ \mu\text{A}) + (-1.28\times10^{-3}\text{S})(0.5\ \text{V} - 0.7\ \text{V}) + (2.43\times10^{-6})(100 - 80)$

$= \mathbf{0.313\ mA}$

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

$= \mathbf{83.69}$

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

$= \mathbf{-1.48.04\times10^{-6}S}$

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

$= \mathbf{4.83\times10^{-6}A}$

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

$= (83.69)(10\ \mu\text{A} - 0.2\ \mu\text{A}) + (-1.48.04\times10^{-6}\text{S})(0.5 - 0.7\ \text{V})$

$+ (4.83\times10^{-6}\text{A})(245.4 - 196.32)$

$= \mathbf{1.087\ mA}$

69.

Type	$S(I_{CO})$	$S(V_{BE})$	$S(\beta)$
Fixed-bias	120	-235×10^{-6}S	30×10^{-6} A
Emitter-bias	62.44	-229.36×10^{-6}S	15.65×10^{-6} A
Voltage-divider	11.06	-1280×10^{-6}S	2.43×10^{-6}A
Collector feedback	83.69	-148.04×10^{-6}S	4.83×10^{-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 the most sensitive .
$S(\beta)$: 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.

70. (a) Fixed-bias:

$S(I_{CO})$ = **120**, ΔI_C = **1.176 mA**
$S(V_{BE})$ = $\mathbf{-235 \times 10^{-6}}$**S**, ΔI_C = **0.047 mA**
$S(\beta)$ = $\mathbf{30 \times 10^{-6}}$**A**, ΔI_C = **0.90 mA**

(b) Voltage-divider bias:

$S(I_{CO})$ = **11.06**, ΔI_C = **0.108 mA**
$S(V_{BE})$ = $\mathbf{-1280 \times 10^{-6}}$**S**, ΔI_C = **0.0256 mA**
$S(\beta)$ = $\mathbf{2.43 \times 10^{-6}}$**A**, ΔI_C = $\mathbf{0.0048 \times 10^{-6}}$ **A**

(c) For the fixed-bias configuration there is a strong sensitivity to changes in I_{CO} and β and much 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. No, because they intersect to define the Q point.

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

5. –

6. (a) $$r_o = \frac{V_A + V_{CE_Q}}{I_{C_Q}} = \frac{100\text{ V} + 8\text{ V}}{4\text{ mA}} = \mathbf{27\ k\Omega}$$

   (b) $$r_o = \frac{\Delta V_{CE}}{\Delta I_C} \Rightarrow \Delta I_C = \frac{\Delta V_{CE}}{r_o} = \frac{6\text{ V}}{r_o} = \frac{6\text{ V}}{27\text{ k}\Omega} = \mathbf{0.222\ mA}$$

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

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

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

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

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

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

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

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

(b) $I_b = \dfrac{I_C}{\beta} = \dfrac{\alpha I_e}{\beta} = \dfrac{\not\beta}{\beta+1} \cdot \dfrac{I_e}{\not\beta} = \dfrac{I_e}{\beta+1}$

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

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

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

$A_i = \dfrac{\dfrac{r_o}{r_o + R_L} \cdot \beta \not I_b}{\not I_b} = \dfrac{r_o}{r_o + R_L} \cdot \beta$

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

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

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

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

$r_e = \dfrac{1200}{140} = \mathbf{8.57\ \Omega}$

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

$= \mathbf{-298.89}$

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

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

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

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

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

$I_E = (\beta + 1)I_B = (60 + 1)(51.36\ \mu\text{A})$
$= 3.13\text{ mA}$

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

$Z_i = R_B \parallel \beta r_e = 220\text{ k}\Omega \parallel (60)(8.31\ \Omega) = 220\text{ k}\Omega \parallel 498.6\ \Omega$
$= \mathbf{497.47\ \Omega}$

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

(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)
$Z_o = r_o \parallel R_C = 20\text{ k}\Omega \parallel 2.2\text{ k}\Omega$
$= \mathbf{1.98\ k\Omega}$

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

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

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

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

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

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

13. (a) $$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{8\text{ V} - 0.7\text{ V}}{390\text{ k}\Omega} = \mathbf{18.72\ \mu A}$$

$$I_E = (\beta + 1)I_B = (101)(18.72\ \mu\text{A}) = 1.89\text{ mA}$$

$$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{1.89\text{ mA}} = \mathbf{13.76\ \Omega}$$

$$I_C = \beta I_B = (100)(18.72\ \mu\text{A}) = \mathbf{1.87\text{ mA}}$$

(b) $Z_i = R_B \parallel \beta r_e = 390\text{ k}\Omega \parallel (100)(13.76\ \Omega) = 390\text{ k}\Omega \parallel 1.38\text{ k}\Omega$
$= \mathbf{1.38\text{ k}\Omega}$
$r_o \geq 10R_C \therefore Z_o = R_C = \mathbf{5.6\text{ k}\Omega}$

(c) $$A_v = -\frac{R_C}{r_e} = \frac{-5.6\text{ k}\Omega}{13.76\ \Omega} = \mathbf{-406.98}$$

(d) $$A_v = -\frac{R_C \parallel r_o}{r_e} = -\frac{(5.6\text{ k}\Omega) \parallel (30\text{ k}\Omega)}{13.76\ \Omega} = -\frac{4.72\text{ k}\Omega}{13.76\ \Omega} = \mathbf{-343.03}$$

14. $$A_v = \frac{-R_C}{r_e} = \frac{-406.98}{2} = -203.49$$

$$R_C = (-203.49)(13.76\ \Omega) = \mathbf{2.8\text{ k}\Omega}$$

15. (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) $Z_i = R_1 \| R_2 \| \beta r_e$
$= 4.7\text{ k}\Omega \| 39\text{ k}\Omega \| (100)(30.56\ \Omega)$
$= \mathbf{1.77\ k\Omega}$
$r_o \geq 10R_C \therefore Z_o \cong R_C = \mathbf{3.9\ k\Omega}$

(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(unchanged) = $\mathbf{1.77\ k\Omega}$
$Z_o = R_C \| r_o = 3.9\text{ k}\Omega \| 25\text{ k}\Omega = \mathbf{3.37\ k\Omega}$

(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)

16. $\beta R_E \overset{?}{\geq} 10R_2$
$(100)(1\text{ k}\Omega) \geq 10(5.6\text{ k}\Omega)$
$100\text{ k}\Omega > 56\text{ k}\Omega$ (checks!) & $r_o \geq 10R_C \Rightarrow 50\text{ k}\Omega \geq 10(3.3\text{ k}\Omega) = 33\text{ k}\Omega$ (checks)
Use approximate approach:

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

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

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

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

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

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

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

17. 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) $V_E = I_E R_E = (1.372\text{ mA})(2.2\text{ k}\Omega) = 3.02\text{ V}$
$V_B = V_E + V_{BE} = 3.02\text{ V} + 0.7\text{ V}$
$= \mathbf{3.72\ V}$
$V_C = V_{CC} - I_C R_C$
$= 20\text{ V} - \beta I_B R_C = 20\text{ V} - (180)(7.58\ \mu\text{A})(4.7\text{ k}\Omega)$
$= \mathbf{13.59\ V}$

(c) $Z_i = R_1 \parallel R_2 \parallel \beta r_e$
$= 56\text{ k}\Omega \parallel 220\text{ k}\Omega \parallel (180)(18.95\text{ k}\Omega)$
$= 44.64\text{ k}\Omega \parallel 3.41\text{ k}\Omega$
$= \mathbf{3.17\ k\Omega}$
$r_o < 10R_C$
$33.33\text{ k}\Omega < 10(4.7\text{ k}\Omega) = 47\text{ k}\Omega$ (checks)

$$\therefore A_v = -\frac{R_C \parallel r_o}{r_e}$$
$$= -\frac{(6.8\text{ k}\Omega)\parallel(50\text{ k}\Omega)}{18.95\ \Omega}$$
$$= \mathbf{-298.15}$$

18. (a) Test: $\beta R_E \geq 10R_2$
$(70)(2.2\text{ k}\Omega) \geq 10(68\text{ k}\Omega)$
$154\text{ k}\Omega \geq 680\text{ k}\Omega$ No!

$\therefore$Exact method:
$R_{Th} = 27\text{ k}\Omega \parallel 68\text{ k}\Omega = 19.32\text{ k}\Omega$

$$E_{Th} = \frac{68\text{ k}\Omega(12\text{ V})}{68\text{ k}\Omega + 27\text{ k}\Omega} = 8.59\text{ V}$$

$$I_B = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta+1)R_E} = \frac{9.59\text{ V} - 0.7\text{ V}}{19.32\text{ k}\Omega + (70+1)(2.2\text{ k}\Omega)}$$
$= 44.95\ \mu\text{A}$

$I_E = (\beta+1)I_B = (70+1)(44.95\ \mu\text{A}) = 3.19\text{ mA}$

$$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{3.19\text{ mA}} = \mathbf{8.15\ \Omega}$$

(b) $V_B = V_{BE} + I_E R_E = 0.7\text{ V} + (3.19\text{ mA})(2.2\text{ k}\Omega)$
$= 7.72\text{ V}$

$$V_C = 24\text{ V} - I_C R_C = 24\text{ V} - (\beta I_B)(3.3\text{ k}\Omega)$$
$$= 24\text{ V} - (70)(44.95\ \mu\text{A})(3.3\text{ k}\Omega)$$
$$= \mathbf{13.61\ V}$$

$$V_{CB} = V_C - V_B = 13.61\text{ V} - 7.72\text{ V} = \mathbf{5.89\ V}$$
$$V_E = V_B - 0.7 = 7.72\text{ V} - 0.7\text{ V} = \mathbf{7.02\ V}$$
$$V_{CE} = V_C - V_E = 13.61\text{ V} - 7.02\text{ V} = \mathbf{6.59\ V}$$

(c) $Z_i = 68\text{ k}\Omega \,\|\, 27\text{ k}\Omega \,\|\, \beta R_E = 19.3\text{ k}\Omega \,\|\, (70)(2.2\text{ k}\Omega)$
$= 19.32\text{ k}\Omega \,\|\, 154\text{ k}\Omega = \mathbf{17.17\ k\Omega}$

(d) $A_v = \dfrac{-R_C}{R_E} = -\dfrac{3.3\text{ k}\Omega}{2.2\text{ k}\Omega} = \mathbf{-1.5}$

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

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

(d) $Z_b = \beta r_e + \left[\dfrac{(\beta+1) + R_C / r_o}{1 + (R_C + R_E)/r_o}\right] R_E$
$= 747.6\ \Omega \left[\dfrac{(141) + 2.2\text{ k}\Omega / 20\text{ k}\Omega}{1 + (3.4\text{ k}\Omega)/20\text{ k}\Omega}\right] 1.2\text{ k}\Omega$
$= 747.6\ \Omega + 144.72\text{ k}\Omega$
$= 145.47\text{ k}\Omega$

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

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

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

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

20. (a) dc analysis the same

$\therefore\ r_e = \mathbf{5.34\ \Omega}$ (as in #19)

(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 #32

$Z_o = R_C = \mathbf{2.2\ k\Omega}$ (as in #32)

(c) $A_v = \frac{-R_C}{r_e} = \frac{-2.2\text{ k}\Omega}{5.34\ \Omega} = \mathbf{-411.99\ vs}\ -1.81$ in #19

(d) $Z_i = \mathbf{746.17}\ \Omega$ vs. 105.95 kΩ for #19

$Z_o = R_C \parallel r_o = 2.2\text{ k}\Omega \parallel 20\text{ k}\Omega = \mathbf{1.98\ k\Omega}$ vs. 2.2 kΩ in #19

$A_v = -\frac{R_C \parallel r_o}{r_e} = -\frac{1.98\text{ k}\Omega}{5.34\ \Omega} = \mathbf{-370.79}$ vs. −1.81 in #19

Significant difference in the results for A_v.

21. $r_o \ge 10R_C$

$100\text{ k}\Omega \ge 10(8.2\text{ k}\Omega) = 82\text{ k}\Omega$

Therefore:

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

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

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

$V_E = I_E R_E = (6.842\text{ mA})(0.82\text{ k}\Omega) = 5.61\text{ V}$

$V_B = V_E + V_{BE} = 5.61\text{ V} + 0.7\text{ V} = 6.31\text{ V}$

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

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

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

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

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

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

$r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{3.71\text{ mA}}$ **= 7 Ω**

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

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

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

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

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

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

= 83.78 kΩ

$Z_i = R_B \parallel Z_b = 330\text{ k}\Omega \parallel 83.78\text{ k}\Omega =$ **66.82 kΩ**

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

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

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

= −4.57

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

$(200)(1.2\text{ k}\Omega) \geq 10(120\text{ k}\Omega)$

$240\text{ k}\Omega \geq 1.2\text{ M}\Omega$ No!

Exact method:

$$R_{Th} = 430\text{ k}\Omega \,||\, 120\text{ k}\Omega = 93.82\text{ k}\Omega$$

$$E_{Th} = \frac{120\text{ k}\Omega(16\text{ V})}{120\text{ k}\Omega + 430\text{ k}\Omega} = 3.49\text{ V}$$

$$I_B = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta+1)R_E} = \frac{3.49\text{ V} - 0.7\text{ V}}{93.82\text{ k}\Omega + (200+1)(1.2\text{ k}\Omega)}$$

$$= 8.33\ \mu\text{A}$$

$$I_E = (\beta+1)I_B = (200+1)(8.33\ \mu\text{A}) = 1.674\text{ mA}$$

$$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{1.674\text{ mA}} = \mathbf{15.53\ \Omega}$$

(b) $V_B = V_E + 0.7\text{ V} = (I_E)(R_E) + 0.7\text{ V} + (1.674\text{ mA})(1.2\text{ k}\Omega) + 0.7\text{ V}$

$= 2.71\text{ V}$

$I_C = \beta I_B = (200)(8.33\ \mu\text{A}) = 1.67\text{ mA}$

$V_C = V_{CC} - I_C R_C = 16\text{ V} - (1.67\text{ mA})(4.7\text{ k}\Omega)$

$= 16\text{ V} - 7.85\text{ V}$

$= \mathbf{8.15\ V}$

$V_E = I_E R_E = (1.674\text{ mA})(1.2\text{ k}\Omega) = 2.01\text{ V}$

$V_{CE} = V_C - V_E = 8.15\text{ V} - 2.01\text{ V} = \mathbf{6.14\ V}$

$V_{CB} = V_C - V_B = 8.15\text{ V} - 2.71\text{ V} = \mathbf{5.44\ V}$

(c) $Z_i = 120\text{ k}\Omega \,||\, 430\text{ k}\Omega \,||\, \beta R_E = 93.82\text{ k}\Omega \,||\, (200)(1.2\text{ k}\Omega)$

$= 93.82\text{ k}\Omega \,||\, 240\text{ k}\Omega = \mathbf{67.45\ k\Omega}$

$Z_o = \mathbf{4.7\ k\Omega}$

(d) $A_v = \dfrac{-R_C}{R_E} = -\dfrac{4.7\text{ k}\Omega}{1.2\text{ k}\Omega} = \mathbf{-3.92}$

(e) $A_i = A_v \dfrac{Z_i}{R_C} = \dfrac{-(3.92)(67.45\text{ k}\Omega)}{(4.7\text{ k}\Omega)}$

$= \mathbf{56.26}$

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

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

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

$= 2.98\text{ mA}$

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

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

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

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

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

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

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

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

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

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

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

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

$r_o < 10R_E$:

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

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

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

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

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

= **236.1 kΩ**

$Z_o \cong R_E \parallel r_e$

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

= **31.2 Ω**

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

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

= **0.994**

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

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

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

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

$= \mathbf{33.22\ \Omega}$

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

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

$= \mathbf{140.52}$

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

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

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

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

29. (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, $A_v = \mathbf{-298}$

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

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

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

$19R_F + 3800R_C = 200R_F$

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

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

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

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

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

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

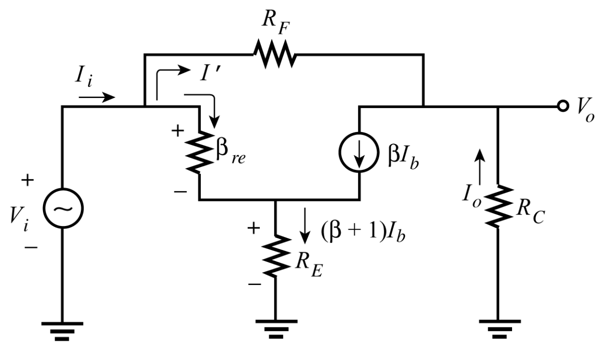
$$I_B = \frac{I_E}{\beta + 1} = \frac{2.6 \text{ mA}}{200 + 1} = 12.94\ \mu\text{A}$$

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

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

$= \mathbf{5.28\ V}$

31. (c)



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

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

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 $V_o = -I_o R_C = -(\beta + 1)I_b R_C$

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

$$\cong \frac{\not\beta \not I_b R_C}{\not\beta \not I_b r_e + \not\beta \not I_b R_E}$$

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

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

For $r_e \ll R_E$

$V_i \cong \beta I_b R_E$

Now $I_i = I' + I_b$

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

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

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

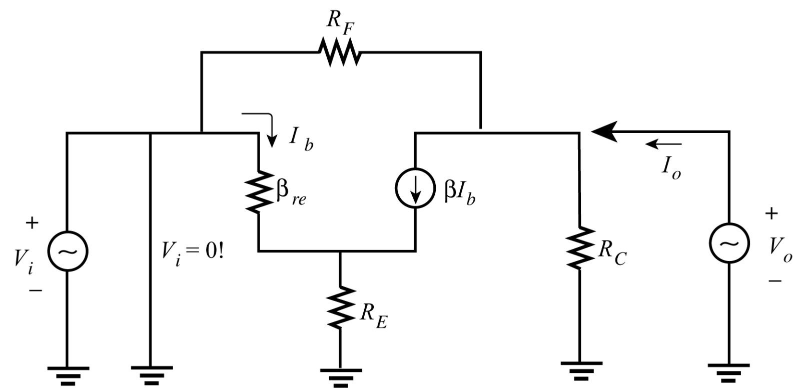
so $Z_i = \dfrac{V_i}{I_i} = \dfrac{\beta R_E}{1 - \dfrac{A_v \beta R_E}{R_F}} = \dfrac{\beta R_E R_F}{R_F + \beta(-A_v) R_E}$

$Z_i = \dfrac{V_i}{I_i} = x \parallel y$ 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 $V_i = 0$



$V_i = I_b\beta r_e + (\beta + 1)I_bR_E$
$V_i \cong \beta I_b(r_e + R_E) = 0$
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 $Z_o = \dfrac{V_o}{I_o} = \dfrac{1}{\dfrac{1}{R_C} + \dfrac{1}{R_F}} = \dfrac{R_C R_F}{R_C + R_F} = \boldsymbol{R_C \parallel R_F}$

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

$Z_i \cong \dfrac{\beta R_E R_F}{\beta R_E\left|A_v\right| + R_F} = \dfrac{(90)(1.2\text{ k}\Omega)(120\text{ k}\Omega)}{(90)(1.2\text{ k}\Omega)(1.83) + 120\text{ k}\Omega}$
$= \mathbf{40.8\ k\Omega}$
$Z_o \cong R_C \parallel R_F$
$= 2.2\text{ k}\Omega \parallel 120\text{ k}\Omega$
$= \mathbf{2.16\ k\Omega}$

32. (a) $I_B = \dfrac{V_{CC} - V_{BE}}{R_F + \beta R_C} = \dfrac{9\text{ V} - 0.7\text{ V}}{(39\text{ k}\Omega + 22\text{ k}\Omega) + (80)(1.8\text{ k}\Omega)}$
$= \dfrac{8.3\text{ V}}{61\text{ k}\Omega + 144\text{ k}\Omega} = \dfrac{8.3\text{ V}}{205\text{ k}\Omega} = 40.49\ \mu\text{A}$
$I_E = (\beta + 1)I_B = (80 + 1)(40.49\ \mu\text{A}) = 3.28\text{ mA}$
$r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{3.28\text{ mA}} = 7.93\ \Omega$
$Z_i = R_{F_1} \parallel \beta r_e$
$= 39\text{ k}\Omega \parallel (80)(7.93\ \Omega) = 39\text{ k}\Omega \parallel 634.4\ \Omega = \mathbf{0.62\ k\Omega}$
$Z_o = R_C \parallel R_{F_2} = 1.8\text{ k}\Omega \parallel 22\text{ k}\Omega = \mathbf{1.66\ k\Omega}$

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

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

33. (a) $Z_i \cong \frac{R_E}{\left[\frac{1}{\beta} + \frac{(R_E + R_C)}{R_F}\right]} = \frac{0.68\text{ k}\Omega}{\left[\frac{1}{80} + \frac{(0.68\text{ k}\Omega + 1.8\text{ k}\Omega)}{61\text{ k}\Omega}\right]}$

$= \frac{0.68\text{ k}\Omega}{\left[12.5\times10^{-3} + 4.066\times10^{-3}\right]} = \frac{0.68\text{ k}\Omega}{53.16\times10^{-3}}$

$= \mathbf{12.79\ k\Omega}$

$Z_o = R_C \| R_F = 1.8\text{ k}\Omega \| 61\text{ k}\Omega = \mathbf{1.75\ k\Omega}$

(b) $A_v = -\frac{R_C}{R_E} = -\frac{1.8\text{ k}\Omega}{0.68\text{ k}\Omega} = \mathbf{-2.65}$

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

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

$= 2.57\text{ mA}$

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

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

$Z_i = R_B \| \beta r_e = 680\text{ k}\Omega \| (100)(10.116\ \Omega)$

$= 680\text{ k}\Omega \| 1{,}011.6\ \Omega$

$= \mathbf{1.01\ k\Omega}$

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

(b) −

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

$= \mathbf{-191.65}$

(d) $A_{i_L} = -A_v \frac{Z_i}{R_L} = -(-191.65)\frac{(1.01\text{ k}\Omega)}{4.7\text{ k}\Omega}$

$= \mathbf{41.18}$

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

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

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

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

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

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

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

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

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

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

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

$Z_i = R_B \parallel \beta r_e = 1\text{ M}\Omega \parallel (180)(12.71\ \Omega) = 1\text{ M}\Omega \parallel 2.288\text{ k}\Omega$
$= \mathbf{2.283\ k\Omega}$
$Z_o = R_C = \mathbf{3\ k\Omega}$

(b) –

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

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

(e) No change!

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

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

(g) No change!

(h) $A_i = A_v \frac{Z_i}{R_C} = -(-236)\frac{(2.283\text{ k}\Omega)}{3\text{ k}\Omega}$
$= \mathbf{179.6}$

37. (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 $= -214.98$

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

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

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

(g) No change!

38. (a) Exact analysis:

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

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

$$I_B = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta+1)R_E} = \frac{3.048\text{ V} - 0.7\text{ V}}{12.95\text{ k}\Omega + (101)(0.75\text{ k}\Omega)}$$
$= 26.47\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (101)(26.47\ \mu\text{A})$
$= 2.673\text{ mA}$

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

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

$Z_i = 68\text{ k}\Omega \parallel 16\text{ k}\Omega \parallel \beta r_e$
$= 12.95\text{ k}\Omega \parallel (100)(9.726\ \Omega)$
$= 12.95\text{ k}\Omega \parallel 972.6\ \Omega$
$= \mathbf{904.66\ \Omega}$

$Z_o = R_C = \mathbf{2.2\text{ k}\Omega}$

(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) $$A_{v_L} = \frac{-R_C \parallel R_e}{r_e} = \frac{-2.2\text{ k}\Omega \parallel 5.6\text{ k}\Omega}{9.726\ \Omega}$$
$= \mathbf{-162.4}$

$$Z_i = 68\text{ k}\Omega \parallel 16\text{ k}\Omega \parallel \underbrace{972.6\ \Omega}_{\beta r_e}$$
$= \mathbf{904.66\ \Omega}$

$$A_{i_L} = -A_{v_L}\frac{Z_i}{R_L}$$
$$= \frac{(-162.4)(904.66\ \Omega)}{5.6\text{ k}\Omega}$$
$= \mathbf{26.24}$

$Z_o = R_C = \mathbf{2.2\text{ k}\Omega}$

Same results!

39. (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!

40. (a) $I_B = \dfrac{V_{CC} - V_{BE}}{R_B + (\beta+1)R_E} = \dfrac{18\text{ V} - 0.7\text{ V}}{680\text{ k}\Omega + (111)(0.82\text{ k}\Omega)}$

$= 22.44\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (110 + 1)(22.44\ \mu\text{A})$

$= 2.49\text{ mA}$

$r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{2.49\text{ mA}} = 10.44\ \Omega$

$A_{v_{NL}} = -\dfrac{R_C}{r_e + R_E} = -\dfrac{3\text{ k}\Omega}{10.44\ \Omega + 0.82\text{ k}\Omega}$

$= \mathbf{-3.61}$

$Z_i \cong R_B \parallel Z_b = 680\text{ k}\Omega \parallel (\beta r_e + (\beta + 1)R_E)$

$= 680\text{ k}\Omega \parallel (610)(10.44\ \Omega) + (110 + 1)(0.82\text{ k}\Omega)$

$= 680\text{ k}\Omega \parallel 92.17\text{ k}\Omega$

$= \mathbf{81.17\text{ k}\Omega}$

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

(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!

$$\frac{V_i}{V_s} = \frac{Z_i}{Z_i + R_s} = \frac{81.17\text{ k}\Omega}{81.17\text{ k}\Omega + 1\text{ k}\Omega} = 0.988$$

$A_{v_s} = (-2.2)(0.988)$

$= \mathbf{-2.17}$

$R_s\uparrow$, $A_{v_s}\downarrow$, (but only slightly for moderate changes in R_s since Z_i is typically much larger than R_s)

(f) $A_i = A_{v_L}\dfrac{Z_i}{R_L} = (-2.2)\dfrac{(81.17\text{ k}\Omega)}{4.7\text{ k}\Omega}$

$= \mathbf{37.99}$

41. Using the exact approach:

$$I_B = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta+1)R_E} = \frac{2.33\text{ V} - 0.7\text{ V}}{10.6\text{ k}\Omega + (121)(1.2\text{ k}\Omega)} = 10.46\ \mu\text{A}$$

$$E_{Th} = \frac{R_2}{R_1 + R_2}V_{CC} = \frac{12\text{ k}\Omega}{91\text{ k}\Omega + 12\text{ k}\Omega}(20\text{ V}) = 2.33\text{ V}$$

$R_{Th} = R_1 \parallel R_2 = 91\text{ k}\Omega \parallel 12\text{ k}\Omega = 10.6\text{ k}\Omega$

$I_E = (\beta + 1)I_B = (121)(10.46\ \mu\text{A})$

$= 1.266\text{ mA}$

$$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{1.266\text{ mA}} = 20.54\ \Omega$$

(a) $A_{v_{NL}} \cong \dfrac{R_E}{r_e + R_E} = \dfrac{1.2\text{ k}\Omega}{20.54\ \Omega + 1.2\text{ k}\Omega} = \mathbf{0.983}$

$Z_i = R_1 \parallel R_2 \parallel (\beta r_e + (\beta+1)R_E)$

$= 91\text{ k}\Omega \parallel 12\text{ k}\Omega \parallel ((120)(20.54\ \Omega) + (120 + 1)(1.2\text{ k}\Omega))$

$= 10.6\text{ k}\Omega \parallel (2.46\text{ k}\Omega + 145.2\text{ k}\Omega)$

$= 10.6\text{ k}\Omega \parallel 147.66\text{ k}\Omega$

$= \mathbf{9.89\ k\Omega}$

$Z_o = R_E \parallel r_e = 1.2\text{ k}\Omega \parallel 20.54\ \Omega$

$= \mathbf{20.19\ \Omega}$

(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)

$$A_{v_s} = \frac{Z_i}{Z_i + R_s} A_{v_L} = \frac{9.89 \text{ k}\Omega(0.976)}{9.89 \text{ k}\Omega + 1 \text{ k}\Omega}$$

$= \mathbf{0.886}$ (vs. 0.92 with $R_s = 0.6$ kΩ)

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) $$A_{v_L} = \frac{R_L}{R_L + Z_o}\left(A_{v_{NL}}\right) = \frac{5.6 \text{ k}\Omega(0.983)}{5.6 \text{ k}\Omega + 20.19\ \Omega}$$

$= \mathbf{0.979}$ (vs. 0.976 with $R_L = 2.7$ kΩ)

$$A_{v_s} = \frac{Z_i}{Z_i + R_s}(A_{v_L}) = \frac{9.89 \text{ k}\Omega(0.979)}{9.89 \text{ k}\Omega + 0.6 \text{ k}\Omega}$$

$= \mathbf{0.923}$ (vs. 0.92 with $R_L = 2.7$ kΩ)

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

(g) $$A_i = A_{v_L}\frac{Z_i}{R_L} = (0.979)\frac{(9.89 \text{ k}\Omega)}{2.7 \text{ k}\Omega}$$

$= \mathbf{3.59}$

42. (a) $$I_E = \frac{V_{EE} - V_{BE}}{R_E} = \frac{6 \text{ V} - 0.7 \text{ V}}{2.2 \text{ k}\Omega}$$

$= 2.41$ mA

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

$$A_{v_{NL}} = \frac{R_C}{r_e} = \frac{4.7 \text{ k}\Omega}{10.79\ \Omega} = \mathbf{435.59}$$

$Z_i = R_E \parallel r_e = 2.2 \text{ k}\Omega \parallel 10.79\ \Omega = \mathbf{10.74\ \Omega}$

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

(b) −

(c) $$A_{v_L} = \frac{R_L}{R_L + R_o} A_{v_{NL}} = \frac{5.6 \text{ k}\Omega(435.59)}{5.6 \text{ k}\Omega + 4.7 \text{ k}\Omega} = \mathbf{236.83}$$

$$V_i = \frac{Z_i}{Z_i + R_s} V_s = \frac{10.74\ \Omega\,(V_s)}{10.74\ \Omega + 100\ \Omega} = 0.097\ V_s$$

$$A_{v_s} = \frac{V_o}{V_i} \cdot \frac{V_i}{V_s} = (236.83)(0.097)$$

$= \mathbf{22.97}$

(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) $A_{v_L} = \dfrac{R_L}{R_L + R_o} A_{v_{NL}} = \dfrac{2.2\text{ k}\Omega}{2.2\text{ k}\Omega + 4.7\text{ k}\Omega}(435.59)$

$= \mathbf{138.88}$

$A_{v_s} = \dfrac{V_0}{V_i}\cdot\dfrac{V_i}{V_s}$, $\quad \dfrac{V_i}{V_s} = \dfrac{Z_i}{Z_i + R_s} = \dfrac{10.74\ \Omega}{10.74\ \Omega + 500\ \Omega} = 0.021$

$A_{v_s} = (138.88)(0.021) = \mathbf{2.92}$

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; $R_L\downarrow$, $A_v\downarrow$

(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!

(h) $A_i = A_{v_L}\dfrac{Z_i}{R_L} = \dfrac{(236.82)(10.74\text{ k}\Omega)}{5.6\text{ k}\Omega}$

$= \mathbf{0.454}$

43. (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) $A_{i_1} = -\dfrac{A_v Z_i}{R_L} = \dfrac{-(-97.67)(1\text{ k}\Omega)}{1\text{ k}\Omega}$ = **97.67**

$A_{i_2} = \dfrac{-A_v Z_i}{R_L} = \dfrac{-(-189)(1\text{ k}\Omega)}{2.7\text{ k}\Omega}$ = **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

44. (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

$A_{v_2} = \dfrac{R_L}{R_L + Z_{o_2}} A_{v_{2NL}} = \dfrac{2.2\text{ k}\Omega}{2.2\text{ k}\Omega + 4.6\text{ k}\Omega}(-640)$

= **−207.06**

(b) $A_{v_L} = A_{v_1} \cdot A_{v_2}$ = (0.984)(−207.06)

= **−203.74**

$A_{v_s} = \dfrac{Z_i}{Z_i + R_s} A_{v_L}$

$= \dfrac{50\text{ k}\Omega}{50\text{ k}\Omega + 1\text{ k}\Omega}(-203.74)$

= **−199.75**

(c) $A_{i_1} = -A_{v_1} \dfrac{Z_{i_1}}{Z_{i_2}}$

$= -(0.984)\dfrac{(50\text{ k}\Omega)}{1.2\text{ k}\Omega}$

= **−41**

$A_{i_2} = -A_{v_2} \dfrac{Z_{i_2}}{R_L}$

$= -(-207.06)\dfrac{(1.2\text{ k}\Omega)}{2.2\text{ k}\Omega}$

= **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.

45. For each stage:

$$V_B = \frac{6.2\text{ k}\Omega}{24\text{ k}\Omega + 6.2\text{ k}\Omega}(15\text{ V}) = \mathbf{3.08\text{ V}}$$

$$V_E = V_B - 0.7\text{ V} = 3.08\text{ V} - 0.7\text{ V} = \mathbf{2.38\text{ V}}$$

$$I_E \cong I_C = \frac{V_E}{R_E} = \frac{2.38\text{ V}}{1.5\text{ k}\Omega} = \mathbf{1.59\text{ mA}}$$

$$V_C = V_{CC} - I_C R_C = 15\text{ V} - (1.59\text{ mA})(5.1\text{ k}\Omega) = \mathbf{6.89\text{ V}}$$

46. (a) $r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{1.59\text{ mA}} = 16.35\ \Omega$

$$R_{i_1} = R_{i_2} = R_1 \parallel R_2 \parallel \beta r_e = 6.2\text{ k}\Omega \parallel 24\text{ k}\Omega \parallel (150)(16.35\ \Omega) = 1.64\text{ k}\Omega$$

$$A_{v_1} = -\frac{R_C \parallel R_{i_2}}{r_e} = \frac{5.1\text{ k}\Omega \parallel 1.64\text{ k}\Omega}{16.35\ \Omega} = \mathbf{-75.8}$$

$$A_{v_2} = -\frac{R_C}{r_e} = \frac{-5.1\text{ k}\Omega}{16.35\ \Omega} = \mathbf{-311.9}$$

$$A_v = A_{v_1} A_{v_2} = (-75.8)(-311.9) = \mathbf{23{,}642}$$

(b) $A_{i_T} = \dfrac{I_o}{I_i} = A_{v_T}\dfrac{Z_i}{R_L}$

$$= \frac{(23{,}642)(1.64\text{ k}\Omega)}{5.1\text{ k}\Omega} = \mathbf{7602.5}$$

47. $V_{B_1} = \dfrac{3.9\text{ k}\Omega}{3.9\text{ k}\Omega + 6.2\text{ k}\Omega + 7.5\text{ k}\Omega}(20\text{ V}) = \mathbf{4.4\text{ V}}$

$$V_{B_2} = \frac{6.2\text{ k}\Omega + 3.9\text{ k}\Omega}{3.9\text{ k}\Omega + 6.2\text{ k}\Omega + 7.5\text{ k}\Omega}(20\text{ V}) = \mathbf{11.48\text{ V}}$$

$$V_{E_1} = V_{B_1} - 0.7\text{ V} = 4.4\text{ V} - 0.7\text{ V} = \mathbf{3.7\text{ V}}$$

$$I_{C_1} \cong I_{E_1} = \frac{V_{E_1}}{R_E} = \frac{3.7\text{ V}}{1\text{ k}\Omega} = 3.7\text{ mA} \cong I_{E_2} \cong I_{C_2}$$

$$V_{C_2} = V_{CC} - I_C R_C = 20\text{ V} - (3.7\text{ mA})(1.5\text{ k}\Omega) = \mathbf{14.45\text{ V}}$$

$$V_{C_1} = V_{B_2} - V_{BE_2} = 11.48\text{ V} - 0.7\text{ V} = \mathbf{10.78\text{ V}}$$

48. $r_e = \dfrac{26 \text{ mV}}{I_E} = \dfrac{26 \text{ mV}}{3.7 \text{ mA}} = 7\ \Omega$

$A_{v_1} = -\dfrac{r_e}{r_e} = \mathbf{-1}$

$A_{v_2} = \dfrac{R_C}{r_e} = \dfrac{1.5 \text{ k}\Omega}{7\ \Omega} \cong \mathbf{214}$

$A_{v_T} = A_{v_1} A_{v_2} = (-1)(214) = \mathbf{-214}$

$V_o = A_{v_T} V_i = (-214)(10 \text{ mV}) = \mathbf{-2.14\ V}$

49. $R_o = R_D = 1.5 \text{ k}\Omega$ (V_o (from problem #48) = −2.14 V)

$V_o(\text{load}) = \dfrac{R_L}{R_o + R_L}(V_o) = \dfrac{10 \text{ k}\Omega}{10 \text{ k}\Omega + 1.5 \text{ k}\Omega}(-2.14 \text{ V})$

$= \mathbf{-1.86\ V}$

50. (a) $\beta_D = \beta_1\beta_2 = (50)(120) = 6000$

$I_B = \dfrac{V_{CC} - V_{BE_1} - V_{BE_2}}{R_B + \beta_D R_E} = \dfrac{16 \text{ V} - 1.4 \text{ V}}{2.4 \text{ M}\Omega + (6000)(510\ \Omega)}$

$= 2.67\ \mu\text{A}$

$V_{B_1} = 16 \text{ V} - (I_B)(2.4 \text{ M}\Omega) = 16 \text{ V} - (2.67\ \mu\text{A})(2.4 \text{ M}\Omega)$

$= \mathbf{9.59\ V}$

$V_{C_1} = \mathbf{16\ V}$

$V_{E_2} = I_{E_2} R_E = \beta_D I_B R_E$

$= (6000)(2.67\ \mu\text{A})(510\ \Omega)$

$= \mathbf{8.17\ V}$

$V_{CB_1} = V_{C_1} - V_{B_1} = 16 \text{ V} - 9.59 \text{ V} = \mathbf{6.41\ V}$

$V_{CE_2} = 16 \text{ V} - V_{E_2} = 16 \text{ V} - 8.17 \text{ V} = \mathbf{7.83\ V}$

(b) $I_{B_1} = \mathbf{2.67\ \mu A}$, $I_{B_2} = I_{C_1} = \beta_1 I_{B_1} = (50)(2.67\ \mu\text{A}) = \mathbf{133.5\ \mu A}$

$I_{E_2} = V_{E_2} / R_E = 8.17 \text{ V} / 510\ \Omega = \mathbf{16.02\ mA}$

(c) $Z_i = R_B \,||\, \beta_D R_E = 2.4 \text{ M}\Omega \,||\, (6000)(510\ \Omega) = 2.4 \text{ M}\Omega \,||\, 3.06 \text{ M}\Omega$

$= \mathbf{1.35\ M\Omega}$

$Z_o = \dfrac{r_{e_1}}{\beta_2} + r_{e_2}$ with $I_{E_1} = (\beta + 1)I_{B_1} = (51)(2.67\ \mu\text{A}) = 136.17\ \mu\text{A}$

and $r_{e_1} = \dfrac{26 \text{ mW}}{I_{E_1}} = \dfrac{26 \text{ mW}}{136.17\ \mu\text{A}} = 190.94\ \Omega$

$r_{e_2} = \dfrac{26 \text{ mW}}{I_{E_2}} = \dfrac{26 \text{ mW}}{16.02 \text{ mA}} = 1.62\ \Omega$

$Z_o = \dfrac{190.94\ \Omega}{120} + 1.62\ \Omega = 1.59\ \Omega + 1.62\ \Omega$

$= \mathbf{3.21\ \Omega}$

(d) $A_v \cong \mathbf{1}$

$$A_i = \frac{\beta_D R_B}{R_B + \beta_D R_E} = \frac{(6000)(2.4\text{ M}\Omega)}{2.4\text{ M}\Omega + (6000)(510\ \Omega)} = \frac{14.4 \times 10^3\text{ M}\Omega}{5.46\text{ M}\Omega}$$
$$= \mathbf{2.64 \times 10^3}$$

51. (a) and (b) the same as problem 50

(a) $V_{B_1} = \mathbf{9.59\ V}$, $V_{C_1} = \mathbf{16\ V}$, $V_{E_2} = \mathbf{8.17\ V}$, $V_{CB_1} = \mathbf{6.41\ V}$, $V_{CE_2} = \mathbf{7.83\ V}$

(b) $I_{B_1} = \mathbf{2.67\ \mu A}$, $I_{B_2} = \mathbf{133.5\ \mu A}$, $I_{E_2} = \mathbf{16.02\ mA}$

(c) $Z_i = R_B \,||\, \beta(R_E \,||\, R_L)$
$$= 2.4\text{ M}\Omega \,||\, (6000)(510\ \Omega \,||\, 1.2\text{ k}\Omega) = 2.4\text{ M}\Omega \,||\, 2.15\text{ M}\Omega$$
$$= \mathbf{1.13\ M\Omega}$$

$Z_o = \dfrac{r_{e_1}}{\beta_2} = r_{e_2}$ not affected by R_L, $Z_o = \mathbf{3.21\ \Omega}$ from problem 50

(d) $A_v \cong \mathbf{1}$

$$A_i = \frac{\beta_D R_B}{R_B + \beta_D (R_E \,||\, R_L)} = \frac{(6000)(2.4\text{ M}\Omega)}{2.4\text{ M}\Omega + (6000)(510\ \Omega \,||\, 0.2\text{ k}\Omega)}$$
$$= \mathbf{3.16 \times 10^3}$$

52. From Problem 51, $Z_i = 1.35\text{ M}\Omega$, and $A_{v_{NL}} \cong 1$

$$V_i = \frac{1.35\text{ M}\Omega(V_s)}{1.35\text{ M}\Omega + 1.2\text{ k}\Omega} = 0.999\ V_s$$
$\therefore\ A_v = V_o / V_s \cong \mathbf{1}$

53. (a) $I_B = \dfrac{V_{CC} - V_{BE_T}}{R_B + \beta_D R_E} = \dfrac{16\text{ V} - 1.6\text{ V}}{2.4\text{ M}\Omega + (4000)(510\ \Omega)} = 3.24\ \mu\text{A}$

$V_{B_1} = V_{CC} - I_B R_B = 16\text{ V} - (3.24\ \mu\text{A})(2.4\text{ M}\Omega) = \mathbf{8.22\ V}$

$V_{E_2} = I_{E_2} R_E = \beta_D I_B R_E = (4000)(3.24\ \mu\text{A})(510\ \Omega) = \mathbf{6.61\ V}$

$$V_{C_2} = V_{CC} - I_{C_2} R_C \cong 16\ V - I_{E_2} R_C$$
$$= 16\text{ V} - \beta_D I_B R_C = 16\text{ V} - (4000)(3.24\ \mu\text{A})(470\ \Omega)$$
$$= \mathbf{9.91\ V}$$

$V_{CE_2} = V_{C_2} - V_{E_2} = 9.91\text{ V} - 6.61\text{ V} = \mathbf{3.3\ V}$

$V_{CB_1} = V_{C_1} - V_{B_1} = V_{C_2} - V_{B_1} = 9.91\text{ V} - 8.22\text{ V} = \mathbf{1.69\ V}$

(c) $I_{E_2} \cong \beta_D I_B = (4000)(3.24\ \mu\text{A}) = 12.96\,\text{mA}$

$r_{e_2} = \dfrac{26\text{ mV}}{I_{E_2}} = \dfrac{26\text{ mW}}{12.96\text{ mA}} = 2\ \Omega$

$Z_i \cong 2.4\text{ M}\Omega \,||\, \beta_D r_{e_2} = 2.4\text{ M}\Omega \,||\, (4000)(2\ \Omega) = 2.4\text{ M}\Omega \,||\, 8\text{ k}\Omega$

$\cong \mathbf{8\ k\Omega}$

$Z_o = R_C = \mathbf{470\ \Omega}$

(d) $A_v = \dfrac{-\beta_D R_C}{Z_i} = \dfrac{-(4000)(470\ \Omega)}{8\text{ k}\Omega} = \mathbf{-235}$

(e) $A_i = \dfrac{-A_v Z_i}{R_C} = \dfrac{-(235)(8\text{ k}\Omega)}{470\ \Omega} = \mathbf{4 \times 10^3}$

54. (a) $I_{B_1} = \dfrac{V_{CC} - V_{BE_1}}{R_B + \beta_1\beta_2 R_C} = \dfrac{16\text{ V} - 0.7\text{ V}}{1.5\text{ M}\Omega + (160)(200)(68\ \Omega)} = 4.16\ \mu\text{A}$

$V_{B_1} = I_{B_1} R_B = (4.16\ \mu\text{A})(1.5\text{ M}\Omega) = \mathbf{6.24\ V}$

$V_{E_2} = \mathbf{0\ V}$

$V_{C_2} = V_{E_1} = 16\text{ V} - I_C\, 68\ \Omega = 16\text{ V} - (\beta_1\beta_2 I_{B_1})68\ \Omega$

$= 16\text{ V} - (160)(200)(4.16\ \mu\text{A})(68\ \Omega) = \mathbf{6.95\ V}$

$V_{B_2} = V_{BE_2} = \mathbf{0.7\ V}$

$V_{C_1} = V_{B_2} = \mathbf{0.7\ V}$

$V_{E_1} = V_{C_2} = \mathbf{6.95\ V}$

(b) $I_{B_1} = \mathbf{4.16\ \mu A}$

$I_{C_1} = \beta_1 I_{B_1} = (160)(4.16\ \mu\text{A}) = \mathbf{0.666\ mA}$

$I_{B_2} = I_{C_1} = \mathbf{0.666 mA}$, $I_{C_2} = I_C = \beta_1\beta_2 I_{B_1} = \mathbf{133.12\ mA}$

$I_{E_2} = I_{C_2} = \mathbf{133.12\ mA}$

(c) $Z_i = R_B \,||\, \beta_1\beta_2 R_C$

$= 1.5\text{ M}\Omega \,||\, (160)(200)(68\ \Omega)$

$= \mathbf{2.17\ M\Omega}$

$Z_o = R_C \,||\, r_{o_1} \cong \mathbf{68\ \Omega}$

(d) $A_v = \mathbf{1}$

(e) $A_i = \dfrac{-\beta_1\beta_2 R_B}{R_B + \beta_1\beta_2 R_C} = \dfrac{-(160)(200)(1.5\text{ M}\Omega)}{1.5\text{ M}\Omega + (160)(200)(68\ \Omega)}\ \mathbf{-\ 13.06 \times 10^3}$

55. (a) $I_{B_1} = \dfrac{V_{CC} - V_{BE_1}}{R_B + \beta_1\beta_2 R_C} = \dfrac{16\text{ V} - 0.7\text{ V}}{1.5\text{ M}\Omega + (160)(200)(68\ \Omega)} = 4.16\ \mu\text{A}$

$V_{B_1} = I_{B_1} R_B = (4.16\ \mu\text{A})(1.5\text{ M}\Omega)$ **= 6.24 V**

$V_{E_2} = I_{E_2} R_B \cong I_{C_2} R_E = (\beta_1\beta_2 I_{B_1})R_E = (160)(200)(4.16\ \mu\text{A})(22\ \Omega)$ **= 2.93 V**

$V_{C_2} = 16\text{ V} - (I_C)(68\ \Omega) = 16\text{ V} - (\beta_1\beta_2 I_{B_1})(68\ \Omega)$
$= 16\text{ V} - (160)(200)(4.16\ \mu\text{A})(68\ \Omega) =$ **6.95 V**

$V_{B_2} = V_{BE_2} + V_{E_2}$ = 0.7 V + 2.93 V = **3.63V**
$V_{C_1} = V_{B_2}$ = **3.63 V**
$V_{E_1} = V_{C_2}$ = **6.95 V**

(b) I_{B_1} = **4.16 μA**
$I_{C_1} = \beta_1 I_{B_1} =$ (160)(4.16 μA) = **0.666 mA**
$I_{B_2} = I_{C_1}$ = **0.666mA**, $I_{C_2} = I_C = \beta_1\beta_2 I_{B_1}$ = **133.12 mA**
$I_{E_2} = I_{C_2}$ = **133.12 mA**

(c) $Z_i = R_B \,||\, \beta_1\beta_2 R_C$
$= 1.5\text{ M}\Omega \,||\, (160)(200)(68\ \Omega)$
= 0.887 MΩ
$Z_o = R_C \,||\, r_{o_1} \cong$ **68 Ω**

(d) $A_v \cong$ **1**

(e) $A_i = \dfrac{-\beta_1\beta_2 R_B}{R_B + \beta_1\beta_2 R_C} = \dfrac{-(160)(200)(1.5\text{ M}\Omega)}{1.5\text{ M}\Omega + (160)(200)(68\ \Omega)}$ $-$ **13.06 × 10**^{3}

56. (a) dc same as 54

(b) dc same as 54

(c) $Z_{i=} = R_B \,||\, \beta_1\beta_2(R_C \,||\, R_L)$
$= 1.5\text{ M}\Omega \,||\, (160)(200)(68\ \Omega \,||\, 1.2\text{ k}\Omega)$
$= 1.5\text{ M}\Omega \,||\, (160)(200)(64.35\ \Omega) = 1.5\text{ M}\Omega \,||\, 2.06\text{ M}\Omega)$
= 0.867 MΩ

$Z_o \cong$ **68 Ω**

(d) $A_v \cong \mathbf{1}$

$$A_i = \frac{= \beta_1\beta_2 R_B}{R_B + \beta_1\beta_2(R_C \parallel R_L)} = \frac{-(160)(200)(1.5\ \text{M}\Omega)}{1.5\ \text{M}\Omega + (160)(200)(64.55\ \Omega)}$$

$$= \mathbf{-13.49 \times 10^3}$$

57. $r_e = \dfrac{26\ \text{mV}}{I_{E(\text{dc})}} = \dfrac{26\ \text{mV}}{1.2\ \text{mA}} = \mathbf{21.67\ \Omega}$

$\beta r_e = (120)(21.67\ \Omega) = \mathbf{2.6\ k\Omega}$

58. –

59. –

60. –

61. –

62. (a) $A_v = \dfrac{V_o}{V_i} = -160$

$V_o = \mathbf{-160\ V_i}$

(b) $I_b = \dfrac{V_i - h_{re}V_o}{h_{ie}} = \dfrac{V_i - h_{re}A_vV_i}{h_{ie}} = \dfrac{V_i(1 - h_{re}A_v)}{h_{ie}}$

$$= \frac{V_i\left(1 - (2 \times 10^{-4})(160)\right)}{1\ \text{k}\Omega}$$

$I_b = \mathbf{9.68 \times 10^{-4} V_i}$

(c) $I_b = \dfrac{V_i}{1\ \text{k}\Omega} = \mathbf{1 \times 10^{-3} V_i}$

(d) $\%\ \text{Difference} = \dfrac{1 \times 10^{-3}V_i - 9.68 \times 10^{-4}V_i}{1 \times 10^{-3}V_i} \times 100\%$

$= \mathbf{3.2\ \%}$

(e) Valid first approximation

63. $\%\ \text{difference in total load} = \dfrac{R_L - R_L \| 1/h_{oe}}{R_L} \times 100\%$

$$= \frac{2.2\ \text{k}\Omega - (2.2\ \text{k}\Omega \| 50\ \text{k}\Omega)}{2.2\ \text{k}\Omega} \times 100\%$$

$$= \frac{2.2\ \text{k}\Omega - 2.1073\ \text{k}\Omega}{2.2\ \text{k}\Omega} \times 100\%$$

$= \mathbf{4.2\ \%}$

In this case the effect of $1/h_{oe}$ can be ignored.

64. (a) $V_o = \mathbf{-180V_i}$ $(h_{ie} = 4\text{ k}\Omega,\ h_{re} = 4.05 \times 10^{-4})$

(b) $I_b = \dfrac{V_i - (4.05\times10^{-4})(180V_i)}{4\text{ k}\Omega}$
$= \mathbf{2.32 \times 10^{-4} V_i}$

(c) $I_b = \dfrac{V_i}{h_{ie}} = \dfrac{V_i}{4\text{ k}\Omega} = \mathbf{2.5 \times 10^{-4} V_i}$

(d) $\%\text{ Difference} = \dfrac{2.5\times10^{-4}V_i - 2.32\times10^{-4}V_i}{2.5\times10^{-4}V_i} \times 100\% = \mathbf{7.2\%}$

(e) Yes, less than 10%

65. From Fig. 5.18

	min	max	
h_{oe}:	1 μS	30 μS	Avg = $\dfrac{(1+30)\mu\text{S}}{2} = \mathbf{15.5\ \mu S}$

$1/h_{oe} = 64.53\text{ k}\Omega$

$\dfrac{3.3\text{ k}\Omega - (3.3\text{ k}\Omega \,\|\, 64.52\text{ k}\Omega)}{3.3\text{ k}\Omega} \times 100\% = 4.88\%$

$\therefore$ Ignore effects

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) $r_e = \mathbf{8.31\ \Omega}$ (from problem 26)

(b) $h_{fe} = \beta = \mathbf{60}$
$h_{ie} = \beta r_e = (60)(8.31\ \Omega) = \mathbf{498.6\ \Omega}$

(c) $Z_i = R_B \,\|\, h_{ie} = 220\text{ k}\Omega \,\|\, 498.6\ \Omega = \mathbf{497.47\ \Omega}$
$Z_o = R_C = \mathbf{2.2\ k\Omega}$

(d) $A_v = \dfrac{-h_{fe}R_C}{h_{ie}} = \dfrac{-(60)(2.2\text{ k}\Omega)}{498.6\ \Omega} = \mathbf{-264.74}$
$A_i \cong h_{fe} = \mathbf{60}$

(e) Z_i = **497.47 Ω** (the same)

$Z_o = r_o \parallel R_C$, $r_o = \dfrac{1}{25\ \mu\text{S}} = 40\text{ k}\Omega$

$= 40\text{ k}\Omega \parallel 2.2\text{ k}\Omega$

$= \mathbf{2.09\ k\Omega}$

(f) $A_v = \dfrac{-h_{fe}(r_o \| R_C)}{h_{ie}} = \dfrac{-(60)(2.085\text{ k}\Omega)}{498.6\ \Omega} = \mathbf{-250.90}$

$A_i = -A_v Z_i/R_C = -(-250.90)(497.47\ \Omega)/2.2\text{ k}\Omega = \mathbf{56.73}$

68. (a) $68\text{ k}\Omega \parallel 12\text{ k}\Omega = 10.2\text{ k}\Omega$

$Z_i = 10.2\text{ k}\Omega \parallel h_{ie} = 10.2\text{ k}\Omega \parallel 2.75\text{ k}\Omega$

$= \mathbf{2.166\ k\Omega}$

$Z_o = R_C \parallel r_o$

$= 2.2\text{ k}\Omega \parallel 40\text{ k}\Omega$

$= \mathbf{2.085\ k\Omega}$

(b) $A_v = \dfrac{-h_{fe}R_C'}{h_{ie}}$ $\qquad R_C' = R_C \parallel r_o = 2.085\text{ k}\Omega$

$= \dfrac{-(180)(2.085\text{ k}\Omega)}{2.75\text{ k}\Omega} = \mathbf{-136.5}$

$A_i = \dfrac{I_o}{I_i} = \dfrac{I_o}{I_i'} \cdot \dfrac{I_i'}{I_i}$

$= \left(\dfrac{h_{f_e}}{1 + h_{oe}R_L}\right)\left(\dfrac{10.2\text{ k}\Omega}{10.2\text{ k}\Omega + 2.68\text{ k}\Omega}\right)$

$= \left(\dfrac{180}{1 + (25\ \mu\text{S})(2.2\text{ k}\Omega)}\right)(0.792)$

$= \mathbf{135.13}$

69. (a) $Z_i = R_E \parallel h_{ib}$

$= 1.2\text{ k}\Omega \parallel 9.45\ \Omega$

$= \mathbf{9.38\ \Omega}$

$Z_o = R_C \parallel \dfrac{1}{h_{ob}} = 2.7\text{ k}\Omega \parallel \dfrac{1}{1\times 10^{-6}\text{ A/V}} = 2.7\text{ k}\Omega \parallel 1\text{ M}\Omega \cong \mathbf{2.7\ k\Omega}$

(b) $A_v = \dfrac{-h_{fb}(R_C \| 1/h_{ob})}{h_{ib}} = \dfrac{-(-0.992)(\cong 2.7\text{ k}\Omega)}{9.45\ \Omega}$

$= \mathbf{284.43}$

$A_i \cong \mathbf{-1}$

(c) $\alpha = -h_{fb} = -(-0.992) = \mathbf{0.992}$

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.992}{1-0.992} = \mathbf{124}$$

$r_e = h_{ib} = \mathbf{9.45\ \Omega}$

$$r_o = \frac{1}{h_{ob}} = \frac{1}{1\ \mu\text{A/V}} = \mathbf{1\ M\Omega}$$

70. (a) $$Z_i' = h_{ie} - \frac{h_{fe}h_{re}R_L}{1+h_{oe}R_L} = 2.75\ \text{k}\Omega - \frac{(180)(2\times10^{-4})(2.2\ \text{k}\Omega)}{(1+25\mu\text{S})(2.2\ \text{k}\Omega)}$$

$$= 2.68\ \text{k}\Omega$$

$Z_i = 10.2\ \text{k}\Omega \parallel Z_i' = \mathbf{2.12\ k\Omega}$

$$Z_o' = \frac{1}{h_{oe} - (h_{fe}h_{re}/h_{ie})} = \frac{1}{25\ \mu\text{S} - (180)(2\times10^{-4})/2.75\ \text{k}\Omega}$$

$$= 83.75\ \text{k}\Omega$$

$Z_o = 2.2\ \text{k}\Omega \parallel 83.75\ \text{k}\Omega = 2.14\ \text{k}\Omega$

(b) $$A_v = \frac{-h_{fe}R_L}{h_{ie} + (h_{ie}h_{oe}) - h_{fe}h_{re})R_L} = \frac{-(180)(2.2\ \text{k}\Omega)}{2.75\ \text{k}\Omega + \left((2.75\ \text{k}\Omega)(25\mu\text{S}) - (180)*2\times10^{-4}\right)2.2\ \text{k}\Omega}$$

$$= \mathbf{-140.3}$$

(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) $$Z_i' = h_{ie} - \frac{h_{fe}h_{re}R_L}{1+h_{oe}R_L}$$

$$= 0.86\ \text{k}\Omega - \frac{(140)(1.5\times10^{-4})(2.2\ \text{k}\Omega)}{1+(25\ \mu\text{S})(2.2\ \text{k}\Omega)}$$

$= 0.86\ \text{k}\Omega - 43.79\ \Omega$

$= 816.21\ \Omega$

$Z_i = R_B \parallel Z_i'$

$= 470\ \text{k}\Omega \parallel 816.21\ \Omega$

$= \mathbf{814.8\ \Omega}$

(b) $$A_v = \frac{-h_{fe}R_L}{h_{ie} + (h_{ie}h_{oe} - h_{fe}h_{re})R_L}$$

$$= \frac{-(140)(2.2\ \text{k}\Omega)}{0.86\ \text{k}\Omega + ((0.86\ \text{k}\Omega)(25\ \mu\text{S}) - (140)(1.5\times10^{-4}))2.2\ \text{k}\Omega}$$

$$= \mathbf{-357.68}$$

(c) $A_i = \dfrac{I_o}{I_i} = \dfrac{h_{fe}}{1 + h_{oe}R_L} = \dfrac{140}{1 + (25\ \mu\text{S})(2.2\ \text{k}\Omega)}$

$= 132.70$

$A_i' = \dfrac{I_o}{I_i'} = \left(\dfrac{I_o}{I_i}\right)\left(\dfrac{I_i}{I_i'}\right)$ $\qquad I_i = \dfrac{470\ \text{k}\Omega\ I_i'}{470\ \text{k}\Omega + 0.816\ \text{k}\Omega}$

$= (132.70)(0.998)$ $\qquad \dfrac{I_i}{I_i'} = 0.998$

$=$ **132.43**

(d) $Z_o = \dfrac{1}{h_{oe} - \left(h_{fe}h_{re}/(h_{ie} + R_s)\right)} = \dfrac{1}{25\ \mu\text{S} - \left((140)(1.5 \times 10^{-4})/(0.86\ \text{k}\Omega + 1\ \text{k}\Omega)\right)}$

$= \dfrac{1}{13.71\ \mu\text{S}} \cong$ **72.9 kΩ**

72. (a) $Z_i' = h_{ib} - \dfrac{h_{fb}h_{rb}R_L}{1 + h_{ob}R_L} = 9.45\ \text{k}\Omega - \dfrac{(-0.997)(1 \times 10^{-4})(2.2\ \text{k}\Omega)}{1 + (0.5\mu\text{A/V})(2.2\ \text{k}\Omega)}$

$= 9.67\ \Omega$

$Z_i = 1.2\ \text{k}\Omega \parallel Z_i' = 1.2\ \text{k}\Omega \parallel 9.67\ \Omega =$ **9.59 Ω**

(b) $A_i' = \dfrac{h_{fb}}{1 + h_{ob}R_L} = \dfrac{0.997}{1 + (0.5\ \mu\text{A/V})(2.2\ \text{k}\Omega)} = -0.996$

$A_i = \dfrac{I_o}{I_i'} \cdot \dfrac{I_i'}{I_i} = (-0.996)\left(\dfrac{1.2\ \text{k}\Omega}{1.2\ \text{k}\Omega + 9.67\ \text{k}\Omega}\right)$

$\cong -0.988$

(c) $A_v = \dfrac{-h_{fL}R_L}{h_{ib} + (h_{ib}h_{ob} - h_{fb}h_{fb})R_L}$

$= \dfrac{-(-0.997)(2.2\ \text{k}\Omega)}{9.45\ \Omega + \left((9.45\ \Omega)(0.5\ \mu\text{A/V}) - (0.997)(1 \times 10^{-4})\right)(2.2\ \text{k}\Omega)}$

$=$ **226.21**

(d) $Z_o' = \dfrac{1}{h_{ob} - \left[h_{fb}h_{rb}/h_{ib}\right]}$

$= \dfrac{1}{0.5\ \mu\text{A/V} - \left[(-0.997)(1 \times 10^{-4})/9.45\ \Omega\right]}$

$= 90.5\ \text{k}\Omega$

$Z_o = 2.2\ \text{k}\Omega \parallel Z_o' =$ **2.15 kΩ**

73. –

74. (a) h_{fe} (0.2 mA) ≅ 0.6 (normalized)
h_{fe} (1 mA) = 1.0

$$\% \text{ change} = \left|\frac{h_{fe}(0.2 \text{ mA}) - h_{fe}(1 \text{ mA})}{h_{fe}(0.2 \text{ mA})}\right| \times 100\%$$

$$= \left|\frac{0.6-1}{0.6}\right| \times 100\%$$

$$= \mathbf{66.7\%}$$

(b) h_{fe}(1 mA) = 1.0
h_{fe}(5 mA) ≅ 1.5

$$\% \text{ change} = \left|\frac{h_{fe}(1 \text{ mA}) - h_{fe}(5 \text{ mA})}{h_{fe}(1 \text{ mA})}\right| \times 100\%$$

$$= \left|\frac{1-1.5}{1}\right| \times 100\%$$

$$= \mathbf{50\%}$$

75. Log-log scale!

(a) I_c = 0.2 mA, h_{ie} = 4 (normalized)
I_c = 1 mA, h_{ie} = 1(normalized)

$$\% \text{ change} = \left|\frac{4-1}{4}\right| \times 100\% = \mathbf{75\%}$$

(b) I_e = 5 mA, h_{ie} = 0.3 (normalized)

$$\% \text{ change} = \left|\frac{1-0.3}{1}\right| \times 100\% = \mathbf{70\%}$$

76. (a) h_{oe} = 20 μS @ 1 mA
I_c = 0.2 mA, h_{oe} = 0.2(h_{oe} @ 1 mA)
= 0.2(20 μS)
= **4 μS**

(b) $$r_o = \frac{1}{h_{oe}} = \frac{1}{4\ \mu\text{S}} = 250\ \text{k}\Omega \gg 6.8\ \text{k}\Omega$$

Ignore $1/h_{oe}$

77. (a) I_c = 10 mA, h_{oe} = 10(20 μS) = **200 μS**

(b) $$r_o = \frac{1}{h_{oe}} = \frac{1}{200\mu\text{S}} = 5\ \text{k}\Omega \text{ vs. } \mathbf{8.6\ k\Omega}$$

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) $h_{oe} \cong 30\ \mu\text{S}$ (normalized) to $h_{oe} \cong 0.1\ \mu\text{S}$ (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!

$R_{Th} = 39\text{ k}\Omega \parallel 150\text{ k}\Omega = 30.95\text{ k}\Omega$

$$E_{Th} = \frac{39\text{ k}\Omega(14\text{ V})}{39\text{ k}\Omega + 150\text{ k}\Omega} = 2.89\text{ V}$$

$$I_B = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta+1)R_E} = \frac{2.89\text{ V} - 0.7\text{ V}}{30.95\text{ k}\Omega + (71)(1.5\text{ k}\Omega)}$$
$= 15.93\ \mu\text{A}$

$V_B = E_{Th} - I_BR_{Th}$
$= 2.89\text{ V} - (15.93\ \mu\text{A})(30.95\text{ k}\Omega)$
$= 2.397\text{ V}$

V_E = 2.397 V − 0.7 V = 1.697 V

and $I_E = \frac{V_E}{R_E} = \frac{1.697 \text{ V}}{1.5 \text{ k}\Omega}$ = 1.13 mA

$V_{CE} = V_{CC} - I_C(R_C + R_E)$
= 14 V − 1.13 mA(2.2 kΩ + 1.5 kΩ)
= 9.819 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 μA

$V_B = V_{CC} - I_BR_B$ = 14 V − (51.85 μA)(150 kΩ)
= **6.22 V** as noted in Fig. 5.194.

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. –

4. (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) $r_d = \dfrac{233.33\ \Omega}{[1-(-2\text{ V})/(-4\text{ V})]^2} = \dfrac{233.33\ \Omega}{0.25} = \mathbf{933.2\ \Omega}$

   (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!

5. (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
$\Delta I_D =$ **1.5 mA**

(d) $V_{GS} = -3$ V, $I_D = 0.5$ mA
$V_{GS} = -4$ V, $I_D = 0$ mA
$\Delta I_D =$ **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.

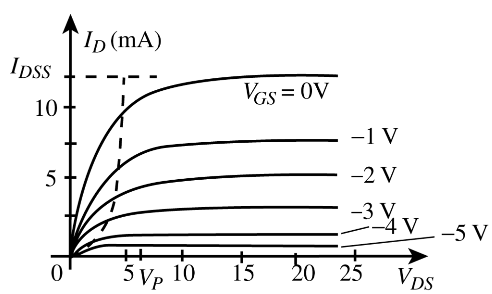
6. The collector characteristics of a BJT transistor are a plot of output current versus the output voltage for different levels of *input current*. The drain characteristics of a JFET transistor are a plot of the output current versus input voltage. For the BJT transistor increasing levels of input 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.

7. (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).

8. $V_{GS} = 0$ 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.



9. 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.

10. (b) $I_{DSS} =$ **10 mA**, $V_P =$ **−6 V**

11. $V_{GS} = 0\text{ V}$, $I_D = I_{DSS} = 12\text{ mA}$
$V_{GS} = V_P = -4\text{ V}$, $I_D = 0\text{ mA}$
$V_{GS} = \dfrac{V_P}{2} = -2\text{ V}$, $I_D = \dfrac{I_{DSS}}{4} = 3\text{ mA}$
$V_{GS} = 0.3V_P = -1.2\text{ V}$, $I_D = 6\text{ mA}$
$V_{GS} = -3\text{ V}$, $I_D = 0.75\text{ mA}$ (Shockley's equation)

12. (a) $I_D = I_{DSS} = \mathbf{9\ mA}$

(b) $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$
$= 9\text{ mA}(1 - (-2)/(-4))^2$
$= \mathbf{2.25\ mA}$

(c) $V_{GS} = V_P = -4\text{ V}$, $I_D = \mathbf{0\ mA}$

(d) $|V_{GS}| \geq |V_P|$, $I_D = \mathbf{0\ mA}$

13. $V_{GS} = \mathbf{0\ V}$, $I_D = \mathbf{16\ mA}$
$V_{GS} = 0.3V_P = 0.3(-5\text{ V}) = \mathbf{-1.5\ V}$, $I_D = I_{DSS}/2 = \mathbf{8\ mA}$
$V_{GS} = 0.5V_P = 0.5(-5\text{ V}) = \mathbf{-2.5\ V}$, $I_D = I_{DSS}/4 = \mathbf{4\ mA}$
$V_{GS} = V_P = \mathbf{-5\ V}$, $I_D = \mathbf{0\ mA}$

14. $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$
$4\text{ mA} = 12\text{ mA}(1 - (-3)/V_P)^2$

$$0.333 = \left(1 - \frac{(-3)}{V_P}\right)^2$$

$$\sqrt{0.333} = 1 - \frac{(-3)}{V_P}$$

$$0.577 = 1 - \frac{(-3)}{V_P}$$

$$0.423 = \frac{-3}{V_P}$$

$$V_P = \frac{-3}{0.423} \cong \mathbf{-7.1\ V}$$

15. (a) $I_D = I_{DSS}(1 - V_{GS}/V_P)^2 = 6\text{ mA}(1 - (-2\text{ V})/(-4.5\text{ V}))^2$
$= \mathbf{1.852\ mA}$
$I_D = I_{DSS}(1 - V_{GS}/V_P)^2 = 6\text{ mA}(1 - (-3.6\text{ V})/(-4.5\text{ V}))^2$
$= \mathbf{0.24\ mA}$

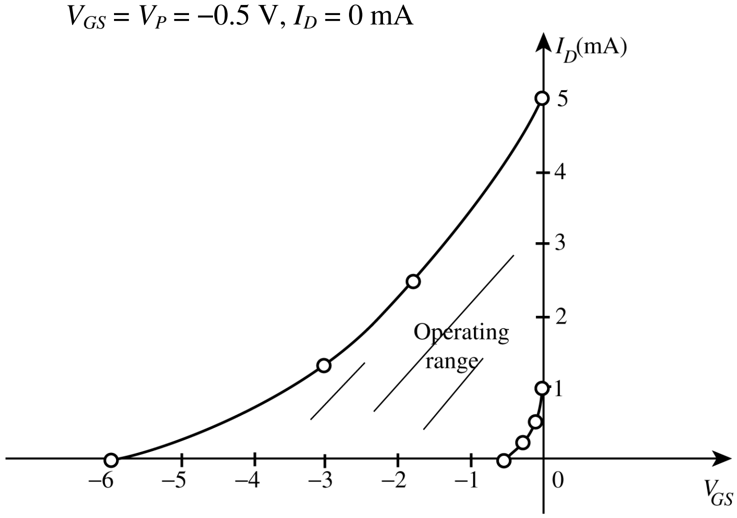
(b) $$V_{GS} = V_P\left(1 - \sqrt{\frac{I_D}{I_{DSS}}}\right) = (-4.5\text{ V})\left(1 - \sqrt{\frac{3\text{ mA}}{6\text{ mA}}}\right)$$
$= \mathbf{-1.318\ V}$

$$V_{GS} = V_P\left(1 - \sqrt{\frac{I_D}{I_{DSS}}}\right) = (-4.5\text{ V})\left(1 - \sqrt{\frac{5.5\text{ mA}}{6\text{ mA}}}\right)$$
$= \mathbf{-0.192\ V}$

16. $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$
$3 \text{ mA} = I_{DSS}(1 - (-3 \text{ V})/(-6 \text{ V}))^2$
$3 \text{ mA} = I_{DSS}(0.25)$
$I_{DSS} = \mathbf{12 \text{ mA}}$

17. $V_{GS} = 0$ V, $I_D = I_{DSS} = \mathbf{7.5 \text{ mA}}$
$V_{GS} = 0.3V_P = (0.3)(4 \text{ V}) = 1.2$ V, $I_D = I_{DSS}/2 = 7.5 \text{ mA}/2 = \mathbf{3.75 \text{ mA}}$
$V_{GS} = 0.5V_P = (0.5)(4 \text{ V}) = 2$ V, $I_D = I_{DSS}/4 = 7.5 \text{ mA}/4 = \mathbf{1.875 \text{ mA}}$
$V_{GS} = V_P = 4$ V, $I_D = \mathbf{0 \text{ mA}}$

18. 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:
$V_{GS} = 0$ V, $I_D = 5$ mA
$V_{GS} = 0.3V_P = -1.8$ V, $I_D = 2.5$ mA
$V_{GS} = V_P/2 = -3$ V, $I_D = 1.25$ mA
$V_{GS} = V_P = -6$ V, $I_D = 0$ mA
For $I_{DSS} = 1$ mA and $V_P = -0.5$ V:
$V_{GS} = 0$ V, $I_D = 1$ mA
$V_{GS} = 0.3V_P = -0.15$ V, $I_D = 0.5$ mA
$V_{GS} = V_P/2 = -0.25$ V, $I_D = 0.25$ mA
$V_{GS} = V_P = -0.5$ V, $I_D = 0$ mA



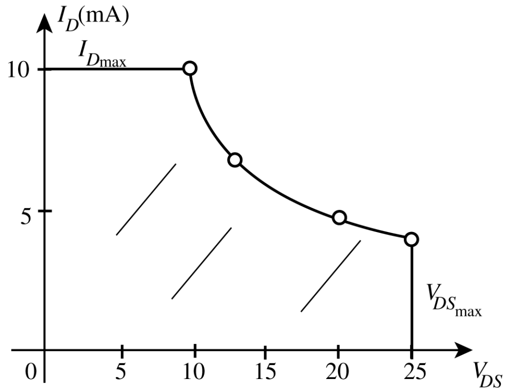
19. At 25°C, $P_D = 625$ mW
$45°\text{C} - 25°\text{C} = 20°\text{C}$
$$20°\text{C}\left(\frac{5 \text{ mW}}{°\text{C}}\right) = 100 \text{ mW}$$
$$P_D' = 625 \text{ mW} - 100 \text{ mW}$$
$$= \mathbf{525 \text{ mW}}$$

20. $V_{DS} = V_{DS_{max}}$ = **25 V**, $I_D = \dfrac{P_{D_{max}}}{V_{DS_{max}}} = \dfrac{100 \text{ mW}}{25 \text{ V}}$ = **4 mA**

$I_D = I_{DSS}$ = **10 mA**, $V_{DS} = \dfrac{P_{D_{max}}}{I_{DSS}} = \dfrac{100 \text{ mW}}{10 \text{ mA}}$ = **10 V**

$V_D = 20 \text{ V}$, $I_D = 6.67 \text{ mA}$

$V_D = 15 \text{ V}$, $I_D = 5 \text{ mA}$



21. $V_{GS} = -0.5 \text{ V}, I_D = 6.5 \text{ mA}$
$V_{GS} = -1 \text{ V}, I_D = 4 \text{ mA}$ } 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 mA + 1.5 mA = **5.5 mA** corresponding with values determined from a purely graphical approach.

22. Yes, all knees of V_{GS} curves at or below $|V_P| = 3$ V.

23. From Fig 6.25, $I_{DSS} \cong 9$ mA
At $V_{GS} = -1$ V, $I_D = 4$ mA
$I_D = I_{DSS}(1 - V_{GS}/V_P)^2$

$$\sqrt{\frac{I_D}{I_{DSS}}} = 1 - V_{GS}/V_P$$

$$\frac{V_{GS}}{V_P} = 1 - \sqrt{\frac{I_D}{I_{DSS}}}$$

$$V_P = \frac{V_{GS}}{1 - \sqrt{\dfrac{I_D}{I_{DSS}}}} = \frac{-1 \text{ V}}{1 - \sqrt{\dfrac{4 \text{ mA}}{9 \text{ mA}}}}$$

= **−3 V** (an exact match)

24. $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$
= 9 mA$(1 - (-1 \text{ V})/(-3 \text{ V}))^2$
= **4 mA**, which compares very well with the level obtained using Fig. 6.25.

25. (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) $$r_d = \frac{r_o}{(1 - V_{GS}/V_P)^2} = \frac{175\ \Omega}{(1-(-0.5\text{ V})/(-3\text{ V})^2}$$

$= \mathbf{252\ \Omega}$ vs. 233 Ω from part (b)

26. –

27. 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.

28. –

29. At $V_{GS} = 0$ V, $I_D = \mathbf{6\ mA}$
At $V_{GS} = -1$ V, $I_D = 6\text{ mA}(1 - (-1\text{ V})/(-3\text{ V}))^2 = \mathbf{2.66\ mA}$
At $V_{GS} = +1$ V, $I_D = 6\text{ mA}(1 - (+1\text{ V})/(-3\text{ V}))^2 = 6\text{ mA}(1.333)^2 = \mathbf{10.667\ mA}$
At $V_{GS} = +2$ V, $I_D = 6\text{ mA}(1 - (+2\text{ V})/(-3\text{ V}))^2 = 6\text{ mA}(1.667)^2 = \mathbf{16.67\ mA}$

$\Delta I_D = 4.67$ mA

V_{GS}	I_D
−1 V	2.66 mA
0	6.0 mA
+1 V	10.67 mA
+2 V	16.67 mA

−1 V to 0: $\Delta I_D = \mathbf{3.34\ mA}$
0 to +1 V: $\Delta I_D = \mathbf{4.67\ mA}$
+1 V to +2 V: $\Delta I_D = \mathbf{6\ mA}$

From −1 V to 0 V, $\Delta I_D = 3.34$ mA
while from +1 V to +2 V, $\Delta I_D = 6$ 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.

30. $V_{GS} = 0$ V, $I_D = I_{DSS} = 12$ mA; $V_{GS} = -8$ V, $I_D = 0$ mA; $V_{GS} = \frac{V_P}{2} = -4$ 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

31. From problem 20:

$$V_P = \frac{V_{GS}}{1-\sqrt{\dfrac{I_D}{I_{DSS}}}} = \frac{+1\text{ V}}{1-\sqrt{\dfrac{14\text{ mA}}{9.5\text{ mA}}}} = \frac{+1\text{ V}}{1-\sqrt{1.473}} = \frac{+1\text{ V}}{1-1.21395}$$

$$= \frac{1}{-0.21395} \cong \mathbf{-4.67\text{ V}}$$

32. $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$

$$I_{DSS} = \frac{I_D}{\left(1-V_{GS}/V_P\right)^2} = \frac{4\text{ mA}}{(1-(-2\text{ V})/(-5\text{ V}))^2} = \mathbf{11.11\text{ mA}}$$

33. From problem 14(b):

$$V_{GS} = V_P\left(1-\sqrt{\frac{I_D}{I_{DSS}}}\right) = (-5\text{ V})\left(1-\sqrt{\frac{20\text{ mA}}{2.9\text{ mA}}}\right)$$

$= (-5\text{ V})(1 - 2.626) = (-5\text{ V})(-1.626)$

$= \mathbf{8.13\text{ V}}$

34. From Fig. 6.34, $P_{D_{max}} = 200$ mW, $I_D = 8$ mA

$P = V_{DS}I_D$

and $V_{DS} = \dfrac{P_{max}}{I_D} = \dfrac{200\text{ mW}}{8\text{ mA}} = \mathbf{25\text{ V}}$

35. (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.

36. (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	

37. (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 mA/V²**

$I_D = k(V_{GS} - V_T)^2 = \mathbf{1 \times 10^{-3}(V_{GS} - 4\ V)^2}$

(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

38. From Fig. 6.58, $V_T = 2.0$ V

At $I_D = 6.5$ mA, $V_{GS} = 5.5$ V: $I_D = k(V_{GS} - V_T)^2$

$6.5\text{ mA} = k(5.5\text{ V} - 2\text{ V})^2$

$k = \mathbf{5.31 \times 10^{-4}}$

$I_D = \mathbf{5.31 \times 10^{-4}(V_{GS} - 2)^2}$

39. $I_D = k\left(V_{GS(\text{on})} - V_T\right)^2$

and $\left(V_{GS(\text{on})} - V_T\right)^2 = \dfrac{I_D}{k}$

$V_{GS(\text{on})} - V_T = \sqrt{\dfrac{I_D}{k}}$

$V_T = V_{GS(\text{on})} - \sqrt{\dfrac{I_D}{k}}$

$= 4\text{ V} - \sqrt{\dfrac{3\text{ mA}}{0.4 \times 10^{-3}}} = 4\text{ V} - \sqrt{7.5}\text{ V}$

$= 4\text{ V} - 2.739\text{ V}$

= 1.261 V

40. $I_D = k(V_{GS} - V_T)^2$

$$\frac{I_D}{k} = (V_{GS} - V_T)^2$$

$$\sqrt{\frac{I_D}{k}} = V_{GS} - V_T$$

$$V_{GS} = V_T + \sqrt{\frac{I_D}{k}} = 5\text{ V} + \sqrt{\frac{30\text{ mA}}{0.06 \times 10^{-3}}}$$

$$= \mathbf{27.36\text{ V}}$$

41. Enhancement-type MOSFET:

$I_D = k(V_{GS} - V_T)^2$

$$\frac{dI_D}{dV_{GS}} = 2k(V_{GS} - V_T)\underbrace{\frac{d}{dV_{GS}}(V_{GS} - V_T)}_{1}$$

$$\frac{dI_D}{dV_{GS}} = \mathbf{2k(V_{GS} - V_T)}$$

Depletion-type MOSFET:

$I_D = I_{DSS}(1 - V_{GS}/V_P)^2$

$$\frac{dI_D}{dV_{GS}} = I_{DSS}\frac{d}{dV_{GS}}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

$$= I_{DSS}\,2\left(1 - \frac{V_{GS}}{V_P}\right)\underbrace{\frac{d}{dV_{GS}}\left(0 - \frac{V_{GS}}{V_P}\right)}_{-\frac{1}{V_P}}$$

$$= 2I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)\left(-\frac{1}{V_P}\right)$$

$$= -\frac{2I_{DSS}}{V_P}\left(1 - \frac{V_{GS}}{V_P}\right)$$

$$= -\frac{2I_{DSS}}{V_P}\left(\frac{V_P}{V_P}\right)\left(1 - \frac{V_{GS}}{V_P}\right)$$

$$\frac{dI_D}{dV_{GS}} = \boldsymbol{\frac{2I_{DSS}}{V_P^2}(V_{GS} - V_P)}$$

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.

42. $I_D = k(V_{GS} - V_T)^2 = 0.45 \times 10^{-3}(V_{GS} - (-5\text{ V}))^2$

$= 0.45 \times 10^{-3}(V_{GS} + 5\text{ V})^2$

$V_{GS} = -5$ 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

43. –

44. –

45. –

46. –

(b) For the "on" transistor: $R = \frac{V}{I} = \frac{0.1\text{ V}}{4\text{ mA}}$ = **25 ohms**

For the "off" transistor: $R = \frac{V}{I} = \frac{4.9\text{ V}}{0.5\ \mu\text{A}}$ = **9.8 MΩ**

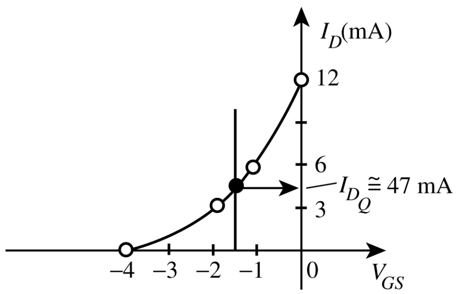
Absolutely, the high resistance of the "off" resistance will ensure V_o is very close to 5 V.

47. –

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**

$V_{DS_Q} = V_{DD} - I_{D_Q}R_D = 14\text{ V} - (4.7\text{ mA})(1.8\text{ k}\Omega)$
= **5.54 V**

(d) $I_{D_Q} = I_{DSS}(1 - V_{GS}/V_P)^2 = 12\text{ mA}(1 - (-1.5\text{ V})/(-4\text{ V}))^2$
= **4.69 mA**

$V_{DS_Q} = V_{DD} - I_{D_Q}R_D = 14\text{ V} - (4.69\text{ mA})(1.8\text{ k}\Omega)$
= **5.56 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} = **1.11 mA**

(b) V_{GS_Q} = **−3 V**

(c) $V_{DS} = V_{DD} - I_D(R_D + R_S)$
$= 16\text{ V} - (1.11\text{ mA})(2.2\text{ k}\Omega)$
$= 16\text{ V} - 2.444\text{ V}$
= **13.56 V**
$V_D = V_{DS}$ = **13.56 V**
$V_G = V_{GS_Q}$ = **−3 V**
V_S = **0 V**

3. (a) $I_{D_Q} = \dfrac{V_{DD} - V_D}{R_D} = \dfrac{12\text{ V} - 6\text{ V}}{2.2\text{ k}\Omega}$ = **2.727 mA**

(b) $V_{DS} = V_D - V_S = 6\text{ V} - 0\text{ V} =$ **6 V**

(c) $I_D = I_{DSS}(1 - V_{GS}/V_P)^2 \Rightarrow V_{GS} = V_P \;\; 1 - \sqrt{\dfrac{I_D}{I_{DSS}}}$

$V_{GS} = (-4\text{ V}) \;\; 1 - \sqrt{\dfrac{2.727\text{ mA}}{8\text{ mA}}}$

$= -1.66\text{ V}$

$\therefore V_{GG} =$ **1.66 V**

4. V_{GS_Q} = **0 V**, $I_D = I_{DSS} = 5$ mA

$V_D = V_{DD} - I_D R_D$

$= 20\text{ V} - (5\text{ mA})(2.2\text{ k}\Omega)$

$= 20\text{ V} - 11\text{ V}$

= **9 V**

5. $V_{GS} = V_P =$ **−4 V**

$\therefore I_{D_Q} = 0$ mA

and $V_D = V_{DD} - I_{D_Q} R_D = 18\text{ V} - (0)(2\text{ k}\Omega)$

= **18 V**

6. (a)(b) $V_{GS} = 0$ V, $I_D = 10$ mA

$V_{GS} = V_P = -4$ V, $I_D = 0$ mA

$V_{GS} = \dfrac{V_P}{2} = -2$ V, $I_D = 2.5$ mA

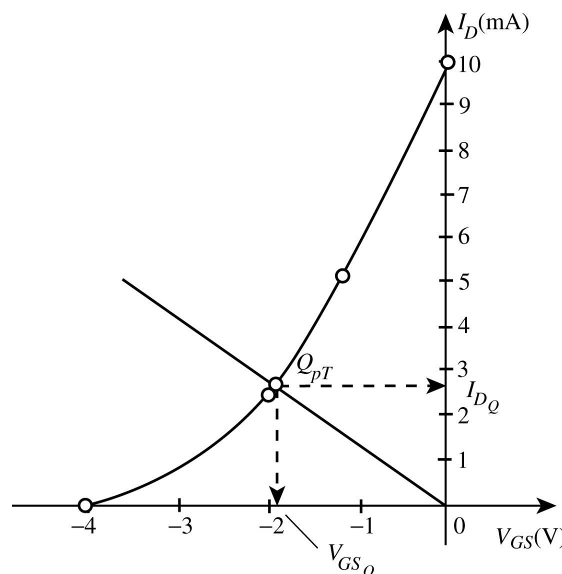
$V_{GS} = 0.3V_P = -1.2$ V, $I_D = 5$ mA

$V_{GS} = -I_D R_S$

$I_D = 5$ mA:

$V_{GS} = -(5\text{ mA})(0.75\text{ k}\Omega)$

$= -3.75$ V



(c) $I_{D_Q} \cong$ **2.7 mA**

$V_{GS_Q} \cong$ **−1.9 V**

(d) $V_{DS} = V_{DD} - I_D(R_D + R_S)$

$= 18\text{ V} - (2.7\text{ mA})(1.5\text{ k}\Omega + 0.75\text{ k}\Omega)$

= **11.93 V**

$V_D = V_{DD} - I_D R_D$

$= 18\text{ V} - (2.7\text{ mA})(1.5\text{ k}\Omega)$

= **13.95 V**

$V_G =$ **0 V**

$V_S = I_S R_S = I_D R_S$

$= (2.7\text{ mA})(0.75\text{ k}\Omega)$

= **2.03 V**

7. $I_D = I_{DSS}(1 - V_{GS}/V_P)^2 = I_{DSS}\;\; 1 + \dfrac{2I_DR_S}{V_P} + \dfrac{I_D^2R_S^2}{V_P^2}$

$$\frac{I_{DSS}R_S^2}{V_P^2}\;\; I_D^2 + \;\; \frac{2I_{DSS}R_S}{V_P} - 1 \;\; I_D + I_{DSS} \;\; = 0$$

Substituting: $351.56\,I_D^2 - 4.75I_D + 10\text{ mA} = 0$

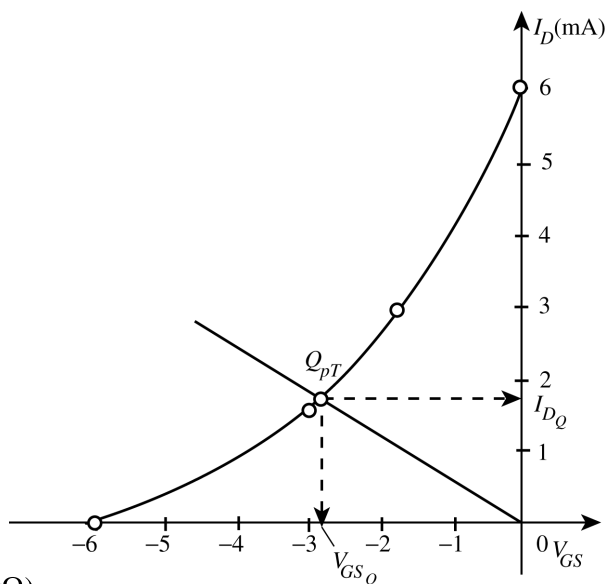
$I_D = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a} = 10.91\text{ mA}, 2.60\text{ mA}$

I_{D_Q} = **2.6 mA** (exact match #6)

$V_{GS} = -I_DR_S = -(2.60\text{ mA})(0.75\text{ k}\Omega)$
$= -1.95\text{ V}$ vs. -2 V (#6)

8. $V_{GS} = 0\text{ V}, I_D = I_{DSS} = 6\text{ mA}$
$V_{GS} = V_P = -6\text{ V}, I_D = 0\text{ mA}$
$V_{GS} = \dfrac{V_P}{2} = -3\text{ V}, I_D = 1.5\text{ mA}$

$V_{GS} = 0.3V_P = -1.8\text{ V}, I_D = 3\text{ mA}$
$V_{GS} = -I_DR_S$
$I_D = 2\text{ mA}$:
$V_{GS} = -(2\text{ mA})(1.6\text{ k}\Omega)$
$= -3.2\text{ V}$



(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) $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$
$3.33 \text{ mA} = I_{DSS}(1 - (-1.7 \text{ V})/(-4 \text{ V}))^2$
$3.33 \text{ mA} = I_{DSS}(0.331)$
$I_{DSS} = \mathbf{10.06 \text{ mA}}$

(d) $V_D = V_{DD} - I_{D_Q} R_D$
$= 18 \text{ V} - (3.33 \text{ mA})(2 \text{ k}\Omega) = 18 \text{ V} - 6.66 \text{ V}$
$= \mathbf{11.34 \text{ V}}$

(e) $V_{DS} = V_D - V_S = 11.34 \text{ V} - 1.7 \text{ V}$
$= \mathbf{9.64 \text{ V}}$

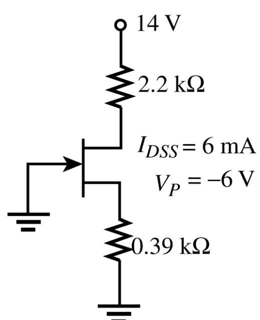
10. (a) $V_{GS} = 0 \text{ V}$
$\therefore I_D = I_{DSS} = \mathbf{4.5 \text{ mA}}$

(b) $V_{DS} = V_{DD} - I_D(R_D + R_S)$
$= 20 \text{ V} + 4 \text{ V} - (4.5 \text{ mA})(2.2 \text{ k}\Omega + 0.68 \text{ k}\Omega)$
$= 24 \text{ V} - 12.96$
$= \mathbf{11.04 \text{ V}}$

(c) $V_D = V_{DD} - I_D R_D$
$= 20 \text{ V} - (4.5 \text{ mA})(2.2 \text{ k}\Omega)$
$= \mathbf{10.1 \text{ V}}$

(d) $-4 \text{ V} + I_S R_S - V_S = 0$
$V_S = I_S R_S - 4 \text{ V} = I_D R_S - 4 \text{ V} = (4.5 \text{ mA})(0.68 \text{ k}\Omega) - 4 \text{ V}$
$= 3.06 \text{ V} - 4 \text{ V}$
$= \mathbf{-0.94 \text{ V}}$

11. Network redrawn:



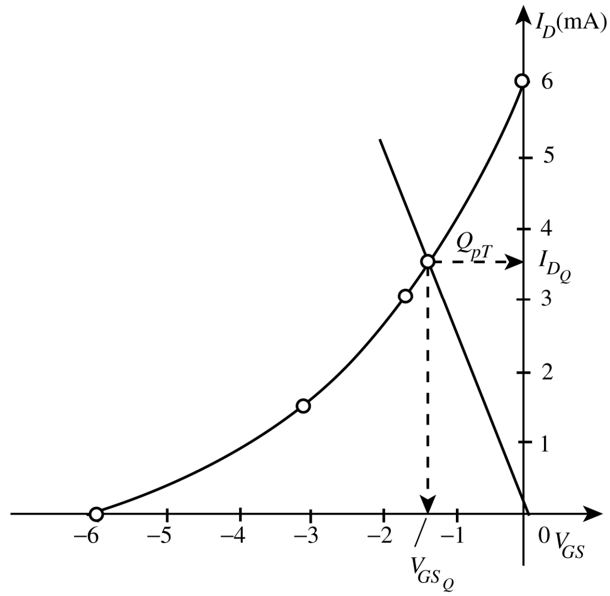
$V_{GS} = 0 \text{ V}, I_D = I_{DSS} = 6 \text{ mA}$
$V_{GS} = V_P = -6 \text{ V}, I_D = 0 \text{ mA}$
$V_{GS} = \dfrac{V_P}{2} = -3 \text{ V}, I_D = 1.5 \text{ mA}$
$V_{GS} = 0.3V_P = -1.8 \text{ V}, I_D = 3 \text{ mA}$
$V_{GS} = -I_D R_S = -I_D(0.39 \text{ k}\Omega)$
For $I_D = 5 \text{ mA}, V_{GS} = -1.95 \text{ V}$

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) $V_G = \dfrac{R_2}{R_1 + R_2}V_{DD} = \dfrac{110\text{ k}\Omega(20\text{ V})}{910\text{ k}\Omega + 110\text{ k}\Omega}$

$= \mathbf{2.16\ V}$

$V_{GS} = 0$ V, $I_D = I_{DSS} = 10$ mA

$V_{GS} = V_P = -3.5$ V, $I_D = 0$ mA

$V_{GS} = \dfrac{V_P}{2} = -1.75$ V, $I_D = 2.5$ mA

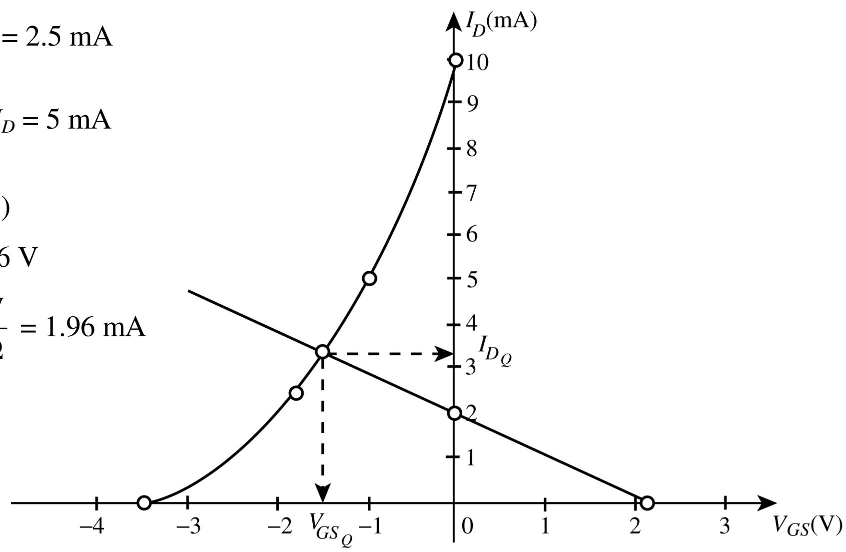
$V_{GS} = 0.3V_P = -1.05$ V, $I_D = 5$ mA

$V_{GS_Q} = V_G - I_D R_S$

$V_{GS_Q} = 2.16 - I_D(1.1\text{ k}\Omega)$

$I_D = 0$: $V_{GS_Q} = V_G = 2.16$ V

$V_{GS_Q} = 0$ V, $I_D = \dfrac{2.16\text{ V}}{1.1\text{ k}\Omega} = 1.96$ mA



(b) $I_{D_Q} \cong \mathbf{3.3\ mA}$

$V_{GS_Q} \cong \mathbf{-1.5\ V}$

(c) $V_D = V_{DD} - I_{D_Q} R_D$

$= 20\text{ V} - (3.3\text{ mA})(2.2\text{ k}\Omega)$

$= \mathbf{12.74\ V}$

$V_S = I_S R_S = I_D R_S$

$= (3.3\text{ mA})(1.1\text{ k}\Omega)$

$= \mathbf{3.63\ V}$

(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

$$V_G = \frac{110\text{ k}\Omega(20\text{ V})}{110\text{ k}\Omega + 910\text{ k}\Omega} = \mathbf{2.16\text{ V}}$$

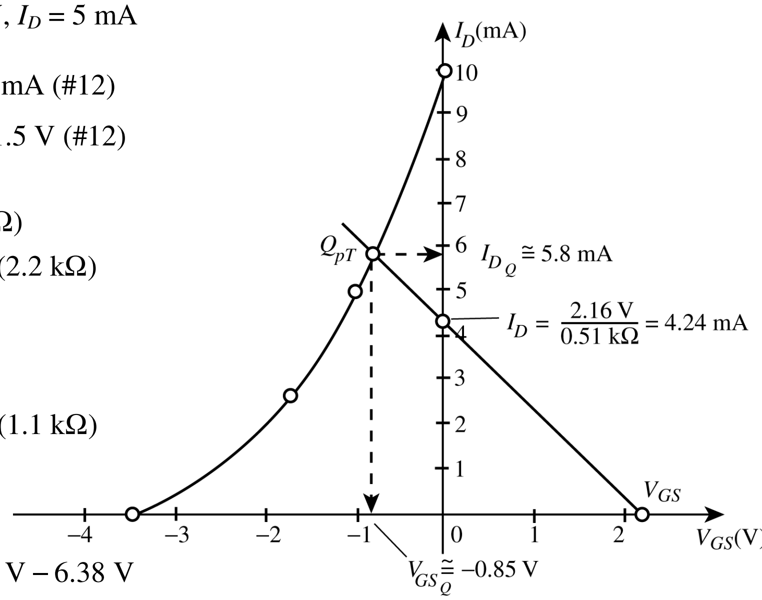
$$V_{GS} = \frac{V_P}{2} = \frac{-3.5\text{ V}}{2} = -1.75\text{ V},\ I_D = 2.5\text{ mA}$$

$V_{GS} = 0.3V_P = -1.05$ V, $I_D = 5$ mA

$I_{D_Q} \cong$ **5.8 mA** vs. 3.3 mA (#12)
$V_{GS_Q} \cong$ **−0.85 V** vs. −1.5 V (#12)

$$\begin{aligned} V_D &= 20\text{ V} - I_D(2.2\text{ k}\Omega) \\ &= 20\text{ V} - (5.8\text{ mA})(2.2\text{ k}\Omega) \\ &= 20\text{ V} - 12.76\text{ V} \\ &= \mathbf{7.24\text{ V}} \end{aligned}$$

$$V_S = I_D R_S = (5.8\text{ mA})(1.1\text{ k}\Omega) = \mathbf{6.38\text{ V}}$$



$$V_{DS_Q} = V_D - V_S = 7.24\text{ V} - 6.38\text{ V} = \mathbf{0.86\text{ V}}$$

(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) $$I_D = \frac{V_{R_D}}{R_D} = \frac{V_{DD} - V_D}{R_D} = \frac{18\text{ V} - 12\text{ V}}{2\text{ k}\Omega} = \frac{6\text{ V}}{2\text{ k}\Omega} = \mathbf{3\text{ mA}}$$

(b) $V_S = I_S R_S = I_D R_S = (3\text{ mA})(0.68\text{ k}\Omega) = \mathbf{2.04\text{ V}}$

$$\begin{aligned} V_{DS} &= V_{DD} - I_D(R_D + R_S) = 18\text{ V} - (3\text{ mA})(2\text{ k}\Omega + 0.68\text{ k}\Omega) \\ &= 18\text{ V} - 8.04\text{ V} = \mathbf{9.96\text{ V}} \end{aligned}$$

(c) $$V_G = \frac{110\text{ k}\Omega(12\text{ V})}{110\text{ k}\Omega + 680\text{ k}\Omega} = \mathbf{1.67\text{ V}}$$

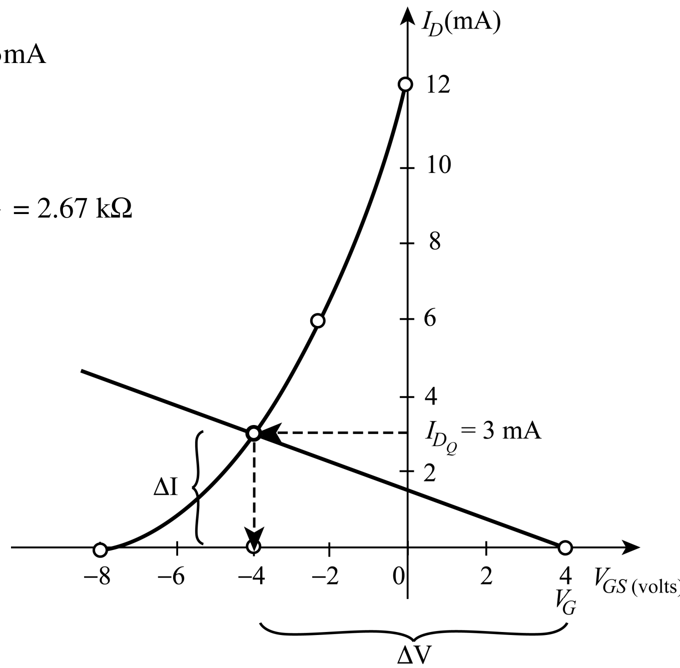
$$\begin{aligned} V_{GS} &= V_G - I_S R_S = V_G - I_D R_S = V_G - V_S = 1.67\text{ V} - 2.04\text{ V} \\ &= \mathbf{-0.37\text{ V}} \end{aligned}$$

(d) $$V_P = \frac{V_{GS}}{1 - \sqrt{\dfrac{I_D}{I_{DSS}}}} = \frac{-0.37\text{ V}}{1 - \sqrt{\dfrac{3\text{ mA}}{8\text{ mA}}}} = \frac{-0.37\text{ V}}{1 - 0.612} = \frac{-0.37\text{ V}}{0.388} = \mathbf{-0.954\text{ V}}$$

15. $I_{D_Q} = \dfrac{16\text{ V} - 10\text{ V}}{2\text{ k}\Omega} = \dfrac{6\text{ V}}{2\text{ k}\Omega} = 3\text{mA}$

$V_G = \dfrac{12\text{ k}\Omega(16\text{ V})}{12\text{ k}\Omega + 36\text{ k}\Omega} = 4\text{ V}$

$R_S = \dfrac{\Delta V}{\Delta I} = \dfrac{4\text{ V} + 4\text{ V}}{3\text{ mA}} = \dfrac{8\text{ V}}{3\text{ mA}} = 2.67\text{ k}\Omega$



16. (a) $V_{GS} = 0\text{ V},\ I_D = I_{DSS} = 6\text{ mA}$

$V_{GS} = V_P = -6\text{ V},\ I_D = 0\text{ mA}$

$V_{GS} = V_P/2 = -3\text{ V},\ I_D = 1.5\text{ mA}$

$V_{GS} = 0.3V_P = -1.8\text{ V},\ I_D = 3\text{ mA}$

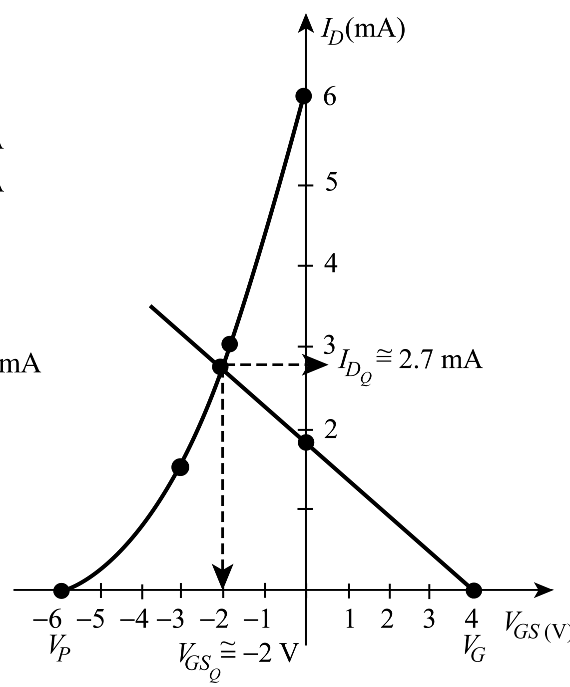
$V_{GS} = V_{SS} - I_D R_S$

$V_{GS} = 4\text{ V} - I_D(2.2\text{ k}\Omega)$

$V_{GS} = 0\text{ V},\ I_D = \dfrac{4\text{ V}}{2.2\text{ k}\Omega} = 1.818\text{ mA}$

$I_D = 0\text{ mA},\ V_{GS} = 4\text{ V}$

$I_{D_Q} \cong$ **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 $V_S = -(V_{GS_Q}) = -(2\text{ V}) =$ **2 V**

17. (a) $I_D = \dfrac{V_{DD} + V_{SS} - V_{DS}}{R_D + R_S} = \dfrac{20\text{ V} - 2\text{ V} - 4\text{ V}}{3\text{ k}\Omega + 1.2\text{ k}\Omega} = \dfrac{14\text{ V}}{4.2\text{ k}\Omega}$ = **3.3 mA**

(b) $V_D = V_{DD} - I_D R_D = 20\text{ V} - (3.33\text{ mA})(3\text{ k}\Omega)$
= **10 V**
$V_S = I_S R_S + V_{SS} = I_D R_S + V_{SS}$
= (3.33 mA)(1.2 kΩ) + (2 V)
= 4 V + 2 V
= **6 V**

(c) $V_{GS} = V_G - V_S$
= 0 V − 6 V
= **−6 V**

18. (a) I_{D_Q} = **4 mA**

(b) $V_{D_Q} = 18\text{ V} - 4\text{ mA}(1.8\text{ k}\Omega) = 18\text{ V} - 7.2\text{ V}$ = **10.8 V**

$V_{DS_Q} = V_D - V_S = 10.8\text{ V} - I_D R_S = 10.8\text{ V} - (4\text{ mA})(1.2\text{ k}\Omega) = 10.8\text{ V} - 4.8\text{ V}$ = **6 V**

(c) P_s = (18 V)(4 mA) = **72 mW**
P_d = (6 V)(4 mA) = **24 mW**

19. $V_G = \dfrac{(1.2\text{ k}\Omega)(16\text{ V})}{1.2\text{ k}\Omega + 3.6\text{ k}\Omega} = 4\text{ V}$

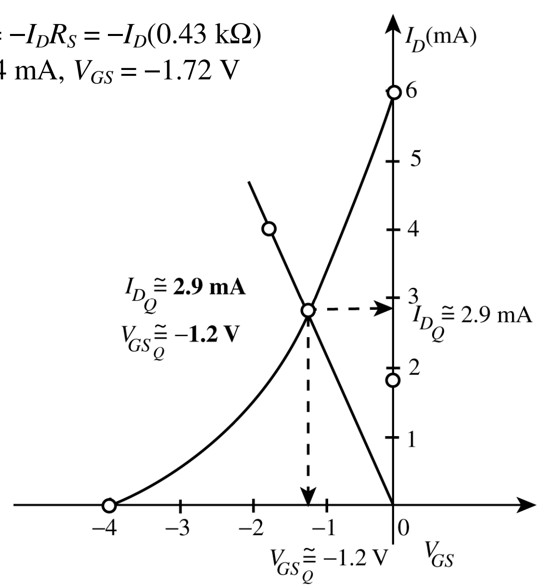
$I_S = I_D = \dfrac{4\text{ V}}{1\text{ k}\Omega} = 4\text{ mA}$

$V_D = 16\text{ V} - I_D(1.8\text{ k}\Omega) = 16\text{ V} - (4\text{ mA})(1.8\text{ k}\Omega)$
= **8.8 V**

$V_{GS} = V_G - V_S = 4\text{ V} - 4\text{ V}$ = **0 V** (requiring $I_D = I_{DSS} = 4\text{ mA}$)

20. $V_{GS} = 0\text{ V}$, $I_D = I_{DSS} = 6\text{ mA}$
$V_{GS} = V_P = -4\text{ V}$, $I_D = 0\text{ mA}$
$V_{GS} = V_P/2 = -2\text{ V}$, $I_D = I_{DSS}/4 = 1.5\text{ mA}$
$V_{GS} = 0.3V_P = -1.2\text{ V}$, $I_D = I_{DSS}/2 = 3\text{ mA}$

$V_{GS} = -I_D R_S = -I_D(0.43\text{ k}\Omega)$
$I_D = 4\text{ mA}$, $V_{GS} = -1.72\text{ V}$



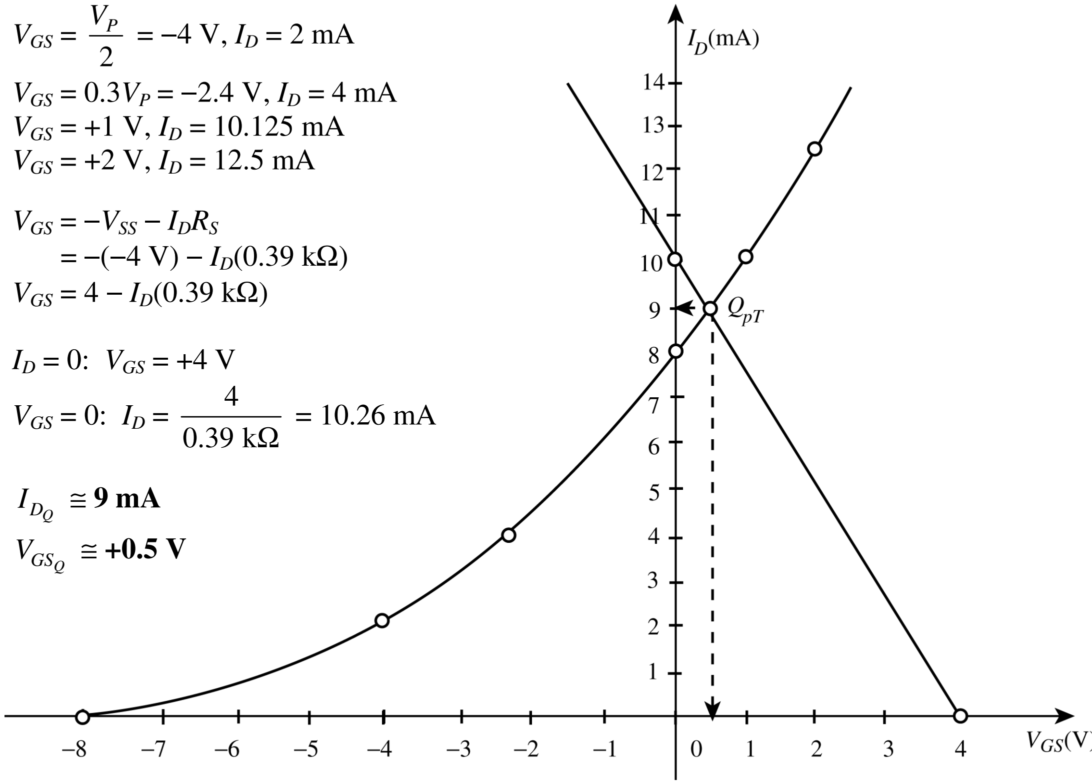
(b) $V_{DS} = V_{DD} - I_D(R_D + R_S)$
= 14 V − 2.9 mA(1.2 kΩ + 0.43 kΩ)
= **9.27 V**
$V_D = V_{DD} - I_D R_D$
= 14 V − (2.9 mA)(1.2 kΩ)
= **10.52 V**

21. (a) $V_{GS} = 0$ V, $I_D = I_{DSS} = 8$ mA
$V_{GS} = V_P = -8$ V, $I_D = 0$ mA
$V_{GS} = \frac{V_P}{2} = -4$ 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

$V_{GS} = -V_{SS} - I_D R_S$
$= -(-4\text{ V}) - I_D(0.39\text{ k}\Omega)$
$V_{GS} = 4 - I_D(0.39\text{ k}\Omega)$

$I_D = 0$: $V_{GS} = +4$ V
$V_{GS} = 0$: $I_D = \frac{4}{0.39\text{ k}\Omega} = 10.26$ mA

$I_{D_Q} \cong$ **9 mA**
$V_{GS_Q} \cong$ **+0.5 V**



(b) $V_{DS} = V_{DD} - I_D(R_D + R_S) + V_{SS}$
$= 18\text{ V} - 9\text{ mA}(1.2\text{ k}\Omega + 0.39\text{ k}\Omega) + 4\text{ V}$
$= 22\text{ V} - 14.31\text{ V}$
$=$ **7.69 V**
$V_S = -\left(V_{GS_Q}\right) =$ **−0.5 V**

22. $I_D = k(V_{GS} - V_T)^2$

$$k = \frac{I_{D(\text{on})}}{\left(V_{GS(\text{on})} - V_{Th}\right)^2} =$$

$$\frac{5\text{ mA}}{(7\text{ V} - 4\text{ V})^2} = \frac{5\text{ mA}}{9\text{ V}^2}$$

$Ie = 0.556 \times 10^{-3}$ A/V^2

and $I_D = \mathbf{0.556 \times 10^{-3}(V_{GS} - 4\ V)^2}$

$V_{DS} = V_{DD} - I_D(R_D + R_S)$

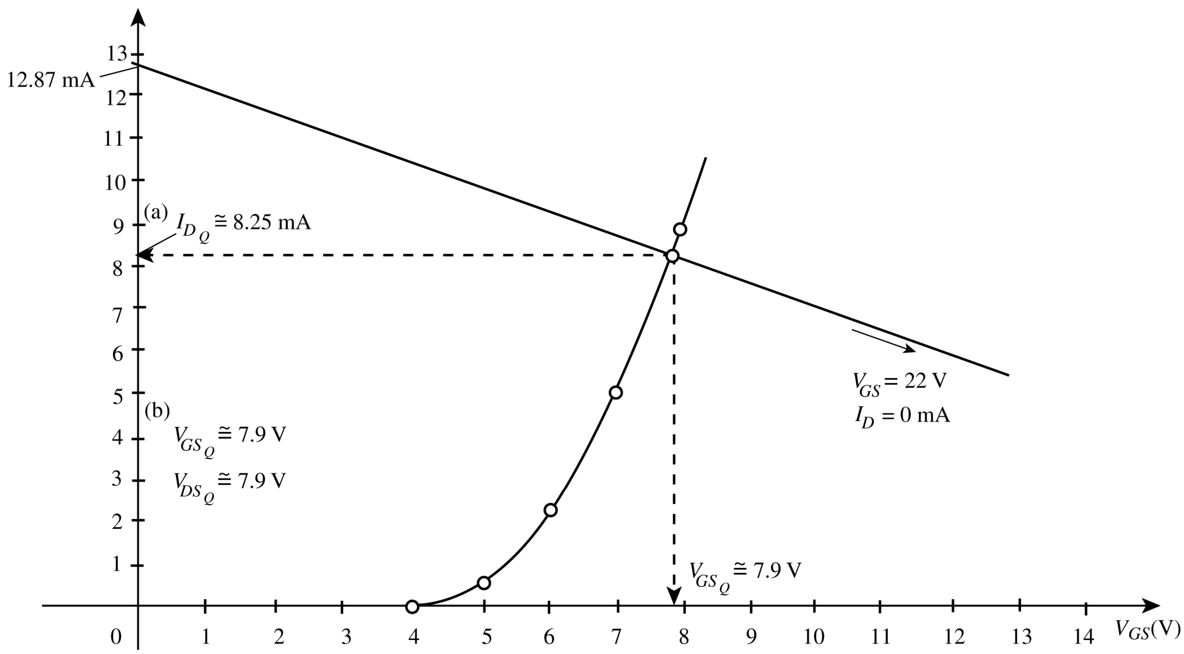
$V_{DS} = 0$ V; $I_D = \dfrac{V_{DD}}{R_D + R_S}$

$$= \frac{22\text{ V}}{1.2\text{ k}\Omega + 0.51\text{ k}\Omega}$$

$= 12.87$ mA

$I_D = 0$ mA, $V_{DS} = V_{DD}$

$= 22$ V



(c) $V_D = V_{DD} - I_D R_D$

$= 22$ V − (8.25 mA)(1.2 kΩ)

= 12.1 V

$V_S = I_S R_S = I_D R_S$

= (8.25 mA)(0.51 kΩ)

= 4.21 V

(d) $V_{DS} = V_D - V_S$

= 12.1 V − 4.21 V

= 7.89 V

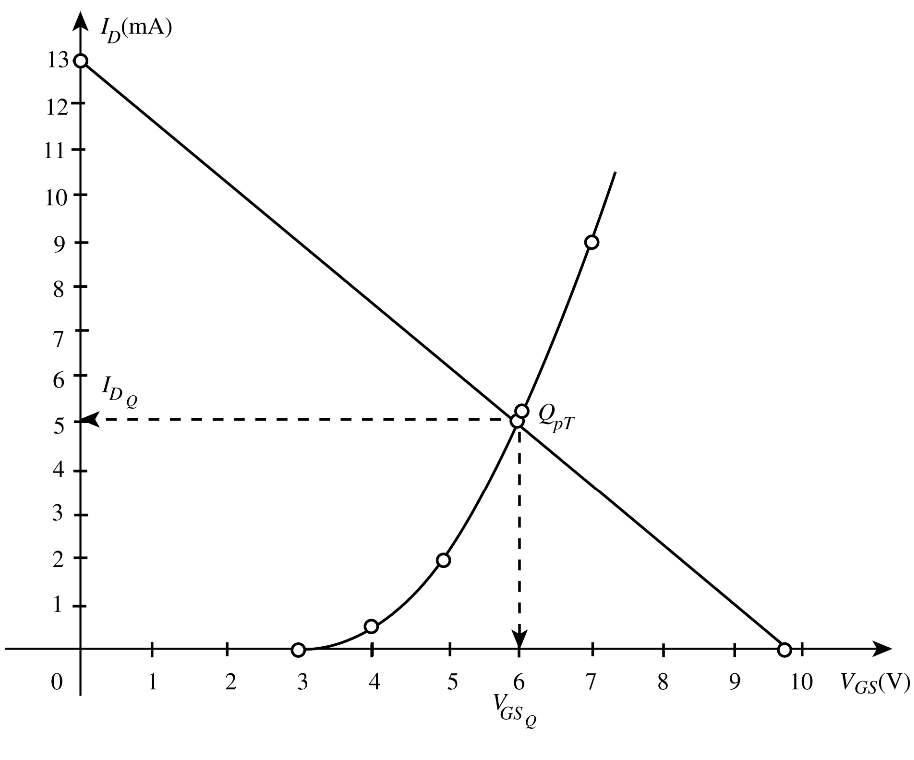
vs. 7.9 V obtained graphically

23. (a) $V_G = \frac{R_2}{R_1 + R_2}V_{DD} = \frac{6.8\ \text{M}\Omega}{10\ \text{M}\Omega + 6.8\ \text{M}\Omega}(24\ \text{V}) = 9.71\ \text{V}$

$V_{GS} = V_G - I_D R_S$
$V_{GS} = 9.71 - I_D(0.75\ \text{k}\Omega)$
At $I_D = 0$ mA, $V_{GS} = 9.71$ V
At $V_{GS} = 0$ V, $I_D = \frac{9.71\ \text{V}}{0.75\ \text{k}\Omega} = 12.95$ mA

$$k = \frac{I_{D(\text{on})}}{\left(V_{GS(\text{on})} - V_{GS(Th)}\right)^2} = \frac{5\ \text{mA}}{(6\ \text{V} - 3\ \text{V})^2} = \frac{5\ \text{mA}}{(3\ \text{V})^2}$$
$= 0.556 \times 10^{-3}\text{A/V}^2$
$\therefore I_D = \mathbf{0.556 \times 10^{-3}(V_{GS} - 3\ V)^2}$

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



$I_{D_Q} \cong \mathbf{5\ mA}$
$V_{GS_Q} \cong \mathbf{6\ V}$

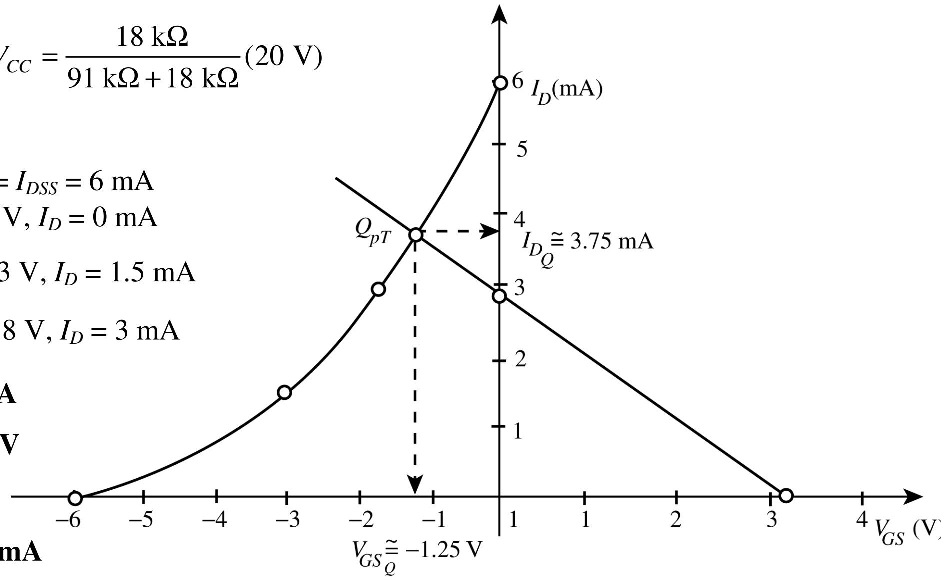
(b) $V_D = V_{DD} - I_D R_D = 24\text{ V} - (5\text{ mA})(2.2\text{ k}\Omega)$
$= \mathbf{13\ V}$

$V_S = I_S R_S = I_D R_S$
$= (5\text{ mA})(0.75\text{ k}\Omega)$
$= \mathbf{3.75\ V}$

24. (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) $V_C = V_{CC} - I_C R_C = 20\text{ V} - (3.75\text{ mA})(1.1\text{ k}\Omega)$
$= \mathbf{15.88\ V}$

25. 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) $I_B = \frac{I_C}{\beta} = \frac{2.08\text{ mA}}{100}$ = $\mathbf{20.8\ \mu A}$

(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

$V_C = 3.2 - (-2.47\text{ V})$

= **5.67 V**

$V_S = V_C$ = **5.67 V**

$V_D = V_{DD} - I_D R_D$

= 16 V − (2.08 mA)(2.2 kΩ)

= **11.42 V**

(f) $V_{CE} = V_C - V_E$ = 5.67 V − 2.5 V

= **3.17 V**

(g) $V_{DS} = V_D - V_S$ = 11.42 V − 5.67 V

= **5.75 V**

26. $V_{GS} = V_P\left(1 - \sqrt{\frac{I_D}{I_{DSS}}}\right) = (-6\text{ V})\left(1 - \sqrt{\frac{4\text{ mA}}{8\text{ mA}}}\right)$

$= -1.75$ V

$V_{GS} = -I_D R_S$: $R_S = -\frac{V_{GS}}{I_D} = \frac{-(-1.75\text{ V})}{4\text{ mA}}$ = **0.44 kΩ**

$R_D = 3R_S$ = 3(0.44 kΩ) = **1.32 kΩ**

Standard values: R_S = **0.43 kΩ**

R_D = **1.3 kΩ**

27. $V_{GS} = V_P\left(1 - \sqrt{\frac{I_D}{I_{DSS}}}\right) = (-4\text{ V})\left(1 - \sqrt{\frac{2.5\text{ mA}}{10\text{ mA}}}\right)$

= **−2 V**

$V_{GS} = V_G - V_S$

and $V_S = V_G - V_{GS}$ = 4 V − (−2 V)

= 6 V

$R_S = \frac{V_S}{I_D} = \frac{6\text{ V}}{2.5\text{ mA}}$ = **2.4 kΩ** (a standard value)

$R_D = 2.5R_S$ = 2.5(2.4 kΩ) = 6 kΩ ⇒ use **6.2 kΩ**

$V_G = \frac{R_2 V_{DD}}{R_1 + R_2} \Rightarrow 4\text{ V} = \frac{R_2(24\text{ V})}{22\text{ M}\Omega + R_2} \Rightarrow 88\text{ M}\Omega + 4R_2 = 24R_2$

$20R_2$ = 88 MΩ

R_2 = 4.4 MΩ

Use R_2 = **4.3 MΩ**

28. $I_D = k(V_{GS} - V_T)^2$

$$\frac{I_D}{k} = (V_{GS} - V_T)^2$$

$$\sqrt{\frac{I_D}{k}} = V_{GS} - V_T$$

and $V_{GS} = V_T + \sqrt{\frac{I_D}{k}} = 4\text{ V} + \sqrt{\frac{6\text{ mA}}{0.5\times10^{-3}\text{ A/V}^2}} = 7.46\text{ V}$

$$R_D = \frac{V_{R_D}}{I_D} = \frac{V_{DD} - V_{DS}}{I_D} = \frac{V_{DD} - V_{GS}}{I_D} = \frac{16\text{ V} - 7.46\text{ V}}{6\text{ mA}} = \frac{8.54\text{ V}}{6\text{ mA}}$$

$= 1.42\text{ k}\Omega$

Standard value: $R_D =$ **0.75 kΩ**

$R_G =$ **10 MΩ**

29. (a) $I_D = I_S = \frac{V_S}{R_S} = \frac{4\text{ V}}{1\text{ k}\Omega} = 4\text{ mA}$

$V_{DS} = V_{DD} - I_D(R_D + R_S) = 12\text{ V} - (4\text{ mA})(2\text{ k}\Omega + 1\text{ k}\Omega)$

$= 12\text{ V} - (4\text{ mA})(3\text{ k}\Omega)$

$= 12\text{ V} - 12\text{ V}$

$= 0\text{ V}$

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.

30. $V_G = \frac{75\text{ k}\Omega(20\text{ V})}{75\text{ k}\Omega + 330\text{ k}\Omega} = 3.7\text{ V}$ (seems correct!)

$V_{GS} = 3.7\text{ V} - 6.25\text{ V} = -2.55\text{ V}$ (possibly okay)

$I_D = I_{DSS}(1 - V_{GS}/V_P)^2$

$= 10\text{ mA}(1 - (-2.55\text{ V})/(-6\text{ V}))^2$

$= 3.3$ mA (reasonable)

However, $I_S = \frac{V_S}{R_S} = \frac{6.25\text{ V}}{1\text{ k}\Omega} = 6.25\text{ mA} \neq 3.3\text{ mA}$

$V_{R_D} = I_D R_D = I_S R_D = (6.25\text{ mA})(2.2\text{ k}\Omega)$

$= 13.75\text{ V}$

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.

31. $I_D = I_S = \frac{V_S}{R_S} = \frac{6.25\text{ V}}{1\text{ k}\Omega} = 6.25\text{ mA}$

$V_{DS} = V_{DD} - I_D(R_D + R_S)$
$= 20\text{ V} - (6.25\text{ mA})(2.2\text{ k}\Omega + 1\text{ k}\Omega)$
$= 20\text{ V} - 20\text{ V}$
$= 0\text{ V}$ (saturation condition)

$V_G = \frac{R_2V_{DD}}{R_1 + R_2} = \frac{75\text{ k}\Omega(20\text{ V})}{330\text{ k}\Omega + 75\text{ k}\Omega} = 3.7\text{ V}$ (as it should be)

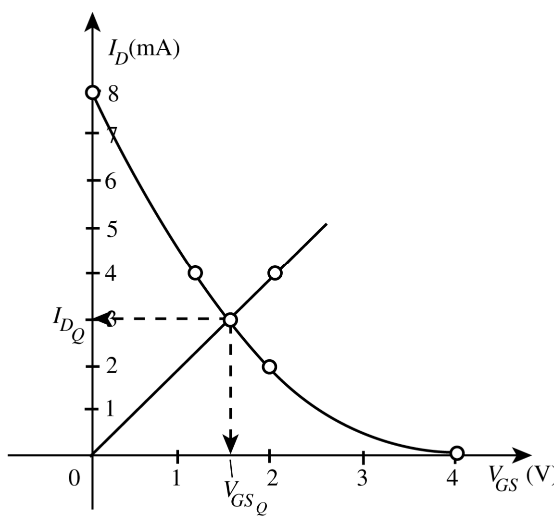
$V_{GS} = V_G - V_S = 3.7\text{ V} - 6.25\text{ V} = -2.55\text{ V}$

$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2 = 10\text{ mA}(1 - (-2.55\text{ V})/(6\text{ V}))^2$
$= 3.3\text{ mA} \neq 6.25\text{ mA}$

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.

32. (a) $V_{GS} = 0\text{ V}, I_D = I_{DSS} = 8\text{ mA}$
$V_{GS} = V_P = +4\text{ V}, I_D = 0\text{ mA}$
$V_{GS} = \frac{V_P}{2} = +2\text{ V}, I_D = 2\text{ mA}$
$V_{GS} = 0.3V_P = 1.2\text{ V}, I_D = 4\text{ mA}$

$V_{GS} = I_DR_S$
$I_D = 4\text{ mA};$
$V_{GS} = (4\text{ mA})(0.51\text{ k}\Omega)$
$= 2.04\text{ V}$
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) $V_D = V_{DD} - I_DR_D$
$= -18\text{ V} - (3\text{ mA})(2.2\text{ k}\Omega)$
$= \mathbf{-11.4\text{ V}}$

33. $k = \frac{I_{D(\text{on})}}{\left(V_{GS(\text{on})} - V_{GS(Th)}\right)^2} = \frac{4\text{ mA}}{\left(-7\text{ V} - (-3\text{ V})\right)^2} = \frac{4\text{ mA}}{(-4\text{ V})^2}$

$= 0.25 \times 10^{-3}\text{ A/V}^2$

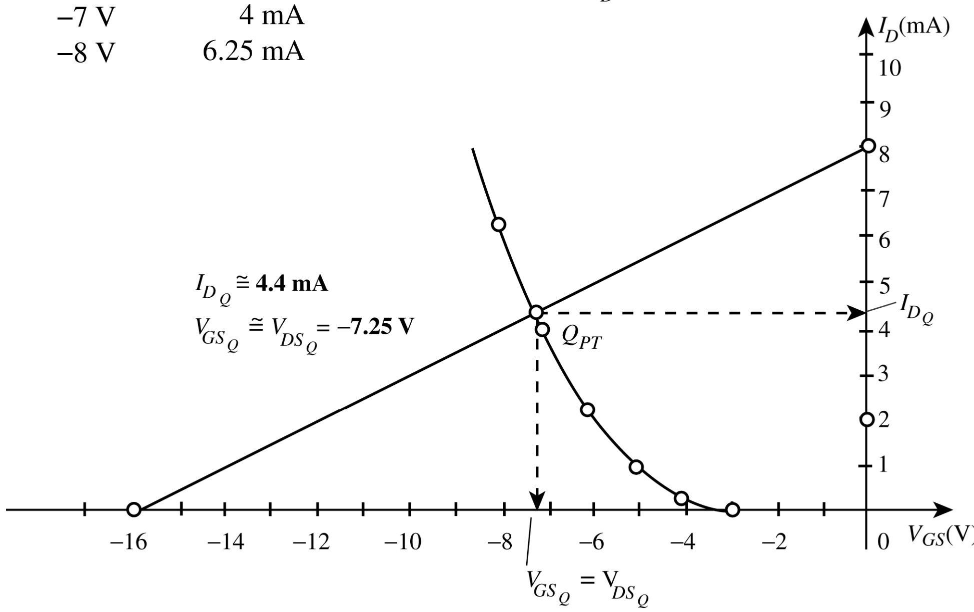
$\mathbf{I_D = 0.25 \times 10^{-3}(V_{GS} + 3\text{ V})^2}$

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

$V_{GS} = V_{DS} = V_{DD} + I_DR_D$

At $I_D = 0$ mA, $V_{GS} = V_{DD} = -16$ V

At $V_{GS} = 0$ V, $I_D = \frac{V_{DD}}{R_D} = \frac{16\text{ V}}{2\text{ k}\Omega} = 8$ mA



(b) $V_{DS} = V_{GS} = \mathbf{-7.25\text{ V}}$

(c) $V_D = V_{DS} = \mathbf{-7.25\text{ V}}$

or $V_{DS} = V_{DD} + I_DR_D$

$= -16\text{ V} + (4.4\text{ mA})(2\text{ k}\Omega)$

$= -16\text{ V} + 8.8\text{ V}$

$V_{DS} = \mathbf{-7.2\text{ V}} = V_D$

34. $\frac{V_{GS}}{|V_P|} = \frac{-1.5\text{ V}}{4\text{ V}} = -0.375$

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.

$\frac{I_D}{I_{DSS}} = 0.39$

and $I_D = 0.39(12\text{ mA}) =$ **4.68 mA** vs. 4.7 mA (#1)

$V_{DS_Q} = V_{DD} - I_DR_D = 14\text{ V} - (4.7\text{ mA})(1.8\text{ k}\Omega)$

$=$ **5.54 V** vs. 5.54 V (#1)

35. $m = \dfrac{|V_P|}{I_{DSS}R_S} = \dfrac{4\text{ V}}{(10\text{ mA})(0.75\text{ k}\Omega)}$

$= \mathbf{0.533}$

$M = m\dfrac{V_{GG}}{|V_P|} = \dfrac{0.533(0)}{4\text{ V}}$

$= \mathbf{0}$

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) −

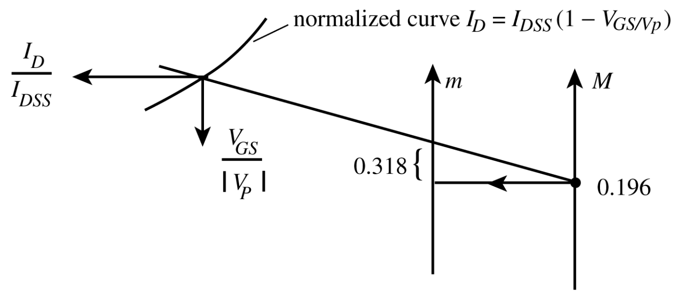
(d) $V_{DS} = V_{DD} - I_D(R_D + R_S) =$ **11.93 V** (like #6)
$V_D = V_{DD} - I_DR_D =$ **13.95 V** (like #6)
$V_G = 0$ V, $V_S = I_DR_S =$ **2.03 V** (like #6)

36. $V_{GG} = \dfrac{R_2V_{DD}}{R_1 + R_2} = \dfrac{110\text{ k}\Omega(20\text{ V})}{110\text{ k}\Omega + 910\text{ k}\Omega} = 2.16\text{ V}$

$m = \dfrac{|V_P|}{I_{DSS}R_S} = \dfrac{3.5\text{ V}}{(10\text{ mA})(1.1\text{ k}\Omega)} = 0.318$

$M = m \times \dfrac{V_{GG}}{|V_P|} = 0.318\dfrac{(2.16\text{ V})}{3.5} = 0.196$

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 (≅ 1.318 in total)—mark the spot. Draw a straight line through the two points located above, as shown below.



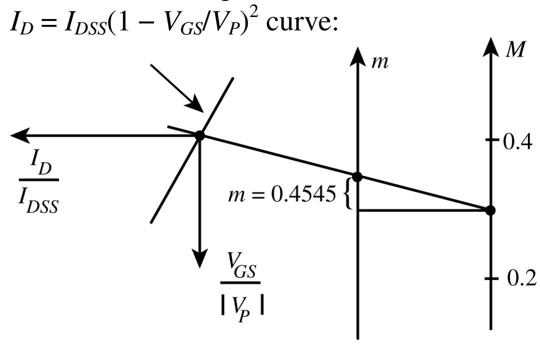
Continue the line until it intersects the $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$ curve. At the intersection move horizontally to obtain the I_D/I_{DSS} ratio and move down vertically to obtain the $V_{GS}/|V_p|$ ratio.

$$\frac{I_D}{I_{DSS}} = 0.33 \text{ and } I_{D_Q} = 0.33(10 \text{ mA}) = \mathbf{3.3 \text{ mA}}$$
vs. 3.3 mA (#12)

$$\frac{V_{GS}}{|V_P|} = -0.425 \text{ and } V_{GS_Q} = -0.425(3.5 \text{ V}) = \mathbf{-1.49 \text{ V}}$$
vs. 1.5 V (#12)

37. $m = \frac{|V_P|}{I_{DSS}R_S} = \frac{6 \text{ V}}{(6 \text{ mA})(2.2 \text{ k}\Omega)}$
$= \mathbf{0.4545}$
$M = m\frac{V_{GG}}{|V_P|} = 0.4545\frac{(4 \text{ V})}{(6 \text{ V})}$
$= \mathbf{0.303}$

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) $I_{D_Q} = \mathbf{2.76\ mA}$, $V_{GS_Q} = \mathbf{-2.04\ V}$

(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. $g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(12 \text{ mA})}{|-4 \text{ V}|} = \mathbf{6\ mS}$

2. $g_{m0} = \dfrac{2I_{DSS}}{|V_P|} \quad |V_P| \quad \dfrac{2I_{DSS}}{g_{m0}} \quad \dfrac{2(12 \text{ mA})}{10 \text{ mS}} = 2.4 \text{ V}$

   $V_P = \mathbf{-2.4\ V}$

3. $g_{m0} = \dfrac{2I_{DSS}}{|V_P|} \Rightarrow I_{DSS} = \dfrac{(g_{mO})(|V_P|)}{2} = \dfrac{5 \text{ mS}(4 \text{ V})}{2} = \mathbf{10\ mA}$

4. $g_m = g_{m0} \ \ 1 - \dfrac{V_{GS_Q}}{V_P} \ \ = \dfrac{2(12 \text{ mA})}{|-3 \text{ V}|} \ \ 1 - \dfrac{-0.5 \text{ V}}{-3 \text{ V}} \ \ = \mathbf{6.67\ mS}$

5. $g_m = \dfrac{2I_{DSS}}{|V_P|} \ \ 1 - \dfrac{V_{GS_Q}}{V_P}$

   $6 \text{ mS} = \dfrac{2I_{DSS}}{2.5 \text{ V}} \ \ 1 - \dfrac{-1 \text{ V}}{-2.5 \text{ V}}$

   $I_{DSS} = \mathbf{12.5\ mA}$

6. $g_m = g_{m0}\sqrt{\dfrac{I_D}{I_{DSS}}} = \dfrac{2I_{DSS}}{|V_P|}\sqrt{\dfrac{I_{DSS}/4}{I_{DSS}}} = \dfrac{2(10 \text{ mA})}{5 \text{ V}}\sqrt{\dfrac{1}{4}}$

   $= \dfrac{20 \text{ mA}}{5 \text{ V}} \ \ \dfrac{1}{2} \ \ = \mathbf{2\ mS}$

7. $g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(8 \text{ mA})}{5 \text{ V}} = 3.2 \text{ mS}$

   $g_m = g_{m0} \ \ 1 - \dfrac{V_{GS_Q}}{V_P} \ \ = 3.2 \text{ mS} \ \ 1 - \dfrac{V_P/4}{V_P} \ \ = 3.2 \text{ mS} \ \ 1 - \dfrac{1}{4} \ \ = 3.2 \text{ mS} \ \ \dfrac{3}{4}$

   $= \mathbf{2.4\ mS}$

8. (a) $g_m = y_{fs} = \mathbf{4.5\ mS}$

   (b) $r_d = \dfrac{1}{y_{os}} = \dfrac{1}{25\mu\text{S}} = \mathbf{40\ k\Omega}$

9. $g_m = g_{fs} = 4.5 \text{ mS}$

   $r_d = \dfrac{1}{g_{os}} = \dfrac{1}{25\mu\text{S}} = 40 \text{ k}\Omega$

   $Z_o = r_d = \mathbf{40\ k\Omega}$

   $A_v(\text{FET}) = -g_m r_d = -(4.5 \text{ mS})(40 \text{ k}\Omega) = \mathbf{-180}$

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) $g_m = \dfrac{\Delta I_D}{\Delta V_{GS}} = \dfrac{9\text{ mA} - 7\text{ mA}}{0.85\text{ V} - 0.3\text{ V}}$ = **3.64 mS**

(c) Eq. 8.6: $g_m = g_{m0}\left(1 - \dfrac{V_{GS_Q}}{V_P}\right) = 4\text{ mS}\left(1 - \dfrac{-0.5\text{ V}}{-5\text{ V}}\right)$ = **3.6 mS**

(d) $g_m = \dfrac{\Delta I_D}{\Delta V_{GS}} = \dfrac{8\text{ mA} - 5\text{ mA}}{1.5\text{ V} - 0.5\text{ V}}$ = **3 mS**

(e) $g_m = g_{m0}\left(1 - \dfrac{V_{GS_Q}}{V_P}\right) = 4\text{ mS}\left(1 - \dfrac{-1\text{ V}}{-5\text{ V}}\right)$ = **3.2 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:

(a) $g_m = y_{fs} = 750\ \mu\text{S}$ = **0.75 mS**

(b) $r_d = \dfrac{1}{y_{os}} = \dfrac{1}{10\mu\text{S}}$ = **100 kΩ**

14. (a) g_m (@ $V_{GS} = -6$ V) = **0**, g_m (@ $V_{GS} = 0$ V) $= g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(12\text{ mA})}{6\text{ V}}$ = **4 mS**

(b) g_m (@ $I_D = 0$ mA) = **0**, g_m (@ $I_D = I_{DSS} = 12$ mA) $= g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(12\text{ mA})}{6\text{ V}}$ = **4 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. $g_m = \frac{2I_{DSS}}{|V_P|}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = \frac{2(10 \text{ mA})}{4 \text{ V}}\left(1 - \frac{-2 \text{ V}}{-4 \text{ V}}\right)$ = **2.5 mS**

$r_d = \frac{1}{y_{os}} = \frac{1}{25\ \mu\text{S}}$ = **40 kΩ**

17. Graphically, $V_{GS_Q} = -1.5$ V

$g_m = \frac{2I_{DSS}}{|V_P|}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = \frac{2(10 \text{ mA})}{6 \text{ V}}\left(1 - \frac{-1.5 \text{ V}}{-6 \text{ V}}\right) = 2.5 \text{ mS}$

$Z_i = R_G$ = **1 MΩ**

$Z_o = R_D \parallel r_d$ = 1.8 kΩ || 40 kΩ = **1.72 kΩ**

$A_v = -g_m(R_D \parallel r_d) = -(2.5 \text{ mS})(1.72 \text{ k}\Omega)$

= **−4.3**

18. (a) $V_{GS_Q} = -1.5$ V, Graphically, $I_{D_Q} = 1.25$ mA

$g_m = \frac{2I_{DSS}}{|V_P|}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = \frac{2(5 \text{ mA})}{3 \text{ V}}\left(1 - \frac{-1.5 \text{ V}}{-3 \text{ V}}\right) = 1.67 \text{ mS}$

$Z_i = R_G$ = **1 MΩ**

$Z_o = R_D \parallel r_d$

= 1.8 kΩ || 40 kΩ

= **1.72 kΩ**

$A_v = -g_m(R_D \parallel r_d) = -(1.67 \text{ mS})(1.72 \text{ k}\Omega)$ = **−2.87**

(b) Z_i and Z_o the same, 33% drop in A_v.

19. (a) $V_{GS_Q} = -2.5$ V

$g_m = \frac{2I_{DSS}}{V_P}\left(1 - \frac{V_{GS}}{V_P}\right) = \frac{2(10 \text{ mA})}{4 \text{ V}}\left(1 - \frac{-2.5 \text{ V}}{-4 \text{ V}}\right)$

$= 5 \text{ mS}[1 - 0.625] = 5 \text{ mS}[0.375] = 1.875 \text{ mS}$

Z_i = **2 MΩ**

Z_o = 4.7 kΩ || 20 kΩ = **3.81 kΩ**

$A_v = -g_m(r_d \parallel R_D) = -1.875 \text{ mS}(3.81 \text{ k}\Omega)$

= **−7.14**

(b) Z_i = **2 MΩ** (the same), Z_o = 4.7 kΩ || 40 kΩ = **4.21 kΩ** (increased)

$A_v = -g_m(R_D \parallel r_d) = -1.875 \text{ mS}[4.21 \text{ k}\Omega]$ = **−7.89** **(**A_v increased)

20. $g_m = y_{fs} = 3000\ \mu\text{S} = 3\text{ mS}$

$r_d = \dfrac{1}{y_{os}} = \dfrac{1}{50\ \mu\text{S}} = 20\text{ k}\Omega$

$Z_i = R_G = \mathbf{10\ M\Omega}$

$Z_o = r_d \parallel R_D = 20\text{ k}\Omega \parallel 3.3\text{ k}\Omega = \mathbf{2.83\ k\Omega}$

$A_v = -g_m(r_d \parallel R_D)$

$= -(3\text{ mS})(2.83\text{ k}\Omega)$

$= \mathbf{-8.49}$

21. $g_m = 3\text{ mS},\ r_d = 20\text{ k}\Omega$

$Z_i = \mathbf{10\ M\Omega}$

$$Z_o = \frac{R_D}{1 + g_m R_S + \dfrac{R_D + R_S}{r_d}} = \frac{3.3\text{ k}\Omega}{1 + (3\text{ mS})(1.1\text{ k}\Omega) + \dfrac{3.3\text{ k}\Omega + 1.1\text{ k}\Omega}{20\text{ k}\Omega}}$$

$$= \frac{3.3\text{ k}\Omega}{1 + 3.3 + 0.22} = \frac{3.3\text{ k}\Omega}{4.52} = \mathbf{730\ \Omega}$$

$$A_v = \frac{-g_m R_D}{1 + g_m R_S + \dfrac{R_D + R_S}{r_d}} = \frac{-(3\text{ mS})(3.3\text{ k}\Omega)}{1 + (3\text{ mS})(1.1\text{ k}\Omega) + \dfrac{3.3\text{ k}\Omega + 1.1\text{ k}\Omega}{20\text{ k}\Omega}}$$

$$= \frac{-9.9}{1 + 3.3 + 0.22} = -\frac{9.9}{4.52} = \mathbf{-2.19}$$

22. $g_m = y_{fs} = 3000\ \mu\text{S} = 3\text{ mS}$

$r_d = \dfrac{1}{y_{os}} = \dfrac{1}{10\ \mu\text{S}} = 100\text{ k}\Omega$

$Z_i = R_G = \mathbf{10\ M\Omega}$ (the same)

$Z_o = r_d \parallel R_D = 100\text{ k}\Omega \parallel 3.3\text{ k}\Omega = \mathbf{3.195\ k\Omega}$ (higher)

$A_v = -g_m(r_d \parallel R_D)$

$= -(3\text{ mS})(3.195\text{ k}\Omega)$

$= \mathbf{-9.59}$ (higher)

23. (a) $A_v = -g_m R_D$

$-2 = -\, g_m\,(2.7\text{ k}\Omega)$

$g_m = \dfrac{2}{2.7\text{ k}\Omega} = 0.74\text{ mS}$

$$g_m = \frac{2I_{DSS}}{|V_P|}\left(1 - \frac{V_{GS}}{V_P}\right)$$

$$0.74\text{ mS} = \frac{2(9\text{ mA})}{8\text{ V}}\left(1 - \frac{V_{GS}}{-8\text{ V}}\right)$$

$$0.74\text{ mS} = 2.25\text{ mS}\left(1 - \frac{V_{GS}}{-8\text{ V}}\right) = 2.25\text{ mS} + 2.25\text{ mS}\left(\frac{V_{GS}}{8\text{ V}}\right)$$

$$-1.51\text{ mS} = 2.25\text{ mS}\left(\frac{V_{GS}}{8\text{ V}}\right)$$

$-0.671 = \frac{V_{GS}}{8\text{ V}}$, $V_{GS_Q} = -(0.671)(8\text{ V}) = \mathbf{-5.37\ V}$

$V_{GS_Q} = I_D R_D$

$R_S = \frac{V_{GS_Q}}{I_D} = \frac{5.37\text{ V}}{1.4\text{ mA}}$ (from Q pt. on graph) = **3.83 kΩ**

(b) $A_v = -g_m R_D$

$-2 = -g_m(2.7\text{ k}\Omega \parallel 30\text{ k}\Omega) = -g_m(2.48\text{ k}\Omega)$

$g_m = \frac{2}{2.48\text{ k}\Omega} = 0.81\text{ mS}$

$g_m = \frac{2I_{DSS}}{|V_P|}\left(1 - \frac{V_{GS}}{V_P}\right) = \frac{2(9\text{ mA})}{8\text{ V}}\left(1 - \frac{V_{GS}}{-8\text{ V}}\right) = 2.25\text{ mS} + 2.25\text{ mS}\left(\frac{V_{GS}}{8\text{ V}}\right)$

$0.81\text{ mS} = 2.25\text{ mS} + 2.25\text{ mS}\left(\frac{V_{GS}}{8\text{ V}}\right)$

$-1.44\text{ mS} = 2.25\text{ mS}\left(\frac{V_{GS}}{8\text{ V}}\right)$

$-0.640\left(\frac{V_{GS}}{8\text{ V}}\right)$, $V_{GS_Q} = -(0.640)(8\text{ V}) = \mathbf{-5.12\ V}$

$V_{GS_Q} = I_D R_D$

$R_S = \frac{V_{GS_Q}}{I_{D_Q}} = \frac{5.12\text{ V}}{1.5\text{ mA}}$ (from Q pt. on graph) = **3.41 kΩ**

Repeat with new value of gm. R_S decreased to 3.41 kΩ from 3.83 kΩ.

24. $V_{GS_Q} = 0\text{ V}$, $g_m = g_{m0} = \frac{2I_{DSS}}{|V_P|} = \frac{2(6\text{ mA})}{6\text{ V}} = 2\text{ mS}$, $r_d = \frac{1}{y_{os}} = \frac{1}{40\ \mu\text{S}} = 25\text{ k}\Omega$

Z_i = **1 MΩ**

$Z_o = r_d \parallel R_D = 25\text{ k}\Omega \parallel 2\text{ k}\Omega$ = **1.852 kΩ**

$A_v = -g_m(r_d \parallel R_D) = -(2\text{ mS})(1.852\text{ k}\Omega) \cong$ **−3.7**

25. $V_{GS_Q} = -0.95\text{ V}$

$g_m = \frac{2I_{DSS}}{V_P}\left(1 - \frac{V_{GS_Q}}{V_P}\right)$

$= \frac{2(12\text{ mA})}{3\text{ V}}\left(1 - \frac{-0.95\text{ V}}{-3\text{ V}}\right)$

$= 5.47\text{ mS}$

$Z_i = 82\text{ M}\Omega \parallel 11\text{ M}\Omega$ = **9.7 MΩ**

$Z_o = r_d \parallel R_D = 50\text{ k}\Omega \parallel 2\text{ k}\Omega$ = **1.92 kΩ**

$A_v = -g_m(r_d \parallel R_D) = -(5.47\text{ mS})(1.92\text{ k}\Omega)$ = **−10.5**

$V_o = A_v V_i = (-10.5)(20\text{ mV})$ = **−210 mV**

26. $V_{GS_Q} = -0.95$ V (as before), $g_m = 5.47$ mS (as before)

Z_i = **9.7 MΩ** as before

$$Z_o = \frac{R_D}{1 + g_m R_S + \dfrac{R_D + R_S}{r_d}}$$

but $r_d \geq 10(R_D + R_S)$

$$\therefore Z_o = \frac{R_D}{1 + g_m R_S} = \frac{2\text{ k}\Omega}{1 + (5.47\text{ mS})(0.61\text{ k}\Omega)} = \frac{2\text{ k}\Omega}{1 + 3.337} = \frac{2\text{ k}\Omega}{4.337}$$

= **461.1 Ω**

$$A_v = \frac{-g_m R_D}{1 + g_m R_S} \quad \text{since } r_d \geq 10(R_D + R_S)$$

$$= \frac{-(5.47\text{ mS})(2\text{ k}\Omega)}{4.337\ \text{(from above)}} = -\frac{10.94}{4.337} = \mathbf{-2.52} \text{ (a big reduction)}$$

$V_o = A_v V_i = (-2.52)(20\text{ mV}) =$ **−50.40 mV** (compared to −214.4 mV earlier)

27. $V_{GS_Q} = -0.95$ V, g_m (problem 23) = 5.47 mS

Z_i (the same) = **9.7 MΩ**

Z_o (reduced) = $r_d \parallel R_D$ = 20 kΩ ∥ 2 kΩ = **1.82 kΩ**

A_v (reduced) = $-g_m(r_d \parallel R_D)$ = −(5.47 mS)(1.82 kΩ) = **−9.94**

V_o (reduced) = $A_v V_i$ = (−9.94)(20 mV) = **−198.8 mV**

28. $V_{GS_Q} = -0.95$ V (as before), $g_m = 5.47$ mS (as before)

Z_i = **9.7 MΩ** as before

$$Z_o = \frac{R_D}{1 + g_m R_S + \dfrac{R_D + R_S}{r_d}} \quad \text{since } r_d < 10(R_D + R_S)$$

$$= \frac{2\text{ k}\Omega}{1 + (5.47\text{ mS})(0.61\text{ k}\Omega) + \dfrac{2\text{ k}\Omega + 0.61\text{ k}\Omega}{20\text{ k}\Omega}}$$

$$= \frac{2\text{ k}\Omega}{1 + 3.33 + 0.13} = \frac{2\text{ k}\Omega}{4.46}$$

= **448.4 Ω** (slightly less than 461.1 Ω obtained in problem 24)

$$A_v = \frac{-g_m R_D}{1 + g_m R_S + \dfrac{R_D + R_S}{r_d}}$$

$$= \frac{-(5.47\text{ mS})(2\text{ k}\Omega)}{1 + (5.47\text{ mS})(0.61\text{ k}\Omega) + \dfrac{2\text{ k}\Omega + 0.61\text{ k}\Omega}{20\text{ k}\Omega}}$$

$$= \frac{-10.94}{1 + 3.33 + 0.13} = \frac{-10.94}{4.46} = \mathbf{-2.45} \text{ slightly less than } -2.52 \text{ obtained in problem 24)}$$

29. $V_{GS_Q} = -1.75$ V, $g_m = 2.14$ mS

$r_d \geq 10R_D$, $\therefore Z_i \cong R_S \parallel 1/g_m = 1.5\ \text{k}\Omega \parallel 1/2.14\ \text{mS}$
$= 1.5\ \text{k}\Omega \parallel 467.29\ \Omega$
$= \mathbf{356.3\ \Omega}$

$r_d \geq 10R_D$, $\therefore Z_o \cong R_D = \mathbf{3.3\ k\Omega}$

$r_d \geq 10R_D$, $\therefore A_v \cong g_m R_D = (2.14\ \text{mS})(3.3\ \text{k}\Omega) = \mathbf{7.06}$

$V_o = A_v V_i = (7.06)(4\ \text{mV}) = \mathbf{28.24\ mV}$

30. $V_{GS_Q} = -1.75$ V, $g_m = \dfrac{2I_{DSS}}{V_P}\ 1 - \dfrac{V_{GS_Q}}{V_P} = \dfrac{2(8\ \text{mA})}{2.8\ \text{V}}\ 1 - \dfrac{-1.75\ \text{V}}{-2.8\ \text{V}} = 2.14$ mS

$$Z_i = R_S \parallel \frac{r_d + R_D}{1 + g_m r_d} = 1.5\ \text{k}\Omega \parallel \frac{25\ \text{k}\Omega + 3.3\ \text{k}\Omega}{1 + (2.14\ \text{mS})(25\ \text{k}\Omega)} = 1.5\ \text{k}\Omega \parallel \frac{28.3\ \text{k}\Omega}{54.5}$$

$= 1.5\ \text{k}\Omega \parallel 0.52\ \text{k}\Omega = \mathbf{386.1\ \Omega}$

$Z_o = R_D \parallel r_d = 3.3\ \text{k}\Omega \parallel 25\ \text{k}\Omega = \mathbf{2.92\ k\Omega}$

$$A_v = \frac{g_m R_D + R_D / r_d}{1 + R_D / r_d} = \frac{(2.14\ \text{mS})(3.3\ \text{k}\Omega) + 3.3\ \text{k}\Omega / 25\ \text{k}\Omega}{1 + 3.3\ \text{k}\Omega / 25\ \text{k}\Omega}$$

$$= \frac{7.062 + 0.132}{1 + 0.132} = \frac{7.194}{1.132} = 6.36$$

$V_o = A_v V_i = (6.36)(4\ \text{mV}) = \mathbf{25.44\ mV}$

31. $V_{GS_Q} \cong -1.2$ V, $g_m = 2.63$ mS

$r_d \geq 10R_D$, $\therefore$ $Z_i \cong R_S \parallel 1/g_m = 1\ \text{k}\Omega \parallel 1/2.63\ \text{mS} = 1\ \text{k}\Omega \parallel 380.2\ \Omega = \mathbf{275.5\ \Omega}$
$Z_o \cong R_D = \mathbf{2.2\ k\Omega}$
$A_v \cong g_m R_D = (2.63\ \text{mS})(2.2\ \text{k}\Omega) = \mathbf{5.79}$

32. $V_{GS_Q} = -2.85$ V, $g_m = \dfrac{2I_{DSS}}{V_P}\ 1 - \dfrac{V_{GS_Q}}{V_P} = \dfrac{2(9\ \text{mA})}{4.5\ \text{V}}\ 1 - \dfrac{-2.85\ \text{V}}{-4.5\ \text{V}} = 1.47$ mS

$Z_i = R_G = \mathbf{10\ M\Omega}$

$Z_o = r_d \parallel R_S \parallel 1/g_m = 40\ \text{k}\Omega \parallel 2.2\ \text{k}\Omega \parallel \underbrace{1/1.47\ \text{mS}}_{680.27\ \Omega} = \mathbf{512.9\ \Omega}$

$$A_v = \frac{g_m(r_d \parallel R_S)}{1 + g_m(r_d \parallel R_S)} = \frac{(1.47\ \text{mS})(40\ \text{k}\Omega \parallel 2.2\ \text{k}\Omega)}{1 + (1.47\ \text{mS})(40\ \text{k}\Omega \parallel 2.2\ \text{k}\Omega)} = \frac{3.065}{1 + 3.065}$$

$= \mathbf{0.754}$

33. $V_{GS_Q} = -2.85$ V, $g_m = 1.47$ mS

$Z_i = \mathbf{10\ M\Omega}$ (as in problem 32)

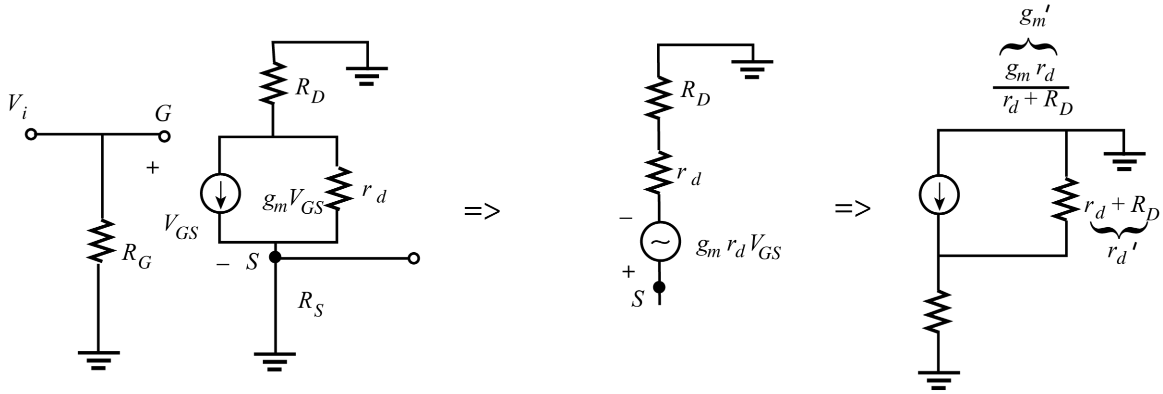
$Z_o = r_d \parallel R_S \parallel 1/g_m = \underbrace{20\ \text{k}\Omega \parallel 2.2\ \text{k}\Omega}_{1.982\ \text{k}\Omega} \parallel 680.27\ \Omega = \mathbf{506.4\ \Omega} < 512.9\ \Omega$ (#27)

$$A_v = \frac{g_m(r_d \parallel R_S)}{1 + g_m(r_d \parallel R_S)} = \frac{1.47\ \text{mS}(20\ \text{k}\Omega \parallel 2.2\ \text{k}\Omega)}{1 + 1.47\ \text{mS}(20\ \text{k}\Omega \parallel 2.2\ \text{k}\Omega)} = \frac{2.914}{1 + 2.914}$$

$= \mathbf{0.745} < 0.754$ (#32)

34. $V_{GS_Q} = -3.8$ 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** $\quad r_d' = r_d + R_D = 30 \text{ k}\Omega + 3.3 \text{ k}\Omega = 33.3 \text{ k}\Omega$

$$Z_o = r_d' \parallel R_S \parallel 1/g_m' = \quad g_m' = \frac{g_m r_d}{r_d + R_D} = \frac{(0.733 \text{ mS})(30 \text{ k}\Omega)}{30 \text{ k}\Omega + 3.3 \text{ k}\Omega} = \frac{21.99}{33.3 \text{ k}\Omega} = 0.66 \text{ mS}$$

$= 33.3 \text{ k}\Omega \parallel 3.3 \text{ k}\Omega \parallel 1/0.66 \text{ mS}$
$= 3 \text{ k}\Omega \parallel 1.52 \text{ k}\Omega$
$\cong$ **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**

35. $r_d = \frac{1}{y_{os}} = \frac{1}{20 \,\mu\text{S}} = 50 \text{ k}\Omega$, $V_{GS_Q} = 0$ V

$$g_m = g_{m0} = \frac{2I_{DSS}}{V_P} = \frac{2(8 \text{ mA})}{3} = 5.33 \text{ mS}$$

$A_v = -g_m R_D = -(5.33 \text{ mS})(1.1 \text{ k}\Omega) = -5.863$
$V_o = A_v V_i = (-5.863)(2 \text{ mV}) =$ **11.73 mV**

36. $V_{GS_Q} = -0.75$ V, $g_m = 5.4$ mS

$Z_i =$ **10 MΩ**
$r_o \geq 10R_D, \therefore \quad Z_o \cong R_D =$ **1.8 kΩ**
$r_o \geq 10R_D, \therefore \quad A_v \cong -g_m R_D = -(5.4 \text{ mS})(1.8 \text{ k}\Omega)$
$=$ **−9.72**

37. Z_i = **10 MΩ**

$Z_o = r_d \parallel R_D$ = 25 kΩ ‖ 1.8 kΩ = **1.68 kΩ**

$A_v = -g_m(r_d \parallel R_D)$

$$g_m = \frac{2I_{DSS}}{V_P}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = \frac{2(12\text{ mA})}{3.5\text{ V}}\left(1 - \frac{-0.75\text{ V}}{-3.5\text{ V}}\right) = 5.4\text{ mS}$$

A_v = −(5.4 mS)(1.68 kΩ)

= **−9.07**

38. $g_m = y_{fs}$ = 6000 μS = 6 mS

$$r_d = \frac{1}{y_{os}} = \frac{1}{35\ \mu\text{S}} = 28.57\text{ k}\Omega$$

$r_d \le 10R_D$, $\therefore A_v = -g_m(r_d \parallel R_D)$

$$= -(6\text{ mS})(\underbrace{28.57\text{ k}\Omega \parallel 6.8\text{ k}\Omega}_{5.49\text{ k}\Omega})$$

= **−32.94**

$V_o = A_vV_i$ = (−32.94)(1.8 mV)

= **−59.29 mV**

39. Z_i = 10 MΩ ‖ 91 MΩ ≅ **9 MΩ**

$$g_m = \frac{2I_{DSS}}{V_P}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = \frac{2(12\text{ mA})}{3\text{ V}}\left(1 - \frac{-1.45\text{ V}}{-3\text{ V}}\right) = 4.13\text{ mS}$$

$Z_o = r_d \parallel R_S \parallel 1/g_m$ = 45 kΩ ‖ 1.1 kΩ ‖ 1/4.13 mS

= 1.074 kΩ ‖ 242.1 Ω

= **197.6 Ω**

$$A_v = \frac{g_m(r_d \| R_S)}{1 + g_m(r_d \| R_S)} = \frac{(4.13\text{ mS})(45\text{ k}\Omega \| 1.1\text{ k}\Omega)}{1 + (4.13\text{ mS})(45\text{ k}\Omega \| 1.1\text{ k}\Omega)}$$

$$= \frac{(4.13\text{ mS})(1.074\text{ k}\Omega)}{1 + (4.13\text{ mS})(1.074\text{ k}\Omega)} = \frac{4.436}{1 + 4.436}$$

= **0.816**

40. $g_m = 2k\left(V_{GS_Q} - V_{GS(Th)}\right)$

$= 2(0.3 \times 10^{-3})(8\text{ V} - 3\text{ V})$

= **3 mS**

41. $V_{GS_Q} = 6.7\text{ V}$

$$g_m = 2k\left(V_{GS_Q} - V_T\right) = 2(0.3 \times 10^{-3})(6.7\text{ V} - 3\text{ V}) = 2.22\text{ mS}$$

$$Z_i = \frac{R_F + r_d \| R_D}{1 + g_m(r_d \| R_D)} = \frac{10\text{ M}\Omega + 100\text{ k}\Omega \| 2.2\text{ k}\Omega}{1 + (2.22\text{ mS})(100\text{ k}\Omega \| 2.2\text{ k}\Omega)}$$

$$= \frac{10\text{ M}\Omega + 2.15\text{ k}\Omega}{1 + 2.22\text{ mS}(2.15\text{ k}\Omega)} \cong \mathbf{1.73\text{ M}\Omega}$$

$Z_o = R_F \| r_d \| R_D = 10\text{ M}\Omega \| 100\text{ k}\Omega \| 2.2\text{ k}\Omega = \mathbf{2.15\text{ k}\Omega}$

$A_v = -g_m(R_F \| r_d \| R_D) = -2.22\text{ mS}(2.15\text{ k}\Omega) = \mathbf{-4.77}$

42. $g_m = 2k\left(V_{GS_Q} - V_T\right) = 2(0.2 \times 10^{-3})(6.7\text{ V} - 3\text{ V})$

$= 1.48\text{ mS}$

$$Z_i = \frac{R_F + r_d \| R_D}{1 + g_m(r_d \| R_D)} = \frac{10\text{ M}\Omega + 100\text{ k}\Omega \| 2.2\text{ k}\Omega}{1 + (1.48\text{ mS})(100\text{ k}\Omega \| 2.2\text{ k}\Omega)}$$

$$= \frac{10\text{ M}\Omega + 2.15\text{ k}\Omega}{1 + (1.48\text{ mS})(2.15\text{ k}\Omega)} = \mathbf{2.39\text{ M}\Omega} > 1.73\text{ M}\Omega \text{ (\#39)}$$

$Z_o = R_F \| r_d \| R_D = \mathbf{2.15\text{ k}\Omega} = 2.15\text{ k}\Omega$ (#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)

43. $V_{GS_Q} = 5.7\text{ V}$, $g_m = 2k\left(V_{GS_Q} - V_T\right) = 2(0.3 \times 10^{-3})(5.7\text{ V} - 3.5\text{ V})$

$= 1.32\text{ mS}$

$$r_d = \frac{1}{30\ \mu\text{S}} = 33.33\text{ k}\Omega$$

$A_v = -g_m(R_F \| r_d \| R_D) = -1.32\text{ mS}(22\text{ M}\Omega \| 33.33\text{ k}\Omega \| 10\text{ k}\Omega)$

$= -10.15$

$V_o = A_vV_i = (-10.15)(20\text{ mV}) = \mathbf{-203\text{ mV}}$

44. $I_D = k(V_{GS} - V_T)^2$

$$\therefore k = \frac{I_{D(\text{on})}}{(V_{GS(\text{on})} - V_T)^2} = \frac{4\text{ mA}}{(7\text{ V} - 4\text{ V})^2} = 0.444 \times 10^{-3}$$

$g_m = 2k(V_{GS_Q} - V_{GS(Th)}) = 2(0.444 \times 10^{-3})(7\text{ V} - 4\text{ V})$

$= 2.66\text{ mS}$

$$A_v = -g_m(R_F \| r_d \| R_D) = -(2.66\text{ mS})(\underbrace{22\text{ M}\Omega \| \underbrace{50\text{ k}\Omega \| 10\text{ k}\Omega}_{8.33\text{ k}\Omega}}_{\cong 8.33\text{ k}\Omega}) = -22.16$$

$V_o = A_vV_i = (-22.16)(4\text{ mV}) = \mathbf{-88.64\text{ mV}}$

45. $V_{GS_Q} = 4.8\text{ V},\ g_m = 2k\left(V_{GS_Q} - V_{GS(Th)}\right) = 2(0.4 \times 10^{-3})(4.8\text{ V} - 3\text{ V}) = 1.44\text{ mS}$

$A_v = -g_m(r_d \parallel R_D) = -(1.44\text{ mS})(40\text{ k}\Omega \parallel 3.3\text{ k}\Omega) = -4.39$

$V_o = A_vV_i = (-4.39)(0.8\text{ mV}) = \mathbf{-3.51\text{ mV}}$

46. $r_d = \dfrac{1}{y_{os}} = \dfrac{1}{20\ \mu\text{S}} = 50\text{ k}\Omega$

$V_{GS_Q} = 0\text{ V},\ \therefore g_m = g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(8\text{ mA})}{2.5\text{ V}} = 6.4\text{ mS}$

$|A_v| = g_m(r_d \parallel R_D)$

$8 = (6.4\text{ mS})(50\text{ k}\Omega \parallel R_D)$

$\dfrac{8}{6.4\text{ mS}} = 1.25\text{ k}\Omega = \dfrac{50\text{ k}\Omega \cdot R_D}{50\text{ k}\Omega + R_D}$

and $R_D = \mathbf{1.28\text{ k}\Omega}$

Use $R_D = \mathbf{1.3\text{ k}\Omega}$

47. $V_{GS_Q} = \dfrac{1}{3}V_P = \dfrac{1}{3}(-3\text{ V}) = -1\text{ V}$

$I_{D_Q} = I_{DSS}\left(1 - \dfrac{V_{GS_Q}}{V_P}\right)^2 = 12\text{ mA}\left(1 - \dfrac{-1\text{ V}}{-3\text{ V}}\right)^2 = 5.33\text{ mA}$

$R_S = \dfrac{V_S}{I_{D_Q}} = \dfrac{1\text{ V}}{5.33\text{ mA}} = 187.62\ \Omega\ \therefore \text{Use } R_S = \mathbf{180\ \Omega}$

$g_m = \dfrac{2I_{DSS}}{V_P}\left(1 - \dfrac{V_{GS_Q}}{V_P}\right) = \dfrac{2(12\text{ mA})}{3\text{ V}}\left(1 - \dfrac{-1\text{ V}}{-3\text{ V}}\right) = 5.33\text{ mS}$

$A_v = -g_m(R_D \parallel r_d) = -10$

or $R_D \parallel 40\text{ k}\Omega = \dfrac{-10}{5.33\text{ mS}} = 1.876\text{ k}\Omega$

$= 1.876\text{ k}\Omega$

$40\text{ k}\Omega R_D = 1.876\text{ k}\Omega R_D + 75.04\text{ k}\Omega^2$

$38.124R_D = 75.04\text{ k}\Omega$

$R_D = 1.97\text{ k}\Omega \Rightarrow R_D = \mathbf{2\text{ k}\Omega}$

48. $Z_i = R_G = \mathbf{1\text{ M}\Omega}$

$Z_o = r_d \parallel R_D \cong R_D = \mathbf{2.7\text{ k}\Omega}$

From graph $V_{GS_Q} \cong -3.4\text{ V}$

$g_m = \dfrac{2(I_{DSS})}{|V_P|}\left(1 - \dfrac{V_{GS}}{V_P}\right)$

$= \dfrac{2[10\text{ mA}]}{6\text{ V}}\left(1 - \dfrac{-3.4\text{ V}}{-6\text{ V}}\right) = 3.33\text{ mS}[1 - 0.567]$

$= 3.33\text{ mS}[0.433] = \mathbf{-1.44\text{ mS}}$

$A_{v_{NL}} = -g_mR_D = (-1.44\text{ mS})(2.7\text{ k}\Omega) = \mathbf{-3.89}$

(b) −

(c) $A_{v_L} = \frac{R_L}{R_L + R_o} A_{v_{NL}} = \frac{4.7\text{ k}\Omega}{4.7\text{ k}\Omega + 2.7\text{ k}\Omega}(-3.89)$

$= \mathbf{-2.47}$

$A_{v_s} = \frac{R_i}{R_i + R_{sig}} A_{v_L} = \frac{1\text{ M}\Omega}{1\text{ M}\Omega + 0.6\text{ k}\Omega}(-2.47)$

$\cong \mathbf{-2.47}$

(d) A_{v_L} the same

$A_{v_s} = \frac{1\text{ M}\Omega}{1\text{ M}\Omega + 10\text{ k}\Omega}(-2.47)$

$\cong \mathbf{-2.45}$

Slight drop in A_{V_s}

(e) remain the same

49. (a) $Z_i = R_G = \mathbf{2\text{ M}\Omega}$

From graph $V_{GS_Q} \cong -3.5\text{ V}$

$g_m = \frac{2(I_{DSS})}{|V_P|} \; 1 - \frac{V_{GS}}{V_P} = \frac{2[6\text{ mA}]}{6\text{ V}} \; 1 - \frac{-3.5\text{ V}}{-6\text{ V}}$

$= \mathbf{0.834\text{ mS}}$

$Z_o \cong R_S \,\|\, 1/g_m = 3.3\text{ k}\Omega \,\|\, 1/0.834\text{ mS} = \mathbf{0.72\text{ k}\Omega}$

$A_{v_{NL}} \cong \frac{g_m R_S}{1 + g_m R_S} = \frac{(0.834)(3.3\text{ k}\Omega)}{1 + (0.834)(3.3\text{ k}\Omega)}$

$\cong \mathbf{0.733}$

(c) $A_{v_L} = \frac{R_L}{R_L + R_o} A_{v_{NL}} = \frac{2.2\text{ k}\Omega}{2.2\text{ k}\Omega + 0.72\text{ k}\Omega} = \mathbf{0.552}$

$A_{v_s} = \frac{R_i}{R_i + R_{sig}} A_{v_L} = \frac{2\text{ M}\Omega}{2\text{ M}\Omega + 0.5\text{ k}\Omega}(0.552)$

$\cong \mathbf{0.552}$

(d) $A_{v_L} = \frac{R_L}{R_L + R_o} A_{v_{NL}} = \frac{4.7\text{ k}\Omega}{4.7\text{ k}\Omega + 0.72\text{ k}\Omega}(0.733)$

$= \mathbf{0.670}$ slight drop in gain

A_{v_S} the same

(e) A_{v_L} the same

$$A_{v_s} = \frac{R_i}{R_i + R_{sig}} A_{v_L} = \frac{2\text{ M}\Omega}{2\text{ M}\Omega + 20\text{ k}\Omega}(0.552)$$

$\cong$ **0.546** slight drop in A_{v_s}

(e) Z_i and Z_o the same.

50. (a) From graph $V_{GS_Q} \cong -1.75\text{ V}$

$$g_m = \frac{2I_{DSS}}{|V_P|}\left(1 - \frac{V_{GS}}{V_P}\right) = \frac{2[5\text{ mA}]}{4\text{ V}}\left(1 - \frac{1.75\text{ V}}{4\text{ V}}\right)$$

$= 1.41\text{ mS}$

$Z_i \cong R_S \,||\, 1/g_m = 1.2\text{ k}\Omega \,||\, 1/1.41\text{ mS} = 1.2\text{ k}\Omega \,||\, 709.22\ \Omega$

$=$ **446 Ω**

$Z_o \cong R_D =$ **3.3 kΩ**

$A_{v_{NL}} = g_m R_D = (1.41\text{ mS})(3.3\text{ k}\Omega) =$ **4.65**

(b) –

(c) $$A_{v_L} = \frac{R_L}{R_L + R_O} A_{v_{NL}} = \frac{4.7\text{ k}\Omega}{4.7\text{ k}\Omega + 3.3\text{ k}\Omega}(4.65) = \mathbf{2.73}$$

$$A_{v_s} = \frac{R_i}{R_i + R_{sig}} A_{v_L} = \frac{446\ \Omega}{446\ \Omega + 500\ \Omega}(2.73) = \mathbf{1.29}$$

(d) $$A_{v_L} = \frac{R_L}{R_L + R_o} A_{v_{NL}} = \frac{2.2\text{ k}\Omega}{2.2\text{ k}\Omega + 3.3\text{ k}\Omega}(4.65) = \mathbf{1.86}$$

$$A_{v_s} = \frac{R_i}{R_i + R_{sig}} A_{v_L} = \frac{446\ \Omega}{446\ \Omega + 500\ \Omega}(1.86) = \mathbf{0.877}$$

severe drop in A_{v_L} + A_{v_s}

(e) $$A_{v_L} = \frac{R_L}{R_L + R_o} A_{v_{NL}} = \frac{4.7\text{ k}\Omega}{4.7\text{ k}\Omega + 3.3\text{ k}\Omega}(4.65) = \mathbf{2.73} \text{ (no change)}$$

$$A_{v_s} = \frac{R_i}{R_i + R_{sig}} A_{v_L} = \frac{446\ \Omega}{446\ \Omega + 100\ \Omega}(2.73) = \mathbf{2.23} \text{ (improved gain)}$$

(f) $$A_{v_L} = \frac{R_L}{R_L + R_o} A_{v_{NL}} = \frac{2.2\text{ k}\Omega(4.65)}{2.2\text{ k}\Omega + 3.3\text{ k}\Omega} = \mathbf{1.86} \text{ (as in part (d))}$$

$$A_{v_s} = \frac{R_i}{R_i + R_{sig}} A_{v_L} = \frac{446\ \Omega}{446\ \Omega + 100\ \Omega}(1.86) = \mathbf{1.52}$$

(g) Increasing R_L and decreasing R_{sig} will improve the gain.

51. From the graph: $V_{GS_Q} \cong$ **−1.45 V**, I_{D_Q} = **3.7 mA**

$V_D = V_{DD} - I_D R_D = 18\text{ V} - (3.7\text{ mA})(2.2\text{ k}\Omega)$ = **9.86 V**

$V_S = I_D R_S = (3.7\text{ mA})(390\ \Omega)$ = **1.44 V**

$V_{DS} = V_D - V_S = 9.86\text{ V} - 1.44\text{ V}$ = **8.42 V**

V_G = **0 V**

52. From Problem 51, $V_{GS_Q} = -1.45\text{ V}$

$$g_m = \frac{2I_{DSS}}{|V_P|}\left(1 - \frac{V_{GS}}{V_P}\right) = \frac{2[8\text{ mA}]}{4.5\text{ V}}\left(1 - \frac{1-1.45\text{ V}}{4.5\text{ V}}\right)$$
$$= 2.41\text{ mS}$$

$A_{v_1} = A_{v_2} = -g_m R_D = -(2.41\text{ mS})(2.2\text{ k}\Omega)$ = **−5.30**

$A_{v_T} = A_{v_1} \cdot A_{v_2} = (-5.30)(-5.30)$ = **28.1**

53. From graph $V_{GS_Q} \cong -1.4\text{ V}$, $I_{D_Q} \cong 3.6\text{ mA}$

$V_D = V_{DD} - I_D R_D = 18\text{ V} - (3.6\text{ mA})(2.2\text{ k}\Omega)$

$= 18\text{ V} - 7.92\text{ V} =$ **10.08 V**

$V_S = I_D R_S = (3.6\text{ mA})(390\ \Omega)$ = **1.4 V**

$V_{DS} = V_D - V_S = 10.08\text{ V} - 1.4\text{ V}$ = **8.68 V**

V_G = **0 V**

54. From problem 53: V_{GS_Q} = **−1.4 V**

$$g_m = \frac{2I_{DSS}}{|V_P|}\left(1 - \frac{V_{GS}}{V_P}\right) = \frac{2[12\text{ mA}]}{3}\left(1 - \frac{1.4\text{ V}}{3\text{ V}}\right)$$
$$= 8\text{ mS}[1 - 0.467] = 0.533(8\text{ mS})$$
$$= 4.26\text{ mS}$$

$A_{v_1} = A_{v_2} = -g_m(R_D \,||\, r_d) = -(4.26\text{ mS})(2.2\text{ k}\Omega \,||\, 40\text{ k}\Omega)$

= **−8.9**

$A_{v_T} = A_{v_1} \cdot A_{v_2} = (-8.9)(-8.9)$ = **79.21**

Increase in A_{v_T} compared to problem 52.

55. $g_{os} = 25\mu\text{S}$, $r_d = 1/25\ \mu\text{S} = 40\text{ k}\Omega$

Z_i = **10 MΩ**

Z_o = **2.7 kΩ**

56. From graph $V_{GS_Q} = -0.95$ V, I_{D_Q} **= 2.9 mA**

$V_D = 10\text{ V} - I_D(1.8\text{ k}\Omega) = 10\text{ V} - (2.9\text{ mA})(1.8\text{ k}\Omega) = 10\text{ V} - 5.22\text{ V}$

$= \mathbf{4.78\ V}$

$V_S = I_D R_S = (2.9\text{ mA})(330\ \Omega) = \mathbf{0.957\ V}$

$V_{DS} = V_D - V_S = 4.78\text{ V} - 0.957\text{ V} = \mathbf{3.82\ V}$

$V_G = \mathbf{0\ V}$

$I_D = I_S = \mathbf{2.9\ mA}$

$I_G = \mathbf{0\ A}$

$$B_{RE} \geq 10R_2$$

$$(150)(2.2\text{ k}\Omega) \geq 10(8.2\text{ k}\Omega)$$

$$330\text{ k}\Omega \geq 82\text{ k}\Omega \quad \text{checks}$$

$$V_B = \frac{8.2\text{ k}\Omega(10\text{ V})}{8.2\text{ k}\Omega + 24\text{ k}\Omega} = \mathbf{2.55\ V}$$

$V_E = V_B - V_{BE} = 2.55\text{ V} - 0.7\text{ V} = \mathbf{1.85\ V}$

$$I_E \cong I_C = \frac{V_E}{R_E} = \frac{1.85\text{ V}}{2.2\text{ k}\Omega} = \mathbf{0.84\ mA}$$

$V_C = 10\text{ V} - I_C 2.7\text{ k}\Omega = 10\text{ V} - (0.84\text{ mA})(2.7\text{ k}\Omega)$

$= 10\text{ V} - 2.27\text{ V} = \mathbf{7.73\ V}$

$V_{CE} = V_C - V_E = 7.73\text{ V} - 1.85\text{ V} = \mathbf{5.88\ V}$

$$I_B = \frac{I_C}{\beta} = \frac{0.84\text{ mA}}{150} = \mathbf{5.6\ \mu A}$$

57. $Z_{i_2} = 8.2\text{ k}\Omega \,||\, 24\text{ k}\Omega \,||\, \beta(2.2\text{ k}\Omega)$

$= 6.11\text{ k}\Omega \,||\, 330\text{ k}\Omega \cong 6\text{ k}\Omega$

$A_{v_1} = -g_m(R_D \,||\, Z_{i_2})$

$$g_m = \frac{2I_{DSS}}{|V_P|}\ 1 - \frac{V_{GS}}{V_P} = \frac{2(6\text{ mA})}{3}\ 1 - \frac{0.95\text{ V}}{3\text{ V}}$$

$= 2.73$ mS

$$A_{v_1} = -(2.73\text{ mS})(1.8\text{ k}\Omega \,\|\, 6\text{ k}\Omega)$$
$$= \mathbf{-3.77}$$
$$A_{v_2} = -\frac{R_C}{r_e}$$
$$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{0.84\text{ mA}} = 30.95\ \Omega$$
$$A_{v_2} = -\frac{2.7\text{ k}\Omega}{30.95\ \Omega} = \mathbf{-87.2}$$

$$A_{v_T} = A_{v_1} \cdot A_{v_2} = (-3.77)(-87.2) = \mathbf{328.74}$$

58. $Z_i = \mathbf{10\ M\Omega}$

$Z_o \cong R_C = \mathbf{2.7\ k\Omega}$

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) $\log_{10} 0.24 \times 10^6 = \mathbf{5.38}$

   (b) $\log_e (0.24 \times 10^6) = 2.3 \log_{10}(0.24 \times 10^6) = \mathbf{12.37}$

   (c) $\log_e (0.24 \times 10^6) = \mathbf{12.39}$

3. (a) same **22.92**
   (b) same **23.98**
   (c) same **0.903**

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) $\text{dB} = 10 \log_{10} \dfrac{100\ \mu\text{W}}{20\ \mu\text{W}} = 10 \log_{10} 5 = 10(0.6987)$
   $= \mathbf{6.99\ dB}$

5. $G_{\text{dBm}} = 10 \log_{10} \dfrac{P_2}{1 \text{ mW}}\bigg|_{600\,\Omega} = 10 \log_{10} \dfrac{25 \text{ W}}{1 \text{ mW}}\bigg|_{600\,\Omega}$
   $= \mathbf{43.98\ dBm}$

6. $G_{\text{dB}} = 20 \log_{10} \dfrac{V_2}{V_1} = 20 \log_{10} \dfrac{220 \text{ V}}{110 \text{ V}} = 20 \log_{10} 2 = 20(0.301)$
   $= \mathbf{6.02\ dB}$

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: $A_{v_1} = 21.05 \text{ dB} = 20 \log_{10} \frac{V_{o_1}}{V_{i_1}}$

$$\frac{21.05}{20} = 1.0526 = \log_{10} \frac{V_{o_1}}{V_{i_1}}$$

$$10^{1.0526} = \frac{V_{o_1}}{V_{i_1}}$$

and $\frac{V_{o_1}}{V_{i_1}} = \mathbf{11.288}$

Stage 2: $A_{v_2} = 42.1 \text{ dB} = 20 \log_{10} \frac{V_{o_2}}{V_{i_2}}$

$$2.105 = \log_{10} \frac{V_{o_2}}{V_{i_2}}$$

$$10^{2.105} = \frac{V_{o_2}}{V_{i_2}}$$

and $\frac{V_{o_2}}{V_{i_2}} = \mathbf{127.35}$

Stage 3: : $A_{v_3} = 56.835 \text{ dB} = 20 \log_{10} \frac{V_{o_3}}{V_{i_3}}$

$$2.8418 = \log_{10} \frac{V_{o_3}}{V_{i_3}}$$

$$10^{2.8418} = \frac{V_{o_3}}{V_{i_3}}$$

and $\frac{V_{o_3}}{V_{i_3}} = \mathbf{694.624}$

$A_{v_T} = A_{v_1} \cdot A_{v_2} \cdot A_{V_3} = (11.288)(127.35)(694.624) = \mathbf{99{,}8541.1}$

$A_T = 120 \text{ dB} \overset{?}{=} 20 \log_{10} 99{,}8541.1$

120 dB ≅ 119.99 dB (difference due to level of accuracy carried through calculations)

9. (a) $G_{dB} = 20 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{48 \text{ W}}{5 \mu\text{W}} = \mathbf{69.83 \text{ dB}}$

(b) $G_v = 20 \log_{10} \frac{V_o}{V_i} = 20 \log_{10} \frac{\sqrt{P_o R_o}}{V_i} = \frac{20 \log_{10} \sqrt{(48 \text{ W})(40 \text{ k}\Omega)}}{100 \text{ mV}}$

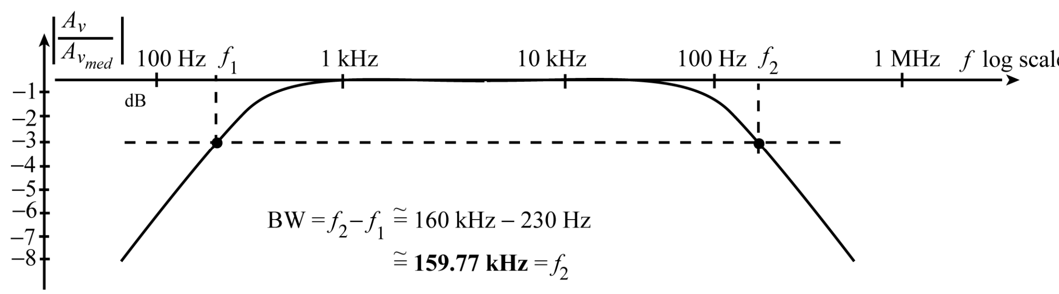
$= \mathbf{82.83 \text{ dB}}$

(c) $R_i = \dfrac{V_i^2}{P} = \dfrac{(100\text{ mV})^2}{5\ \mu\text{W}}$ = **2 kΩ**

(d) $P_o = \dfrac{V_o^2}{R_o} \Rightarrow V_o = \sqrt{P_o R_o} = \sqrt{(48\text{ W})(40\text{ k}\Omega)}$ = **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) = **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

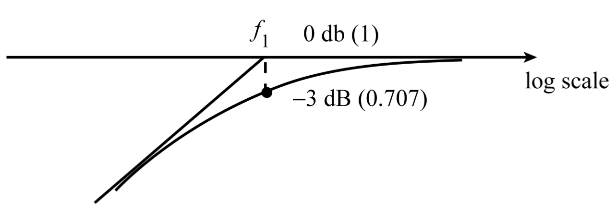
$$|A_v| = \frac{1}{\sqrt{1+\left(\dfrac{1950.43\text{ Hz}}{f}\right)^2}}$$

(b)

		$A_{V_{\text{dB}}}$
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)

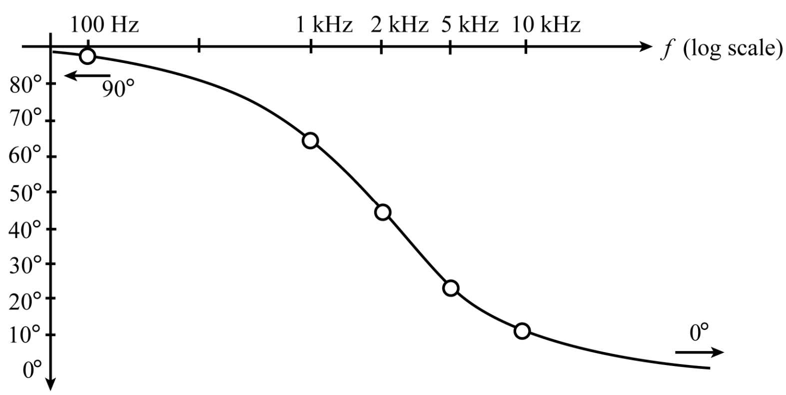


12. (a) $f_1 = \dfrac{1}{2\pi RC} = 1.95\text{ kHz}$

$\theta = \tan^{-1}\dfrac{f_1}{f} = \tan^{-1}\dfrac{1.95\text{ kHz}}{f}$

(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, $r_e = 15.76\ \Omega$

$$A_v = \frac{-R_C \parallel R_L \parallel r_o}{r_e} = \frac{-4\ \text{k}\Omega \parallel 2.2\ \text{k}\Omega \parallel 40\ \text{k}\Omega}{15.76\ \Omega}$$

$= -86.97$ (vs. -90 for Ex. 9.9)

f_{L_s}: r_o does not affect R_i $\therefore$ $f_{L_s} = \dfrac{1}{2\pi(R_s + R_i)C_S}$ the same $\cong$ **6.86 Hz**

$$f_{L_C} = \frac{1}{2\pi(R_o + R_L)C_C} = \frac{1}{2\pi(R_C \parallel r_o + R_L)C_C}$$

$R_C \parallel r_o = 4\ \text{k}\Omega \parallel 40\ \text{k}\Omega = 5.636\ \text{k}\Omega$

$$f_{L_C} = \frac{1}{2\pi(5.636\ \text{k}\Omega + 2\ \text{k}\Omega)(1\ \mu\text{F})}$$

$=$ **28.23** Hz (vs. 25.68 Hz for Ex. 9.9)

f_{L_E}: R_e not affected by r_o, therefore, $f_{L_E} = \dfrac{1}{2\pi R_e C_E}$ $\cong$ **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) $\beta R_E \geq 10R_2$

$(120)(1.2\ \text{k}\Omega) \geq 10(10\ \text{k}\Omega)$

$144\ \text{k}\Omega \geq 100\ \text{k}\Omega$ (checks!)

$$V_B = \frac{10\ \text{k}\Omega(14\ \text{V})}{10\ \text{k}\Omega + 68\ \text{k}\Omega} = 1.795\ \text{V}$$

$V_E = V_B - V_{BE} = 1.795\ \text{V} - 0.7\ \text{V}$

$= 1.095\ \text{V}$

$$I_E = \frac{V_E}{R_E} = \frac{1.095\ \text{V}}{1.2\ \text{k}\Omega} = 0.913\ \text{mA}$$

$$r_e = \frac{26\ \text{mV}}{I_E} = \frac{26\ \text{mV}}{0.913\ \text{mA}} = \mathbf{28.48\ \Omega}$$

(b) $$A_{V_{\text{mid}}} = -\frac{(R_L \parallel R_C)}{r_e} = \frac{-(3.3\ \text{k}\Omega \parallel 5.6\ \text{k}\Omega)}{28.48\ \Omega}$$

$= \mathbf{-72.91}$

(c) $Z_i = R_1 \parallel R_2 \parallel \beta r_e$

$$= 68\ \text{k}\Omega \parallel 10\ \text{k}\Omega \parallel \underbrace{(120)(28.48\ \Omega)}_{3.418\ \text{k}\Omega}$$

$= \mathbf{2.455\ k\Omega}$

(d) $f_{L_s} = \dfrac{1}{2\pi R_i C_S} = \dfrac{1}{2\pi(2.455\text{ k}\Omega)(0.47\ \mu\text{F})}$ = **137.93 Hz**

$f_{L_C} = \dfrac{1}{2\pi(R_o + R_L)C_C} = \dfrac{1}{2\pi(5.6\text{ k}\Omega + 3.3\text{ k}\Omega)(0.47\ \mu\text{F})}$ = **38.05 Hz**

$f_{L_E} = \dfrac{1}{2\pi R_e C_E}$ with $R_e = R_E \,||\, \dfrac{R_1 \,||\, R_2}{\beta} + r_e$

$R_1 \,||\, R_2 = 68\text{ k}\Omega \,||\, 10\text{ k}\Omega = 8.72\text{ k}\Omega$

$\dfrac{R_1 \,||\, R_2}{\beta} = \dfrac{8.72\text{ k}\Omega}{120} = 72.67\Omega$

$R_e = 1.2\text{ k}\Omega \,||\, 72.67\ \Omega + 28.48\ \Omega = 1.2\text{ k}\Omega \,||\, 101.15\ \Omega = 93.29\ \Omega$

$f_{L_E} = \dfrac{1}{2\pi R_E C_E} = \dfrac{1}{2\pi(93.29\ \Omega)(20\ \mu\text{F})}$ = **85.30 Hz**

(e) $f_1 = f_{L_s} = 137.93$ Hz

(f) –

(g) –

16. (a) $I_B = \dfrac{V_{CC} - V_{BE}}{R_B + (\beta+1)R_E} = \dfrac{20\text{ V} - 0.7\text{ V}}{470\text{ k}\Omega + (111)(0.91\text{ k}\Omega)} = \dfrac{19.3\text{ V}}{470\text{ k}\Omega + 101.01\text{ k}\Omega}$

$= 33.8\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (111)(33.8\ \mu\text{A})$

$= 3.752$ mA

$r_e = \dfrac{26\text{ mV}}{3.752\text{ mA}}$ = **6.93 Ω**

(b) $A_{v_{\text{mid}}} = \dfrac{V_o}{V_i} = \dfrac{-(R_C \,||\, R_L)}{r_e} = \dfrac{-(3\text{ k}\Omega \,||\, 4.7\text{ k}\Omega)}{6.93\ \Omega} = \dfrac{-1.831\text{ k}\Omega}{6.93\ \Omega}$

= **−264.24**

(c) $Z_i = R_B \,||\, \beta r_e = 470\text{ k}\Omega \,||\, (110)(6.93\ \Omega) = 470\text{ k}\Omega \,||\, 762.3\ \Omega$

= **761.07 Ω**

(d) $f_{L_S} = \dfrac{1}{2\pi Z_i C_S} = \dfrac{1}{2\pi(761.07\ \Omega)(1\ \mu\text{F})}$

= **209.12 Hz**

$f_{L_C} = \dfrac{1}{2\pi(R_o + R_L)C_C} = \dfrac{1}{2\pi(3\text{ k}\Omega + 4.7\text{ k}\Omega)(1\ \mu\text{F})}$

= **20.67 Hz**

$$f_{L_E} = \frac{1}{2\pi R_e C_E} = \frac{1}{2\pi(762.65\ \Omega)(6.8\ \mu\text{F})} = \mathbf{30.69\ Hz}$$

$$R_e = R_E \parallel \frac{R_B}{\beta} = 0.91\ \text{k}\Omega \parallel \frac{470\ \text{k}\Omega}{100} + 6.93\ \Omega = 0.91\ \text{k}\Omega \parallel 4.71\ \text{k}\Omega = 762.65\ \Omega$$

(e) $f_1 \cong f_{L_s}$ = **209.12 Hz**

(f) –

(g) –

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) $Z_i = R_1 \parallel R_2 \parallel \beta(r_e + R_E')$ $\quad R_E' = R_E \parallel R_L = 2.2\ \text{k}\Omega \parallel 8.2\ \text{k}\Omega = 1.735\ \text{k}\Omega$

$= 120\ \text{k}\Omega \parallel 30\ \text{k}\Omega \parallel (100)(30.23\ \Omega + 1.735\ \text{k}\Omega)$

$= \mathbf{21.13\ k\Omega}$

(d) $f_{L_s} = \dfrac{1}{2\pi R_i C_s}$

$= \dfrac{1}{2\pi(21.13\text{ k}\Omega)(0.1\ \mu\text{F})}$

$=$ **75.32 Hz**

$f_{L_C} = \dfrac{1}{2\pi(R_o + R_L)C_C}$

$R_s' = R_1 \| R_2$

$= 120\text{ k}\Omega \| 30\text{ k}\Omega$

$= 24\text{ k}\Omega$

$R_o = R_E \| \quad \dfrac{R_s'}{\beta} + r_e$

$= 2.2\text{ k}\Omega \| \quad \dfrac{24\text{ k}\Omega}{100} + 30.23\ \Omega$

$= 2.2\text{ k}\Omega \| 270.23\ \Omega = 240.69\ \Omega$

$f_{L_C} = \dfrac{1}{2\pi(240.69\ \Omega + 8.2\text{ k}\Omega)(0.1\ \mu\text{F})}$

$=$ **188.57 Hz**

(e) $f_{1_{\text{low}}} = f_{L_C} \cong$ **188.57 Hz**

(f) –

(g) –

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) $A_{v_{\text{mid}}} = \dfrac{R_C \| R_L}{r_e} = \dfrac{3.3\text{ k}\Omega \| 4.7\text{ k}\Omega}{9.45\ \Omega}$

$=$ **205.1**

(c) $Z_i = R_E \| r_e = 1.2\text{ k}\Omega \| 9.45\ \Omega$

$=$ **9.38 Ω**

(d) $f_{L_s} = \dfrac{1}{2\pi Z_i C_s} = \dfrac{1}{2\pi(9.38\ \Omega)(10\ \mu\text{F})}$

$\cong$ **1.7 kHz**

$f_{L_C} = \dfrac{1}{2\pi(R_o + R_L)C_E} = \dfrac{1}{2\pi(3.3\text{ k}\Omega + 4.7\text{ k}\Omega)(10\ \mu\text{F})}$

$=$ **1.989 Hz**

(e) $f_1 = f_{L_s} \cong$ **1.7 kHz**

(f) –

(g) –

19. From problem 15

(a) $r_e = \mathbf{28.48\ \Omega}$

(b) $A_{V_{\text{mid}}} = \mathbf{-72.91}$

(c) $Z_i = \mathbf{2.455\ k\Omega}$

(d) $$f_{L_s} = \frac{1}{2\pi(R_i + R_S)C_S} = \frac{1}{2\pi(2.455\ \text{k}\Omega + 0.82\ \text{k}\Omega)(0.47\ \mu\text{F})}$$

$f_{L_s} = \mathbf{103.4\ Hz}$

$f_{L_C} = \mathbf{38.05\ Hz}$ from problem 15

$$f_{L_E} = \frac{1}{2\pi R_e C_E}$$

with $R_e = R_E \,|||\, \dfrac{R'_S}{\beta} + r_e$ and $R'_S = R_S \,||\, R_1 \,||\, R_2$

$$R'_S = 0.82\ \text{k}\Omega \,||\, 68\ \text{k}\Omega \,||\, 10\ \text{k}\Omega = 810.2\ \text{k}\Omega \,||\, 10\ \text{k}\Omega = 749.48\ \Omega$$

$$\frac{R'_S}{\beta} + r_e = \frac{749.48\ \Omega}{120} + 28.48\ \Omega = 6.25\ \Omega + 28.48\ \Omega = 34.73\ \Omega$$

$$f_{L_E} = \frac{1}{2\pi(33.75\ \Omega)(20\ \mu\text{F})} = \mathbf{235.79\ Hz}$$

(e) $f_1 = f_{L_E} = \mathbf{235.79\ Hz}$

(f) –

(g) –

20. From problem 16

(a) $r_e = \mathbf{6.93\ \Omega}$

(b) $A_{v_{\text{mid}}} = \mathbf{-264.24}$

(c) $Z_i = \mathbf{761.07\ \Omega}$

(d) $f_{L_S} = \dfrac{1}{2\pi(R_s + Z_i)C_s} = \dfrac{1}{2\pi(600\ \Omega + 761.07\ \Omega)(1\ \mu\text{F})}$
$= \mathbf{116.93\ Hz}$

$f_{L_C} = \dfrac{1}{2\pi(R_o + R_L)C_C} = \dfrac{1}{2\pi(3\ \text{k}\Omega + 4.7\ \text{k}\Omega)(1\ \mu\text{F})}$
$= \mathbf{20.67\ Hz}$

$f_{L_E} = \dfrac{1}{2\pi R_e C_E}$
$= \dfrac{1}{2\pi(12.21\ \Omega)(6.8\ \mu\text{F})}$
$= \mathbf{1.917\ Hz}$

$R_e = R_E \parallel \dfrac{R_s'}{\beta} + r_e = 0.91\ \text{k}\Omega\ \dfrac{R_s \parallel R_B}{\beta} + r_e$
$= 0.91\ \text{k}\Omega \parallel \dfrac{0.6\ \text{k}\Omega \parallel 470\ \text{k}\Omega}{100} + 6.93\ \Omega$
$= 0.91\ \text{k}\Omega \parallel 12.38\ \Omega$
$= 12.21\ \Omega$

(e) $f_1 = f_{L_E} \cong \mathbf{1.917\ kHz}$

(f) –

(g) –

21. From problem 17
(a) $r_e = \mathbf{30.23\ \Omega}$

(b) $A_{v_{\text{mid}}} = \mathbf{0.983}$

(c) $Z_i = \mathbf{21.13\ k\Omega}$

(d) $f_{L_s} = \dfrac{1}{2\pi(R_s + R_i)C_s} = \dfrac{1}{2\pi(1\ \text{k}\Omega + 21.13\ \text{k}\Omega)(0.1\ \mu\text{F})} = \mathbf{71.92\ Hz}$

$f_{L_C} = \dfrac{1}{2\pi(R_o + R_L)C_C}$
$= \dfrac{1}{2\pi(39.12\ \Omega + 8.2\ \text{k}\Omega)(0.1\ \mu\text{F})}$
$= \mathbf{193.16\ Hz}$

$R_o = R_E \parallel \dfrac{R_S'}{\beta} + r_e$
$R_s' = R_s \parallel R_1 \parallel R_2$
$= 1\ \text{k}\Omega \parallel 120\ \text{k}\Omega \parallel 30\ \text{k}\Omega$
$= 0.96\ \text{k}\Omega$
$R_o = (2.2\ \text{k}\Omega) \parallel \dfrac{(0.96\ \text{k}\Omega}{100} + 30.23\ \Omega$
$= 39.12\ \Omega$

(e) $f_{1_{\text{low}}} = f_{L_C} \cong \mathbf{193.16\ Hz}$

(f) –

(g) –

22. From problem 18

(a) r_e = **9.45 Ω**

(b) $A_{v_{\text{mid}}}$ = **205.1**

(c) Z_i = **9.38 Ω**

(d) $f_{L_s} = \dfrac{1}{2\pi(R_s + Z_i)C_s} = \dfrac{1}{2\pi(100\ \Omega + 9.38\ \Omega)(10\ \mu\text{F})}$ = **145.5 kHz**

$f_{L_C} = \dfrac{1}{2\pi(R_o + R_L)C_E} = \dfrac{1}{2\pi(3.3\ \text{k}\Omega + 4.7\ \text{k}\Omega)(10\ \mu\text{F})}$ = **1.989 Hz**

(e) $f_1 = f_{L_s}$ = **145.5 Hz**

(f) –

(g) –

23. (a) $V_{GS} = -I_D R_S$

$I_D = I_{DSS}\ \ 1 - \dfrac{V_{GS}}{V_P}\ \ ^2$ $\Big\}$ $V_{GS_Q} \cong$ **−2.45 V**, $I_{D_Q} \cong$ **2.1 mA**

(b) $g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(6\text{ mA})}{6\text{ V}}$ = **2 mS**

$g_m = g_{m0}\ \ 1 - \dfrac{V_{GS_Q}}{V_P}\ \ = 2\text{ mS}\ \ 1 - \dfrac{(-2.45\text{ V})}{(-6\text{ V})}$

= **1.18 mS**

(c) $A_{v_{\text{mid}}} = -g_m(R_D \parallel R_L)$

$= -1.18\text{ mS}(3\text{ k}\Omega \parallel 3.9\text{ k}\Omega) = -1.18\text{ mS}(1.6956\text{ k}\Omega)$

= **−2**

(d) $Z_i = R_G$ = **1 MΩ**

(e) $A_{v_s} = A_v$ = **−2**

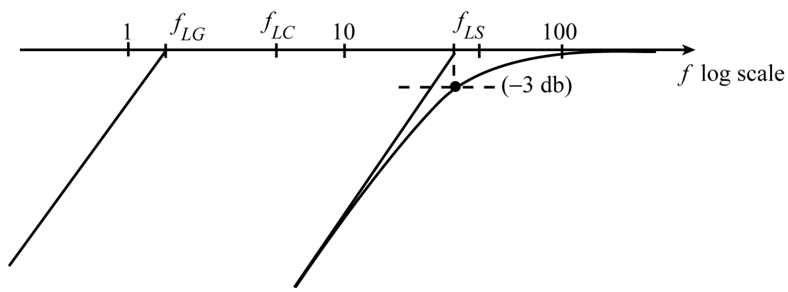
(f) $f_{L_G} = \dfrac{1}{2\pi(R_{\text{sig}} + R_i)C_G} = \dfrac{1}{2\pi(1\text{ k}\Omega + 1\text{ M}\Omega)(0.1\ \mu\text{F})}$
$= \mathbf{1.59\ Hz}$

$f_{L_C} = \dfrac{1}{2\pi(R_o + R_L)C_C}$
$= \dfrac{1}{2\pi(3\text{ k}\Omega + 3.9\text{ k}\Omega)(4.7\ \mu\text{F})}$
$= \mathbf{4.91\ Hz}$

$f_{L_S} = \dfrac{1}{2\pi R_{\text{eq}}C_S}$ $\quad R_{\text{eq}} = R_S \parallel \dfrac{1}{g_m} = 1.2\text{ k}\Omega \parallel \dfrac{1}{1.18\text{ mS}} = 1.2\text{ k}\Omega \parallel 847.46\ \Omega$
$= \dfrac{1}{2\pi(496.69\ \Omega)(10\ \mu\text{F})}$ $\quad = 496.69\ \Omega$
$= \mathbf{32.04\ Hz}$

(g) $f_1 \cong f_{L_S} \cong$ **32 Hz**

(h, i)



24. (a) same as problem 19
$V_{GS_Q} \cong$ **−2.45 V**, $I_{D_Q} \cong$ **2.1 mA**

(b) g_{m0} = **2 mS**, g_m = **1.18 mS** (r_d has no effect!)

(c) $A_{v_{\text{mid}}} = -g_m (R_D \parallel R_L \parallel r_d)$
$= -1.18\text{ mS}(3\text{ k}\Omega \parallel 3.9\text{ k}\Omega \parallel 100\text{ k}\Omega)$
$= -1.18\text{ mS }(1.67\text{ k}\Omega)$
= **−1.971** (vs. −2 for problem 19)

(d) $Z_i = R_G$ = **1 MΩ** (the same)

(e) $A_{v_{s(\text{mid})}} = \dfrac{Z_i}{Z_i + R_{\text{sig}}}(A_{v_{\text{mid}}}) = \dfrac{1\text{ M}\Omega}{1\text{ M}\Omega + 1\text{ k}\Omega}(-1.971)$
= **−1.969** vs. −2 for problem 19

(f) f_{L_G} = **1.59 Hz** (no effect)

f_{L_C}: $R_o = R_D \| r_d = 3\text{ k}\Omega \| 100\text{ k}\Omega = 2.91\text{ k}\Omega$

$$f_{L_C} = \frac{1}{2\pi(R_o + R_L)C_C} = \frac{1}{2\pi(2.91\text{ k}\Omega + 3.9\text{ k}\Omega)(4.7\ \mu\text{F})}$$

= **4.97 Hz** vs. 4.91 Hz for problem 19

$$f_{L_S}:\ R_{\text{eq}} = \frac{R_S}{1 + R_S(1 + g_m r_d)/(r_d + (R_D \| R_L))}$$

$$= \frac{1.2\text{ k}\Omega}{1 + (1.2\text{ k}\Omega)(1 + (1.18\text{ mS})(100\text{ k}\Omega))/(100\text{ k}\Omega + 3\text{ k}\Omega \| 3.9\text{ k}\Omega)}$$

$$= \frac{1.2\text{ k}\Omega}{1 + 1.404}$$

$\cong 499.2\ \Omega$

$$f_{L_S} := \frac{1}{2\pi R_{\text{eq}} C_S} = \frac{1}{2\pi(499.2\ \Omega)(10\ \mu\text{F})}$$

= **31.88** Hz vs. 32.04 for problem 19.

Effect of $r_d = 100\text{ k}\Omega$ insignificant!

25. (a) $V_G = \dfrac{68\text{ k}\Omega(20\text{ V})}{68\text{ k}\Omega + 220\text{ k}\Omega} = 4.72\text{ V}$

$V_{GS} = V_G - I_D R_S$

$V_{GS} = 4.72\text{ V} - I_D(2.2\text{ k}\Omega)$

$I_D = I_{DSS}(1 - V_{GS}/V_P)^2$

$\Big\}$ $V_{GS_Q} \cong$ **−2.55 V**, $I_{D_Q} \cong$ **3.3 mA**

(b) $g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(10\text{ mA})}{6\text{ V}} = 3.33\text{ mS}$

$$g_m = g_{m0}\left(1 - \frac{V_{GS}}{V_P}\right) = 3.33\text{ mS}\left(1 - \frac{(-2.55\text{ V})}{-6\text{ V}}\right)$$

= **1.91 mS**

(c) $A_{v_{\text{mid}}} = -g_m(R_D \| R_L)$

$= -(1.91\text{ mS})(3.9\text{ k}\Omega \| 5.6\text{ k}\Omega)$

= **−4.39**

(d) $Z_i = 68\text{ k}\Omega \| 220\text{ k}\Omega$ = **51.94 kΩ**

(e) $A_{v_{s(\text{mid})}} = \dfrac{V_o}{V_i} \cdot \dfrac{V_i}{V_s}$

$$\frac{V_i}{V_s} = \frac{Z_i}{Z_i + R_s} = \frac{51.94\text{ k}\Omega}{51.94\text{ k}\Omega + 1.5\text{ k}\Omega} = 0.972$$

$A_{v_{s(\text{mid})}} = (-4.39)(0.972) =$ **−4.27**

(f) $f_{L_G} = \dfrac{1}{2\pi(R_{\text{sig}} + R_i)C_G} = \dfrac{1}{2\pi(1.5\text{ k}\Omega + 51.94\text{ k}\Omega)(1\ \mu\text{F})}$

$= \mathbf{2.98\ Hz}$

$f_{L_C} = \dfrac{1}{2\pi(R_o + R_L)C_C} = \dfrac{1}{2\pi(3.9\text{ k}\Omega + 5.6\text{ k}\Omega)(6.8\ \mu\text{F})}$

$= \mathbf{2.46\ Hz}$

$f_{L_S} = \dfrac{1}{2\pi R_{\text{eq}} C_S}$

$= \dfrac{1}{2\pi(388.1\ \Omega)(10\ \mu\text{F})}$

$= \mathbf{41\ Hz}$

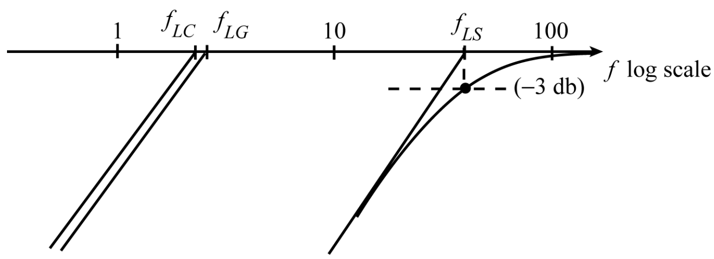
$R_{\text{eq}} = R_S \parallel \dfrac{1}{g_m} = 1.5\text{ k}\Omega \parallel \dfrac{1}{1.91\text{ mS}}$

$= 1.5\text{ k}\Omega \parallel 523.56\ \Omega$

$= 388.1\ \Omega$

(g) $f_1 = f_{L_S} \cong$ **41 Hz**

(h, i)



26. (a) $C_{M_i} = (1 - A_v)C_f$

$= \big(1 - (-120)\big)(10\text{ pF})$

$= \mathbf{1210\ pF}$

(b) $C_{M_O} = (1 - \dfrac{1}{A_v})C_f = 1 - \dfrac{1}{(-120)}\ 10\text{ pF}$

$= \mathbf{10.08\ pF}$

(c) absolutely

27. (a) $f_{H_i} = \dfrac{1}{2\pi R_{Th_1} C_i}$

$= \dfrac{1}{2\pi(614.56\ \Omega)(931.92\ \text{pF})}$

$= \mathbf{277.89\ kHz}$

$R_{Th_1} = R_s \parallel R_1 \parallel R_2 \parallel R_i$

$= \underbrace{0.82\ \text{k}\Omega \parallel 68\ \text{k}\Omega}_{0.81\ \text{k}\Omega} \parallel \underbrace{10\ \text{k}\Omega \parallel 3.418\ \text{k}\Omega}_{2.547\ \text{k}\Omega}$

$= 614.56\ \Omega$

$C_i = C_{W_1} + C_{be} + C_{bc}(1 - A_v)$

$= 5\ \text{pF} + 40\ \text{pF} + 12\ \text{pF}(1 - (-72.91))$

$= 931.92\ \text{pF}$ ↑Prob. 15

$f_{H_o} = \dfrac{1}{2\pi R_{Th_2} C_o}$

$= \dfrac{1}{2\pi(2.08\ \text{k}\Omega)(28\ \text{pF})}$

$= \mathbf{2.73\ MHz}$

$R_{Th_2} = R_C \parallel R_L = 5.6\ \text{k}\Omega \parallel 3.3\ \text{k}\Omega$

$= 2.08\ \text{k}\Omega$

$C_o = C_{W_o} + C_{ce} + C_{M_o}$

$= 8\ \text{pF} + 8\ \text{pF} + 12\ \text{pF}$

$= 28\ \text{pF}$

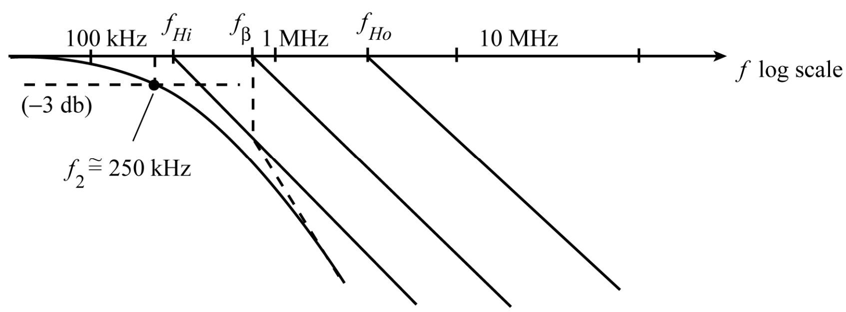
(b) $f_\beta \cong \dfrac{1}{2\pi\beta_{\text{mid}} r_e (C_{be} + C_{bc})} = \dfrac{1}{2\pi(120)(28.48\ \Omega)(40\ \text{pF} + 12\ \text{pF})}$

$= \mathbf{895.56\ kHz}$ ↑ Prob. 15

$f_T = \beta f_\beta = (120)(895.56\ \text{kHz})$

$= \mathbf{107.47\ MHz}$

(c)



(d) $\text{GBP} = (A_{v_{\text{mid}}})(\text{BW})$

$= (72.91)(250\ \text{kHz})$

$= \mathbf{18.23\ MHz}$

28. (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: $I_B = \dfrac{V_{CC} - V_{BE}}{R_B + (\beta + 1)R_E} = \dfrac{20\ \text{V} - 0.7\ \text{V}}{470\ \text{k}\Omega + (111)(0.91\ \text{k}\Omega)}$

$= 33.8\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (110 + 1)(33.8\ \mu\text{A})$

$= 3.75\ \text{mA}$

$$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{3.75\text{ mA}} = 6.93\ \Omega$$

$$R_i = \beta r_e = (110)(6.93\ \Omega)$$
$$= 762.3\ \Omega$$

$$R_{Th_1} = R_s \parallel R_B \parallel R_i = 0.6\text{ k}\Omega \parallel 470\text{ k}\Omega \parallel 762.3\ \Omega$$
$$= 335.50\ \Omega$$

$$f_{H_i} = \frac{1}{2\pi(335.50\ \Omega)(C_i)}$$

C_i: $C_i = C_{W_i} + C_{be} + (1 - A_v)C_{bc}$

A_v: $$A_{v_{\text{mid}}} = \frac{-(R_L \parallel R_C)}{r_e} = \frac{-(4.7\text{ k}\Omega \parallel 3\text{ k}\Omega)}{6.93\ \Omega}$$
$$= -264.2$$

$$C_i = 7\text{ pF} + 20\text{ pF} + (1 - (-264.2)6\text{ pF}$$
$$= 1.62\text{ nF}$$

$$f_{H_i} = \frac{1}{2\pi(335.50\ \Omega)(1.62\text{ nF})}$$
$$\cong \mathbf{293\text{ kHz}}$$

$$f_{H_o} = \frac{1}{2\pi R_{Th_2} C_o}$$

$$R_{Th_2} = R_C \parallel R_L = 3\text{ k}\Omega \parallel 4.7\text{ k}\Omega = 1.831\text{ k}\Omega$$

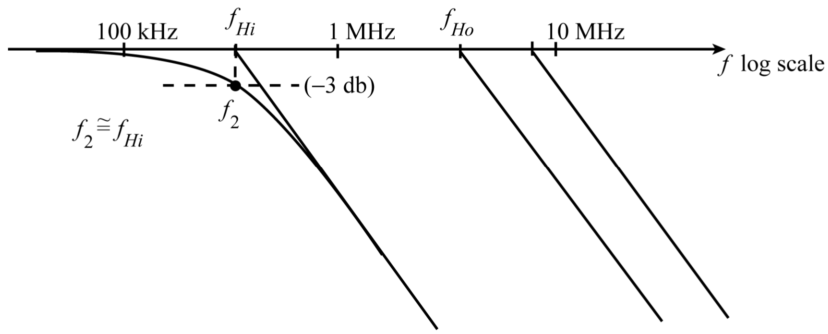
$$C_o = C_{W_o} + C_{ce} + \underbrace{C_{M_o}}_{\cong C_f = C_{bc}}$$
$$= 11\text{ pF} + 10\text{ pF} + 6\text{ pF}$$
$$= 27\text{ pF}$$

$$f_{H_o} = \frac{1}{2\pi(1.831\text{ k}\Omega)(27\text{ pF})}$$
$$= \mathbf{3.22\text{ MHz}}$$

(b) $$f_\beta = \frac{1}{2\pi\beta_{\text{mid}} r_e (C_{be} + C_{bc})}$$
$$= \frac{1}{2\pi(110)(6.93\ \Omega)(20\text{ pF} + 6\text{ pF})}$$
$$= \mathbf{8.03\text{ MHz}}$$

$$f_T = \beta_{\text{mid}} f_\beta = (110)(8.03\text{ MHz})$$
$$= \mathbf{883.3\text{ MHz}}$$

(c)



(d) $\text{GBP} = (A_{v_{\text{mid}}})(\text{BW})$
$= (264.24)(293 \text{ kHz})$
$= \mathbf{77.42\ MHz}$

29. (a) $f_{H_i} = \dfrac{1}{2\pi R_{Th_1} C_i}$
$= \dfrac{1}{2\pi(955\ \Omega)(58\text{ pF})}$
$= \mathbf{2.87\ MHz}$

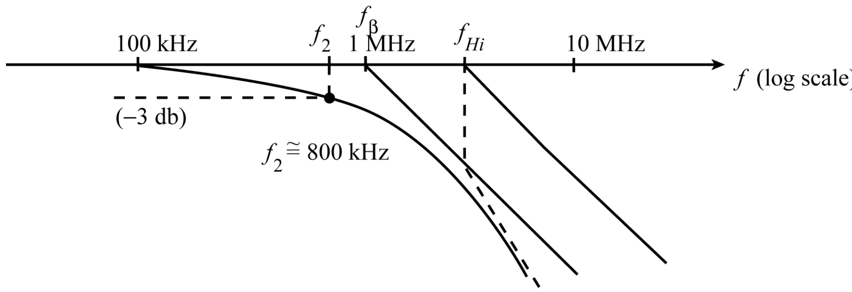
$R_{Th_1} = R_s \| R_1 \| R_2 \| Z_b$
$Z_b = \beta r_e + (\beta + 1)(R_E \| R_L)$
$= (100)(30.23\ \Omega) + (101)(2.2\text{ k}\Omega \| 8.2\text{ k}\Omega)$
$= 3.023\text{ k}\Omega + 175.2\text{ k}\Omega$
$= 178.2\text{ k}\Omega$
$R_{Th_1} = 1\text{ k}\Omega \| 120\text{ k}\Omega \| 30\text{ k}\Omega \| 178.2\text{ k}\Omega$
$= 955\ \Omega$
$C_i = C_{W_i} + C_{be} + C_{bc}$ (No Miller effect)
$= 8\text{ pF} + 30\text{ pF} + 20\text{ pF}$
$= 58\text{ pF}$

$f_{H_o} = \dfrac{1}{2\pi R_{Th_2} C_o}$
$= \dfrac{1}{2\pi(38.94\ \Omega)(32\text{ pF})}$
$= \mathbf{127.72\ MHz}$

$R_{Th_2} = R_E \| R_L \| \quad r_e + \dfrac{\overbrace{R_1 \| R_2 \| R_3}^{24\text{ k}\Omega}}{\beta}$
$= 2.2\text{ k}\Omega \| 8.2\text{ k}\Omega \| \quad 30.23\ \Omega + \dfrac{24\text{ k}\Omega \| 1\text{ k}\Omega}{100}$
$= 1.735\text{ k}\Omega \| (30.23\ \Omega + 9.6\ \Omega)$
$= 1.735\text{ k}\Omega \| 39.83\ \Omega$
$= 38.94\ \Omega$
$C_o = C_{W_o} + C_{ce}$
$= 10\text{ pF} + 12\text{ pF}$
$= 32\text{ pF}$

(b) $f_\beta = \dfrac{1}{2\pi\beta_{\text{mid}} r_e (C_{be} + C_{bc})}$
$= \dfrac{1}{2\pi(100)(30.23\ \Omega)(30\text{ pF} + 20\text{ pF})}$
$= \mathbf{1.05\ MHz}$
$f_T = \beta_{\text{mid}} f_\beta = 100(1.05\text{ MHz}) = \mathbf{105\ MHz}$

(c)



(d) $\text{GBP} = (A_{v_{\text{mid}}})(\text{BW})$

$= (0.983)(800 \text{ kHz})$

$= \mathbf{786.4\ MHz}$

30. (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!)

$= 8\text{ pF} + 24\text{ pF}$

$= 32\text{ pF}$

$R_i = 0.1\text{ k}\Omega \parallel 1.2\text{ k}\Omega \parallel 9.38\ \Omega = 8.52\ \Omega$

$f_{H_i} = \dfrac{1}{2\pi(8.52\ \Omega)(32\text{ pF})} \cong \mathbf{584\ MHz}$

$f_{H_o} = \dfrac{1}{2\pi R_{Th_2} C_o}$ $R_{Th_2} = R_C \parallel R_L = 3.3\text{ k}\Omega \parallel 4.7\text{ k}\Omega = 1.94\text{ k}\Omega$

$C_o = C_{W_o} + C_{bc} +$ (no Miller)

$= 10\text{ pF} + 18\text{ pF}$

$= 28\text{ pF}$

$f_{H_o} = \dfrac{1}{2\pi(1.94\text{ k}\Omega)(28\text{ pF})}$

$= \mathbf{2.93\ MHz}$

(b) $f_\beta = \dfrac{1}{2\pi\beta_{\text{mid}} r_e (C_{be} + C_{bc})}$

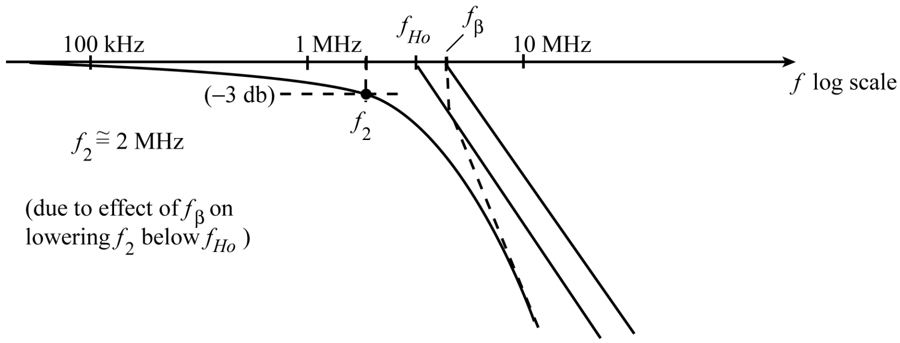
$= \dfrac{1}{2\pi(80)(9.45\ \Omega)(24\text{ pF} + 18\text{ pF})}$

$=$ **5.01 MHz**

$f_T = \beta_{\text{mid}} f_\beta = (80)(5.01\text{ MHz})$

$=$ **400.8 MHz**

(c)



(d) $\text{GBP} = (A_{v_{\text{mid}}})(\text{BW})$

$= (205.1)(2\text{ MHz})$

$=$ **410.2 MHz**

31. (a) From problem 23 $g_{m0} =$ **2 mS**, $g_m =$ **1.18 mS**

(b) From problem 23 $A_{v_{\text{mid}}} \cong A_{v_s\text{ (mid)}} =$ **−2**

(c) $f_{H_i} = \dfrac{1}{2\pi R_{Th_1} C_i}$

$f_{H_i} = \dfrac{1}{2\pi(999\ \Omega)(21\text{ pF})}$

$=$ **7.59 MHz**

$R_{Th_1} = R_{\text{sig}} \parallel R_G$

$= 1\text{ k}\Omega \parallel 1\text{ M}\Omega$

$= 999\ \Omega$

$C_i = C_{W_i} + C_{gs} + C_{M_i}$

$C_{M_i} = (1 - A_v)C_{gd}$

$= (1 - (-2)4\text{ pF}$

$= 12\text{ pF}$

$C_i = 3\text{ pF} + 6\text{ pF} + 12\text{ pF}$

$= 21\text{ pF}$

$f_{H_o} = \dfrac{1}{2\pi R_{Th_2} C_o}$

$= \dfrac{1}{2\pi(1.696\text{ k}\Omega)(12\text{ pF})}$

$=$ **7.82 MHz**

$R_{Th_2} = R_D \parallel R_L$

$= 3\text{ k}\Omega \parallel 3.9\text{ k}\Omega$

$= 1.696\text{ k}\Omega$

$C_o = C_{W_o} + C_{ds} + C_{M_o}$

$C_{M_o} = 1 - \dfrac{1}{-2}\ 4\text{ pF}$

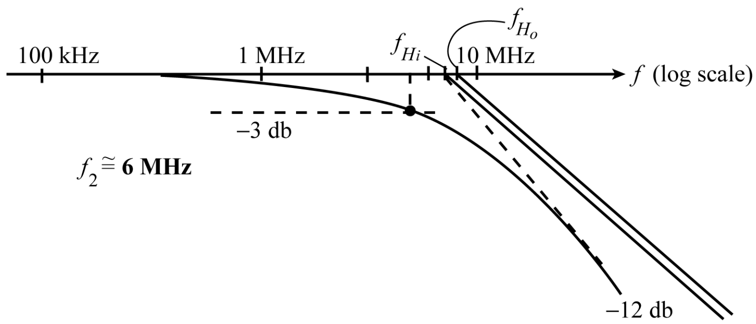
$= (1.5)(4\text{ pF})$

$= 6\text{ pF}$

$C_o = 5\text{ pF} + 1\text{ pF} + 6\text{ pF}$

$= 12\text{ pF}$

(d)



(e) $\text{GBP} = (A_{v_{\text{mid}}})(\text{BW})$

$= (2)(6\text{ MHz})$

$= \mathbf{12\ MHz}$

32. (a) $g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(10\text{ mA})}{6\text{ V}}$ = **3.33 mS**

From problem #21 $V_{GS_Q} \cong$ **−2.55 V**, $I_{D_Q} \cong$ **3.3 mA**

$$g_m = g_{m0}\ 1 - \frac{V_{GS_Q}}{V_P} = 3.33\text{ mS}\ \ 1 - \frac{-2.55\text{ V}}{-6\text{ V}} = \mathbf{1.91\ mS}$$

(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) $f_{H_i} = \dfrac{1}{2\pi R_{Th_1} C_i}$

$R_{Th_1} = R_{\text{sig}} \parallel R_1 \parallel R_2$

$= 1.5\text{ k}\Omega \parallel 51.94\text{ k}\Omega$

$= 1.46\text{ k}\Omega$

$C_i = C_{W_i} + C_{gs} + (1 - A_v)C_{gd}$

$= 4\text{ pF} + 12\text{ pF} + (1 - (-4.39))8\text{ pF}$

$= 59.12\text{ pF}$

$$f_{H_i} = \frac{1}{2\pi(1.46\text{ k}\Omega)(59.12\text{ pF})}$$

$= \mathbf{1.84\ MHz}$

$f_{H_o} = \dfrac{1}{2\pi R_{Th_2} C_o}$

$R_{Th_2} = R_D \parallel R_L = 3.9\text{ k}\Omega \parallel 5.6\text{ k}\Omega$

$= 2.3\text{ k}\Omega$

$$C_o = C_{W_o} + C_{ds} + \left(1 - \frac{1}{A_v}\right) C_{gd}$$

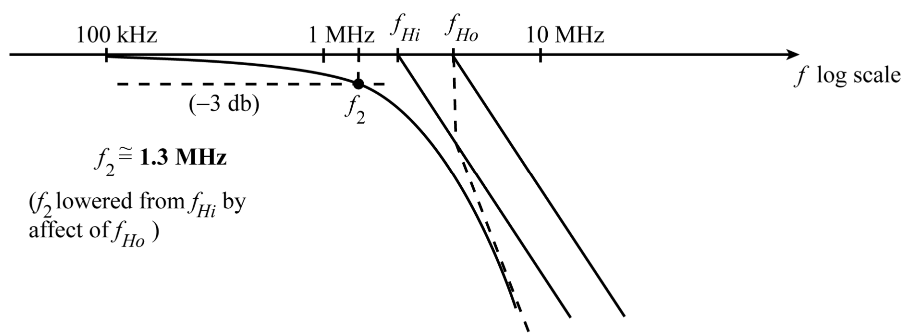
$$= 6\text{ pF} + 3\text{ pF} + \left(1 - \frac{1}{(-4.39)}\right) 8\text{ pF}$$

$$= 18.82\text{ pF}$$

$$f_{H_o} = \frac{1}{2\pi(2.3\text{ k}\Omega)(18.82\text{ pF})}$$

$$= \mathbf{3.68\ MHz}$$

(d)



(e) $\text{GBP} = (A_{v_{\text{mid}}})(\text{BW})$

$$= (4.27)(1.3\text{ MHz})$$

$$= \mathbf{5.55\ MHz}$$

33. $A_{v_T} = A_{v_1} \cdot A_{v_2} \cdot A_{v_3} \cdot A_{v_4}$

$$= A_v^4$$

$$= (20)^4$$

$$= \mathbf{16 \times 10^4}$$

34. $f_2' = \left(\sqrt{2^{1/n} - 1}\right) f_2$

$$= \left(\sqrt{\underbrace{2^{1/4}}_{1.18} - 1}\right)(2.5\text{ MHz})$$

$$= 0.435(2.5\text{ MHz})$$

$$= \mathbf{1.09\ MHz}$$

35. $f_1' = \dfrac{f_1}{\sqrt{2^{1/n} - 1}} = \dfrac{40\text{ Hz}}{\sqrt{2^{1/4} - 1}}$

$$= \frac{40\text{ Hz}}{0.435}$$

$$= \mathbf{91.96\ Hz}$$

36. (a) $v = \frac{4}{\pi}V_m \ \sin 2\pi f_s t + \frac{1}{3}\sin 2\pi(3f_s)t + \frac{1}{5}\sin 2\pi(5f_s)t$

$$+\frac{1}{7}\sin 2\pi(7f_s)t + \frac{1}{9}\sin 2\pi(9f_s)t + \ldots$$

$$= 12.73 \times 10^{-3}(\sin 2\pi(100\times 10^3)t + \frac{1}{3}\sin 2\pi(300\times 10^3)t$$

$$+\frac{1}{5}\sin 2\pi(500\times 10^3)t + \frac{1}{7}\sin 2\pi(700\times 10^3)t + \frac{1}{9}\sin 2\pi(900\times 10^3)t)$$

(b) $BW \cong \frac{0.35}{t_r}$

$\cong \frac{0.35}{0.7\ \mu\text{s}}$

$\cong 500$ 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) $P = \frac{V - V'}{V} = \frac{90\text{ mV} - 80\text{ mV}}{90\text{ mV}} = 0.111$

$f_{L_o} = \frac{P}{\pi}f_s = \frac{(0.111)(100\text{ kHz})}{\pi} \cong$ **3.53 kHz**

Chapter 10

1. $V_o = -\frac{R_F}{R_1}V_1 = -\frac{250\text{ k}\Omega}{20\text{ k}\Omega}(1.5\text{ V}) = \mathbf{-18.75\text{ V}}$

2. $A_v = \frac{V_o}{V_i} = -\frac{R_F}{R_1}$

   For R_1 = 10 kΩ:

   $A_v = -\frac{500\text{ k}\Omega}{10\text{ k}\Omega} = \mathbf{-50}$

   For R_1 = 20 kΩ:

   $A_v = -\frac{500\text{ k}\Omega}{20\text{ k}\Omega} = \mathbf{-25}$

3. $V_o = -\frac{R_f}{R_1}V_1 = -\frac{1\text{ M}\Omega}{20\text{ k}\Omega}\ V_1 = 2\text{ V}$

   $V_1 = \frac{2\text{ V}}{-50} = \mathbf{-40\text{ mV}}$

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:

   $V_o = -10(0.1\text{ V}) = \mathbf{-1\text{ V}}$

   For V_1 = 0.5 V:

   $V_o = -10(0.5\text{ V}) = \mathbf{-5\text{ V}}$

   } V_o ranges from **−1 V to −5 V**

5. $V_o = \ 1+\frac{R_F}{R_1}\ V_1 = \ 1+\frac{360\text{ k}\Omega}{12\text{ k}\Omega}\ (-0.3\text{ V})$

   $= 31(-0.3\text{ V}) = \mathbf{-9.3\text{ V}}$

6. $V_o = \ 1+\frac{R_F}{R_1}\ V_1 = \ 1+\frac{360\text{ k}\Omega}{12\text{ k}\Omega}\ V_1 = 2.4\text{ V}$

   $V_1 = \frac{2.4\text{ V}}{31} = \mathbf{77.42\text{ mV}}$

7. $V_o = \ 1+\frac{R_F}{R_1}\ V_1$

   For R_1 = 10 kΩ:

   $V_o = \ 1+\frac{200\text{ k}\Omega}{10\text{ k}\Omega}\ (0.5\text{ V}) = 21(0.5\text{ V}) = \mathbf{10.5\text{ V}}$

   For R_1 = 20 kΩ:

$$V_o = \quad 1+\frac{200\text{ k}\Omega}{20\text{ k}\Omega} \quad (0.5\text{ V}) = 11(0.5\text{ V}) = \mathbf{5.5\ V}$$

V_o ranges from 5.5 V to 10.5 V.

8. $$V_o = -\ \frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3$$

$$= -\ \frac{330\text{ k}\Omega}{33\text{ k}\Omega}(0.2\text{ V}) + \frac{330\text{ k}\Omega}{22\text{ k}\Omega}(-0.5\text{ V}) + \frac{330\text{ k}\Omega}{12\text{ k}\Omega}(0.8\text{ V})$$

$= -[10(0.2\text{ V}) + 15(-0.5\text{ V}) + 27.5(0.8\text{ V})]$

$= -[2\text{ V} + (-7.5\text{ V}) + 2.2\text{ V}]$

$= -[24\text{ V} - 7.5\text{ V}] = \mathbf{-16.5\ V}$

9. $$V_o = -\ \frac{R_F}{R_1}V_1 + \frac{R_F}{R_2}V_2 + \frac{R_F}{R_3}V_3$$

$$= -\ \frac{68\text{ k}\Omega}{33\text{ k}\Omega}(0.2\text{ V}) + \frac{68\text{ k}\Omega}{22\text{ k}\Omega}(-0.5\text{ V}) + \frac{68\text{ k}\Omega}{12\text{ k}\Omega}(+0.8\text{ V})$$

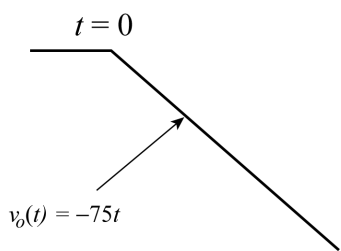
$= -[0.41\text{ V} - 1.55\text{ V} + 4.53\text{ V}]$

$= \mathbf{-3.39\ V}$

10. $$v_o(t) = -\frac{1}{RC} \quad v_1(t)dt$$

$$= -\frac{1}{(200\text{ k}\Omega)(0.1\ \mu\text{F})} \quad 1.5\ dt$$

$= -50(1.5t) = \mathbf{-75}\boldsymbol{t}$



11. $V_o = V_1 = \mathbf{+0.5\ V}$

12. $$V_o = -\frac{R_f}{R_1}V_1 = -\frac{100\text{ k}\Omega}{20\text{ k}\Omega}(1.5\text{ V})$$

$= -5(1.5\text{ V}) = \mathbf{-7.5\ V}$

13. $$V_2 = -\ \frac{200\text{ k}\Omega}{20\text{ k}\Omega} \quad (0.2\text{ V}) \ = \mathbf{-2\ V}$$

$$V_3 = \quad 1+\frac{200\text{ k}\Omega}{10\text{ k}\Omega} \quad (0.2\text{ V}) \ = \mathbf{+4.2\ V}$$

14. $V_o = \left(1+\frac{400\text{ k}\Omega}{20\text{ k}\Omega}\right)(0.1\text{ V})\cdot\left(\frac{-100\text{ k}\Omega}{20\text{ k}\Omega}\right) + \left(-\frac{100\text{ k}\Omega}{10\text{ k}\Omega}\right)(0.1\text{ V})$

$= (2.1\text{ V})(-5) + (-10)(0.1\text{ V})$

$= -10.5\text{ V} - 1\text{ V} = \mathbf{-11.5\text{ V}}$

15. $V_o = -\left[\frac{600\text{ k}\Omega}{15\text{ k}\Omega}(25\text{ mV}) + \frac{600\text{ k}\Omega}{30\text{ k}\Omega}(-20\text{ mV})\right]\left(-\frac{300\text{ k}\Omega}{30\text{ k}\Omega}\right) + \left(-\frac{300\text{ k}\Omega}{15\text{ k}\Omega}\right)(-20\text{ mV})$

$= -[40(25\text{ mV}) + (20)(-20\text{ mV})](-10) + (-20)(-20\text{ mV})$

$= -[1\text{ V} - 0.4\text{ V}](-10) + 0.4\text{ V}$

$= 6\text{ V} + 0.4\text{ V} = \mathbf{6.4\text{ V}}$

16. $V_o = \left(1+\frac{R_f}{R_1}\right)V_{Io} + I_{Io}R_f$

$= \left(1+\frac{200\text{ k}\Omega}{2\text{ k}\Omega}\right)(6\text{ mV}) + (120\text{ nA})(200\text{ k}\Omega)$

$= 101(6\text{ mV}) + 24\text{ mV}$

$= 606\text{ mV} + 24\text{ mV} = \mathbf{630\text{ mV}}$

17. $I_{IB}^{+} = I_{IB^+} + \frac{I_{Io}}{2} = 20\text{ nA} + \frac{4\text{ nA}}{2} = \mathbf{22\text{ nA}}$

$I_{IB}^{-} = I_{IB^-} - \frac{I_{Io}}{2} = 20\text{ nA} - \frac{4\text{ nA}}{2} = \mathbf{18\text{ nA}}$

18. $f_1 = 800\text{ kHz}$

$f_c = \frac{f_1}{A_{v_2}} = \frac{800\text{ kHz}}{150\times 10^3} = \mathbf{5.3\text{ Hz}}$

19. $A_{CL} = \frac{SR}{\Delta V_i/\Delta t} = \frac{2.4\text{ V}/\mu\text{s}}{0.3\text{ V}/10\ \mu\text{s}} = \mathbf{80}$

20. $A_{CL} = \frac{R_f}{R_1} = \frac{200\text{ k}\Omega}{2\text{ k}\Omega} = 100$

$K = A_{CL}V_i = 100(50\text{ mV}) = 5\text{ V}$

$w_s \le \frac{SR}{K} = \frac{0.4\text{ V}/\mu\text{s}}{5\text{ V}} = \mathbf{80\times 10^3\text{ rad/s}}$

$f_s = \frac{w_s}{2\pi} = \frac{80\times 10^3}{2\pi} = \mathbf{12.73\text{ kHz}}$

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) = $20\log\frac{A_d}{A_c} = 20\log\frac{120}{20\times 10^{-3}}$

$$= 20\log(6\times 10^3) = \mathbf{75.56\text{ dB}}$$

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 $V_o = A_d V_d \ \ 1 + \dfrac{1}{CMRR}\dfrac{V_c}{V_d}$

(a) $V_o = 6000(60\ \mu\text{V})\ \ 1 + \dfrac{1}{200}\dfrac{170\ \mu\text{V}}{60\ \mu\text{V}} = \mathbf{365.1\ mV}$

(b) $V_o = 6000(60\ \mu\text{V})\ \ 1 + \dfrac{1}{10^5}\dfrac{170\ \mu\text{V}}{60\ \mu\text{V}} = \mathbf{360.01\ mV}$

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. $V_o = \;1+\frac{R_F}{R_1}\; V_1 = \;1+\frac{750\text{ k}\Omega}{36\text{ k}\Omega}\; (150\text{ mV, rms})$

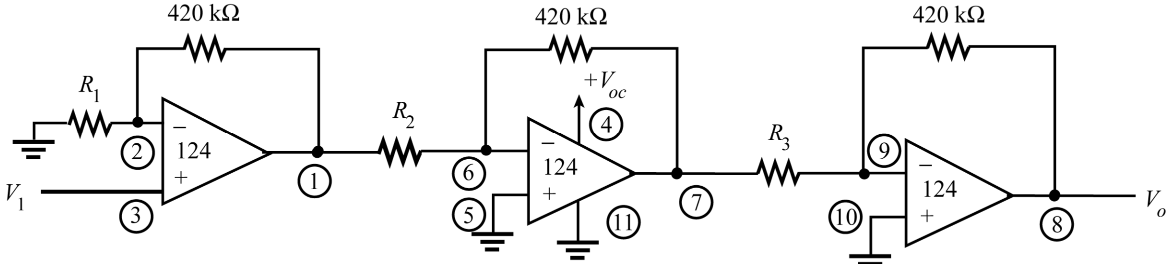
$= \mathbf{3.275\text{ V}}\text{, rms }\angle 0°$

3. $V_o = \;1+\frac{510\text{ k}\Omega}{18\text{ k}\Omega}\; (20\ \mu\text{V})\; -\frac{680\text{ k}\Omega}{22\text{ k}\Omega}\; \; -\frac{750\text{ k}\Omega}{33\text{ k}\Omega}$

$= (29.33)(-30.91)(-22.73)(20\ \mu\text{V})$

$= \mathbf{412\text{ mV}}$

4.



$1+\frac{420\text{ k}\Omega}{R_1} = +15$ $\qquad -\frac{420\text{ k}\Omega}{R_2} = -22$ $\qquad \frac{420\text{ k}\Omega}{R_2} = -30$

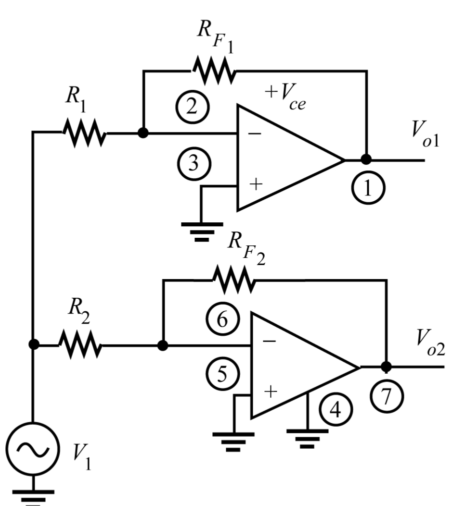
$R_1 = \frac{420\text{ k}\Omega}{14}$ $\qquad R_2 = \frac{420\text{ k}\Omega}{22}$ $\qquad R_3 = \frac{420\text{ k}\Omega}{30}$

$\boldsymbol{R_1 = 71.4\text{ k}\Omega}$ $\qquad \boldsymbol{R_2 = 19.1\text{ k}\Omega}$ $\qquad \boldsymbol{R_3 = 14\text{ k}\Omega}$

$V_o = (+15)(-22)(-30)V_1 = 9000(80\ \mu\text{V}) = 792\text{ mV}$

$= \mathbf{0.792\text{ V}}$

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. $V_o = -\frac{R_F}{R_1}V_1 + \frac{R_F}{R_2}V_2 = -\frac{470\text{ k}\Omega}{47\text{ k}\Omega}(40\text{ mV}) + \frac{470\text{ k}\Omega}{12\text{ k}\Omega}(20\text{ mV})$

$= -[400\text{ mV} + 783.3\text{ mV}] = \mathbf{-1.18\ V}$

7. $V_o = \frac{10\text{ k}\Omega}{10\text{ k}\Omega + 10\text{ k}\Omega}\ \frac{150\text{ k}\Omega + 300\text{ k}\Omega}{150\text{ k}\Omega}\ V_1 - \frac{300\text{ k}\Omega}{150\text{ k}\Omega}V_2$

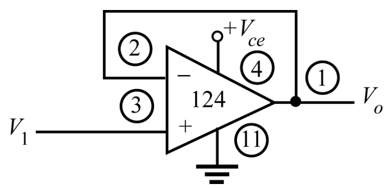
$= 0.5(3)(1\text{ V}) - 2(2\text{ V}) = 1.5\text{ V} - 4\text{ V} = \mathbf{-2.5\ V}$

8. $V_o = -\ \frac{330\text{ k}\Omega}{33\text{ k}\Omega}(12\text{ mV})\ \frac{470\text{ k}\Omega}{47\text{ k}\Omega} + \frac{470\text{ k}\Omega}{47\text{ k}\Omega}(18\text{ mV})$

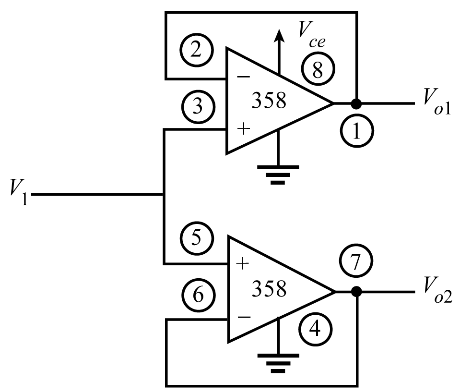
$= -[(-120\text{ mV})(10) + 180\text{ mV}] = -[-1.2\text{ V} + 0.18\text{ V}]$

$= \mathbf{+1.02\ V}$

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. $\frac{I_o}{V_1} = \frac{R_F}{R_1}\ \frac{1}{R_s}$

$I_o = \frac{100\text{ k}\Omega}{200\text{ k}\Omega}\ \frac{1}{10\ \Omega}\ (10\text{ mV}) = \mathbf{0.5\ mA}$

14. $V_o = \ 1 + \frac{2R}{R_p}\ [V_2 - V_1]$

$= \ 1 + \frac{2(5000)}{1000}\ [1\text{ V} - 3\text{ V}] = \mathbf{-22\ V}$

15. $f_{OH} = \dfrac{1}{2\pi R_1 C_1} = \dfrac{1}{2\pi(2.2\text{ k}\Omega)(0.05\ \mu\text{F})}$

$= \mathbf{1.45\ kHz}$

16. $f_{OL} = \dfrac{1}{2\pi R_1 C_1} = \dfrac{1}{2\pi(20\text{ k}\Omega)(0.02\ \mu\text{F})}$

$= \mathbf{397.9\ Hz}$

17. $f_{OL} = \dfrac{1}{2\pi R_1 C_1} = \dfrac{1}{2\pi(10\text{ k}\Omega)(0.05\ \mu\text{F})} = \mathbf{318.3\ Hz}$

$f_{OH} = \dfrac{1}{2\pi R_2 C_2} = \dfrac{1}{2\pi(20\text{ k}\Omega)(0.02\ \mu\text{F})}$

$= \mathbf{397.9\ Hz}$

Chapter 12

2.5 mA

1. $I_{B_Q} = \frac{V_{CC} - V_{BE}}{R_B} = \frac{18\text{ V} - 0.7\text{ V}}{1.2\text{ k}\Omega}$ = 14.42 mA

$I_{C_Q} = \beta I_{B_Q}$ = 40(14.42 mA) = 576.67 mA

$P_i = V_{CC}I_{dc} \cong V_{CC}I_{C_Q}$ = (18 V)(576.67 mA)

$\cong$ **10.4 W**

$I_C(\text{rms}) = \beta I_B(\text{rms})$

= 40(5 mA) = 200 mA

$P_o = I_C^2(\text{rms})R_C$ = (200 mA)^2(16 Ω) = **640 mW**

2. $I_{B_Q} = \frac{V_{CC} - V_{BE}}{R_B} = \frac{18\text{ V} - 0.7\text{ V}}{1.5\text{ k}\Omega}$ = 11.5 mA

$I_{C_Q} = \beta I_{B_Q}$ = 40(11.5 mA) = 460 mA

$P_i(\text{dc}) = V_{CC}I_{dc} = V_{CC}\left(I_{C_Q} + I_{B_Q}\right)$

= 18 V(460 mA + 11.5 mA)

= **8.5 W**

$P_i \approx V_{CC}I_{C_Q}$ = 18 V(460 mA) = 8.3 W

3. From problem 2: I_{C_Q} = 460 mA, P_i = 8.3 W.

For maximum efficiency of 25%:

$\%\eta = 100\% \times \frac{P_o}{P_i} = \frac{P_o}{8.3\text{ W}} \times 100\% = 25\%$

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:

$P_o = \frac{V_{CE}^2(P)}{2R_C} = \frac{(7.36\text{ V})^2}{2(16)} =$ **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, $V_{pri} = aV_L = (3.87)(5.66 \text{ V}) = 21.9 \text{ V}$]

(d) $P_L = I_L^2 R_L$

$$I_L = \sqrt{\frac{P_L}{R_L}} = \sqrt{\frac{2\text{ W}}{16\ \Omega}} = \mathbf{353.55\ mA}$$

$$P_{pri} = 2\text{ W} = I_{pri}^2 R_{pri} = (239.6\ \Omega)\, I_{pri}^2$$

$$I_{pri} = \sqrt{\frac{2\text{ W}}{239.6\ \Omega}} = \mathbf{91.36\ mA}$$

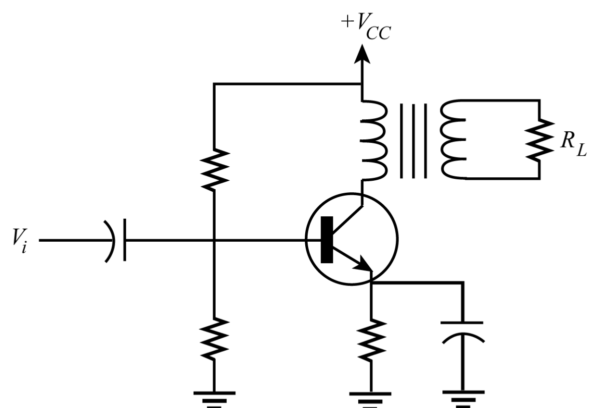
$$\text{or, } I_{pri} = \frac{I_L}{a} = \frac{353.55\text{ mA}}{3.87} = \mathbf{91.36\ mA}$$

9. $I_{dc} = I_{C_Q} = 150$ mA

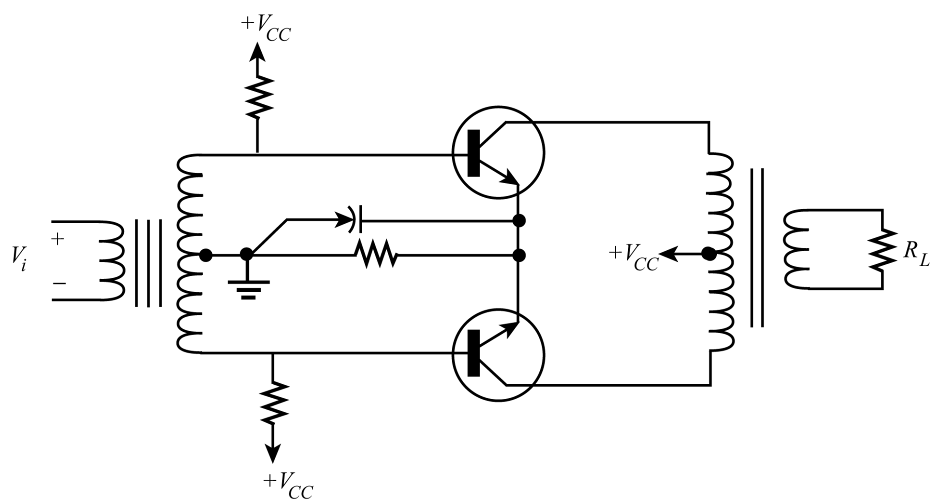
$$P_i = V_{CC} I_{C_Q} = (36\text{ V})(150\text{ mA}) = 5.4\text{ W}$$

$$\%\eta = \frac{P_o}{P_i} \times 100\% = \frac{2\text{ W}}{5.4\text{ W}} \times 100\% = \mathbf{37\%}$$

10.



11.



12. (a) $P_i = V_{CC}I_{dc}$ = (25 V)(1.75 A) = **43.77 W**

Where, $I_{dc} = \frac{2}{\pi}I_p = \frac{2}{\pi}\frac{V_p}{R_L} = \frac{2}{\pi}\cdot\frac{22\text{ V}}{8\ \Omega}$ = 1.75 A

(b) $P_o = \frac{V_p^2}{2R_L} = \frac{(22\text{ V})^2}{2(8\ \Omega)}$ = **30.25 W**

(c) $\%\eta = \frac{P_o}{P_i} \times 100\% = \frac{30.75\text{ W}}{43.77\text{ W}} \times 100\%$ = **69%**

13. (a) max $P_i = V_{CC}I_{dc}$

$= V_{CC}\cdot\left(\frac{2}{\pi}\cdot\frac{V_{CC}}{R_L}\right) = (25\text{ V})\left(\frac{2}{\pi}\cdot\frac{25\text{ V}}{8\ \Omega}\right)$

= **49.74 W**

(b) max $P_o = \frac{V_{CC}^2}{2R_L} = \frac{(25\text{ V})^2}{2(8\ \Omega)}$ = **39.06 W**

(c) max $\%\eta = \frac{\max P_o}{\max P_i} \times 100\% = \frac{39.06\text{ W}}{49.74\text{ W}} \times 100\%$

= **78.5%**

14. (a) $V_{L_{(\text{peak})}}$ = 20 V

$P_i = V_{CC}I_{dc} = V_{CC}\left(\frac{2}{\pi}\cdot\frac{V_L}{R_L}\right)$

$= (22\text{ V})\left(\frac{2}{\pi}\cdot\frac{20\text{ V}}{4\ \Omega}\right)$ = 70 W

$P_o = \frac{V_L^2}{2R_L} = \frac{(20\text{ V})^2}{2(4\ \Omega)}$ = 50 W

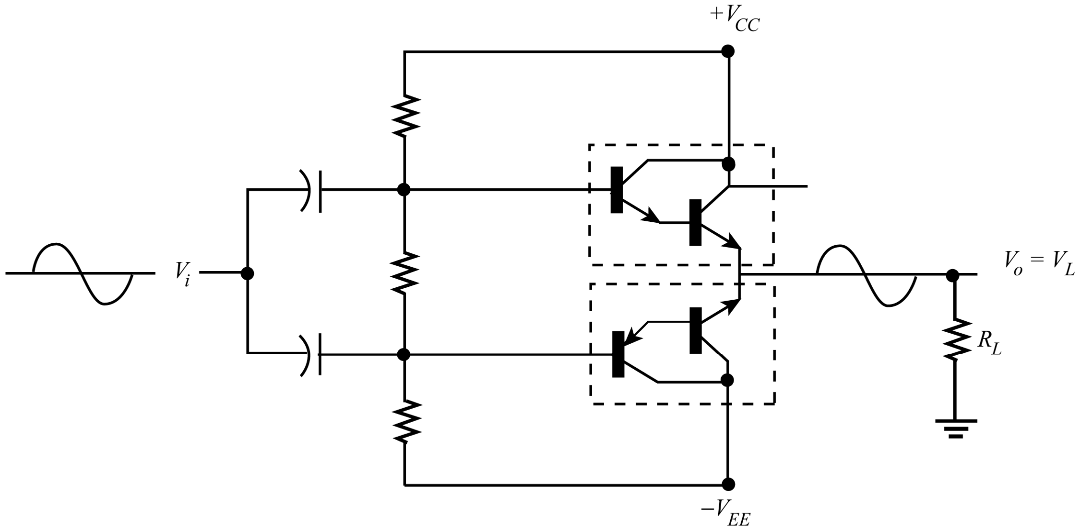
$\%\eta = \frac{P_o}{P_i} \times 100\% = \frac{50\text{ W}}{70\text{ W}} \times 100\%$ = **71.4%**

(b) $P_i = (22\text{ V})\left(\frac{2}{\pi}\cdot\frac{4\text{ V}}{4\ \Omega}\right)$ = 14 W

$P_o = \frac{(4)^2}{2(4)}$ = 2 W

$\%\eta = \frac{P_o}{P_i} \times 100\% = \frac{2\text{ W}}{14\text{ W}} \times 100\%$ = **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) $$P_i(\text{dc}) = V_{CC}I_{\text{dc}} = V_{CC}\cdot\left(\frac{2}{\pi}\ \frac{V_o}{R_L}\right)$$

$$= 30\text{ V}\cdot\left(\frac{2}{\pi}\ \frac{\sqrt{2}\cdot 8}{8}\right) = \mathbf{27\ W}$$

(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) $P_o(\text{ac}) = \dfrac{V_L^2(\text{rms})}{R_L} = \dfrac{(18\text{ V})^2}{8\ \Omega}$ = **40.5 W**

(b) $P_i(\text{dc}) = V_{CC}I_{\text{dc}} = V_{CC}\left(\dfrac{2}{\pi}\cdot\dfrac{V_{L_{\text{peak}}}}{R_L}\right)$

$= (40\text{ V})\left(\dfrac{2}{\pi}\cdot\dfrac{18\sqrt{2}\text{ V}}{8\ \Omega}\right)$ = **81 W**

(c) $\%\eta = \dfrac{P_o}{P_i}\times 100\% = \dfrac{40.5\text{ W}}{81\text{ W}}\times 100\%$ = **50%**

(d) $P_{2_Q} = P_i - P_o = 81\text{ W} - 40.5\text{ W}$ = **40.5 W**

19. $\%D_2 = \left|\dfrac{A_2}{A_1}\right|\times 100\% = \left|\dfrac{0.3\text{ V}}{2.1\text{ V}}\right|\times 100\% \cong$ **14.3%**

$\%D_3 = \left|\dfrac{A_3}{A_1}\right|\times 100\% = \dfrac{0.1\text{ V}}{2.1\text{ V}}\times 100\% \cong$ **4.8%**

$\%D_4 = \left|\dfrac{A_4}{A_1}\right|\times 100\% = \dfrac{0.05\text{ V}}{2.1\text{ V}}\times 100\% \cong$ **2.4%**

20. $\%THD = \sqrt{D_2^2 + D_3^2 + D_4^2}\times 100\%$

$= \sqrt{(0.143)^2 + (0.048)^2 + (0.024)^2}\times 100\%$

= **15.3%**

21. $D_2 = \left|\dfrac{\frac{1}{2}\left(V_{CE_{\max}} + V_{CE_{\min}}\right)}{V_{CE_{\max}} - V_{CE_{\min}}}\right|\times 100\%$

$= \left|\dfrac{\frac{1}{2}(20\text{ V} + 2.4\text{ V}) - 10\text{ V}}{20\text{ V} - 2.4\text{ V}}\right|\times 100\%$

$= \dfrac{1.2\text{ V}}{17.6\text{ V}}\times 100\%$ = **6.8%**

22. $THD = \sqrt{D_2^2 + D_3^2 + D_4^2} = \sqrt{(0.15)^2 + (0.01)^2 + (0.05)^2}$

$\cong 0.16$

$P_1 = \dfrac{I_1^2 R_C}{2} = \dfrac{(3.3\text{ A})^2(4\ \Omega)}{2}$ = **21.8 W**

$P = (1 + THD^2)P_1 = [1 + (0.16)^2]21.8\text{ W}$

= **22.36 W**

23. P_D (150°C) $= P_D(25°C) - (T_{150} - T_{25})$ (Derating Factor)

$= 100\text{ W} - (150°C - 25°C)(0.6\text{ W/°C})$

$= 100\text{ W} - 125(0.6) = 100 - 75$

$=$ **25 W**

24. $$P_D = \frac{T_J - T_A}{\theta_{JC} + \theta_{CS} + \theta_{SA}} = \frac{200°C - 80°C}{0.5\text{ °C/W} + 0.8\text{ °C/W} + 1.5\text{ °C/W}}$$

$$= \frac{120°C}{2.8\text{ °C/W}} = \mathbf{42.9\text{ W}}$$

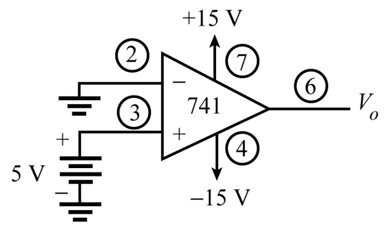
25. $$P_D = \frac{T_J - T_A}{\theta_{JA}}$$

$$= \frac{200°C - 80°C}{(40°C/W)} = \frac{120°C}{40°C/W}$$

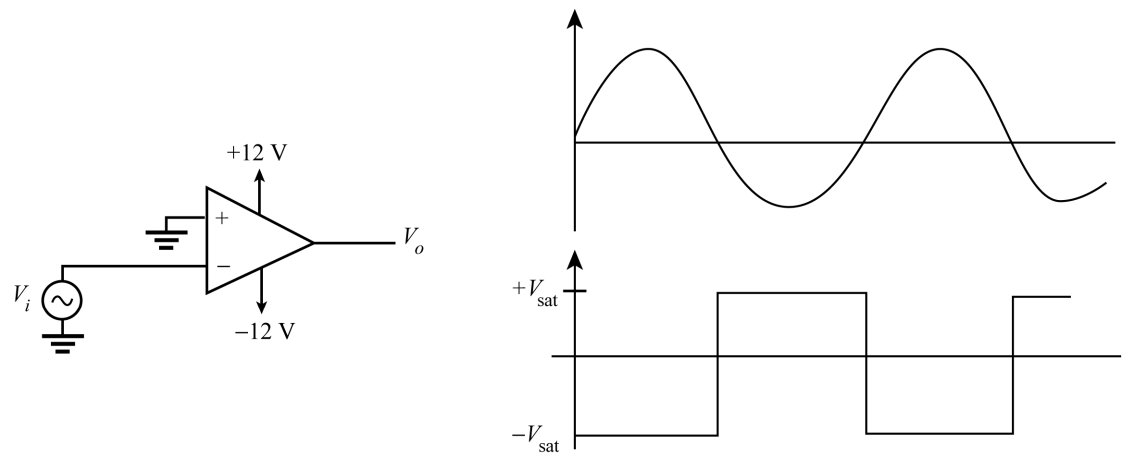
$=$ **3 W**

Chapter 13

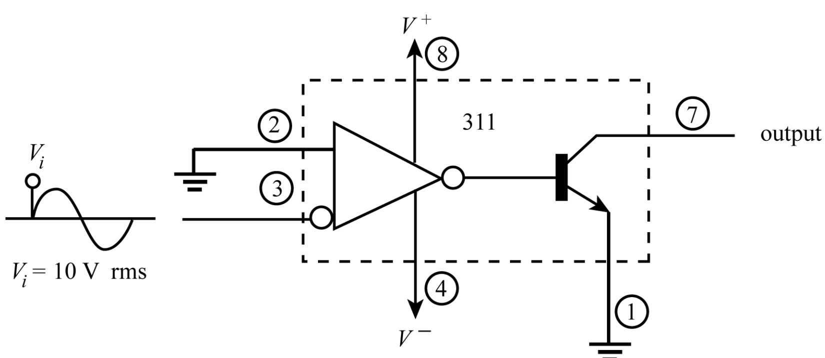
1.



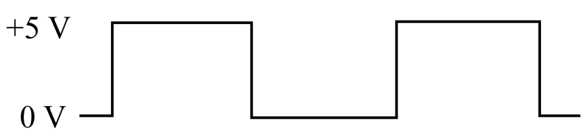
2.



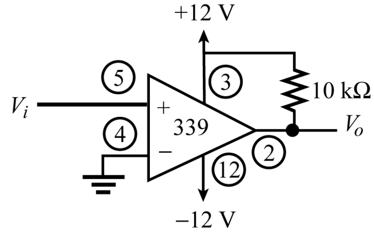
3.

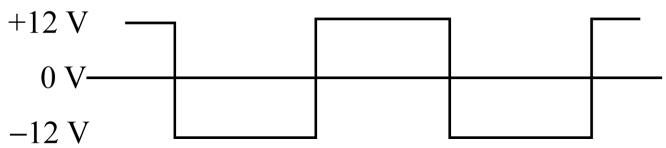


4.



5.



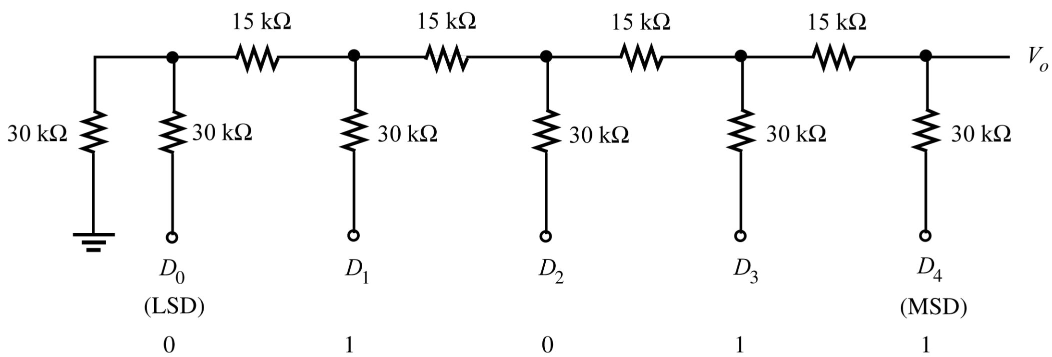
6. 

7. Circuit operates as a window detector.

Output goes *low* for input *above* $\frac{9.1\text{ k}\Omega}{9.1\text{ k}\Omega + 6.2\text{ k}\Omega}(+12\text{ V}) = \mathbf{7.1\ V}$

Output goes *low* for input *below* $\frac{1\text{ k}\Omega}{1\text{ k}\Omega + 6.2\text{ k}\Omega}(+12\text{ V}) = \mathbf{1.7\ V}$

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 = $\frac{V_{REF}}{2^n} = \frac{10\text{ V}}{2^{12}} = \frac{10\text{ V}}{4096} = \mathbf{2.4\ mV/count}$

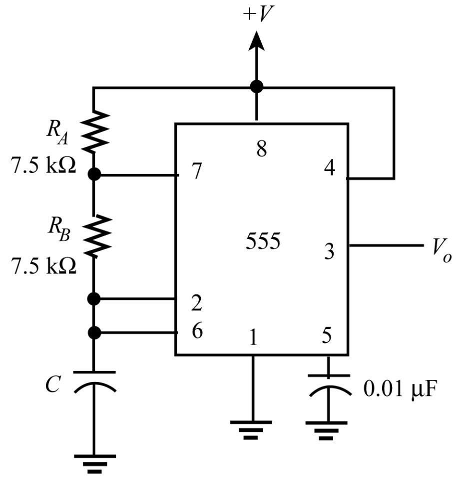
11. See section 13.3.

12. Maximum number of count steps = 2^{12} = **4096**

13. $2^{12} = 4096$ steps at $T = \frac{1}{f} = \frac{1}{20\text{ MHz}} = 50$ ns/count

Period = 4096 counts × $50\frac{\text{ns}}{\text{count}} = \mathbf{204.8\ \mu s}$

14.

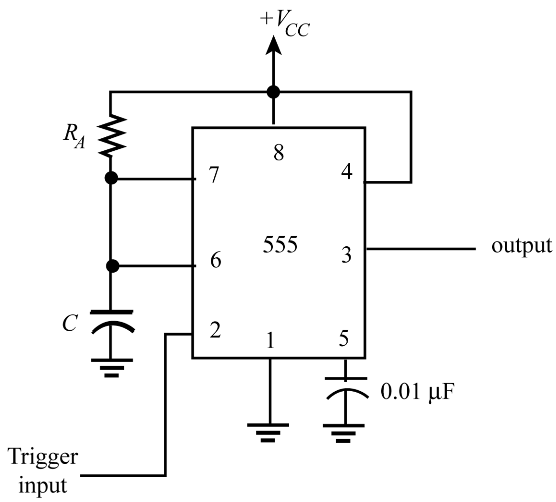


$$f = \frac{1.44}{(R_A + 2R_B)C} = 350\text{ kHz}$$

$$C = \frac{1.44}{7.5\text{ k}\Omega + 2(7.5\text{ k}\Omega)(350\text{ kHz})}$$

$\cong$ **183 pF**

15.



$T = 1.1\ R_A C$

$20\ \mu\text{s} = 1.1(7.5\text{ k}\Omega)C$

$$C = \frac{20\times10^{-6}}{1.1(7.5\times10^{3})}$$

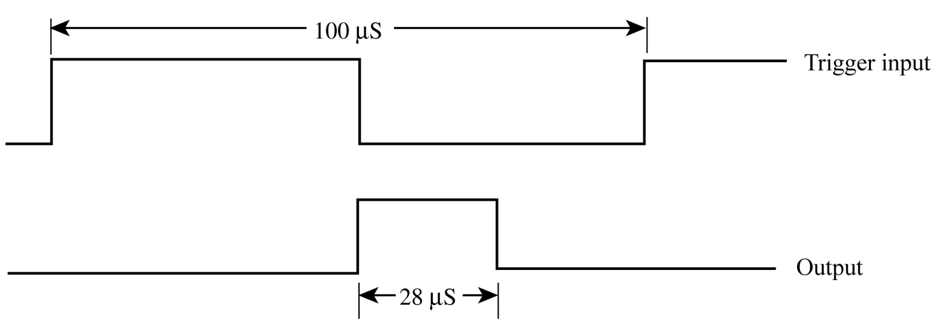
$= 2.4 \times 10^{-9}$

$= 2400 \times 10^{-12}$

= **2400 pF**

16. $T = \dfrac{1}{f} = \dfrac{1}{10\text{ kHz}} = 100\ \mu\text{s}$

$T = 1.1\ R_A C = 1.1(5.1\text{ k}\Omega)(5\text{ nF}) =$ **28 μs**



17. $f_o = \frac{2}{R_1C_1}\left(\frac{V^+ - V_C}{V^+}\right)$

$V^+ = 12$ V

$V_C = \frac{R_3}{R_2 + R_3}(V^+) = \frac{11\text{ k}\Omega}{1.8\text{ k}\Omega + 11\text{ k}\Omega}(+12\text{ V}) = 10.3\text{ V}$

$f_o = \frac{2}{(4.7\text{ k}\Omega)(0.001\ \mu\text{F})}\left(\frac{12\text{ V} - 10.3\text{ V}}{12\text{ V}}\right)$

$= 60.3 \times 10^3 \cong$ **60 kHz**

18. With potentiometer set at top:

$V_C = \frac{R_3 + R_4}{R_2 + R_3 + R_4}V^+ = \frac{5\text{ k}\Omega + 18\text{ k}\Omega}{510\ \Omega + 5\text{ k}\Omega + 18\text{ k}\Omega}(12\text{ V}) = 11.74\text{ V}$

resulting in a lower cutoff frequency of

$f_o = \frac{2}{R_1C_1}\left(\frac{V^+ - V_C}{V^+}\right) = \frac{2}{(10\times 10^3)(0.001\ \mu\text{F})}\left(\frac{12\text{ V} - 11.74\text{ V}}{12\text{ V}}\right)$

= **4.3 kHz**

With potentiometer set at bottom:

$V_C = \frac{R_4}{R_2 + R_3 + R_4}V^+ = \frac{18\text{ k}\Omega}{510\ \Omega + 5\text{ k}\Omega + 18\text{ k}\Omega}(12\text{ V})$

= 9.19 V

resulting in a higher cutoff frequency of

$f_o = \frac{2}{R_1C_1}\left(\frac{V^+ - V_C}{V^+}\right) = \frac{2}{(10\text{ k}\Omega)(0.001\ \mu\text{F})}\left(\frac{12\text{ V} - 9.19\text{ V}}{12\text{ V}}\right)$

= **61.2 kHz**

19. $V^+ = 12$ V

$V_C = \frac{R_3}{R_2 + R_3}V^+ = \frac{10\text{ k}\Omega}{1.5\text{ k}\Omega + 10\text{ k}\Omega}(12\text{ V}) = 10.4\text{ V}$

$f_o = \frac{2}{R_1C_1}\left(\frac{V^+ - V_C}{V^+}\right) = \frac{2}{10\text{ k}\Omega(C_1)}\left(\frac{12\text{ V} - 10.4\text{ V}}{12\text{ V}}\right)$

= 200 kHz

$C_1 = \frac{2}{10\text{ k}\Omega(200\text{ kHz})}(0.133)$

$= 133 \times 10^{-12} =$ **133 pF**

20. $f_o = \frac{0.3}{R_1C_1} = \frac{0.3}{(4.7\text{ k}\Omega)(0.001\ \mu\text{F})}$

= **63.8 kHz**

21. $C_1 = \frac{0.3}{R_1 f} = \frac{0.3}{(10\text{ k}\Omega)(100\text{ kHz})}$ = **300 pF**

22. $f_L = \pm \frac{8 f_o}{V}$

$= \pm \frac{8(63.8 \times 10^3)}{6\ \text{V}}$ $\qquad f_o = \frac{0.3}{R_1 C_1} = \frac{0.3}{4.7\ \text{k}\Omega(0.001\ \mu\text{F})}$

$= \mathbf{85.1\ kHz}$ $\qquad = 63.8\ \text{kHz}$

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. $$\frac{dA_f}{A_f} = \frac{1}{\beta A}\frac{dA}{A} = \frac{1}{-\frac{1}{20}\left(-1000\right)}(10\%) = \mathbf{0.2\%}$$

3. $$A_f = \frac{A}{1+\beta A} = \frac{-300}{1+\left(-\frac{1}{15}\right)(-300)} = \frac{-300}{21} = \mathbf{-14.3}$$

$R_{if} = (1 + \beta A)R_i = 21(1.5\text{ k}\Omega) = \mathbf{31.5\text{ k}\Omega}$

$$R_{of} = \frac{R_o}{1+\beta A} = \frac{50\text{ k}\Omega}{21} = \mathbf{2.4\text{ k}\Omega}$$

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:

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta+1)R_E} = \frac{16\text{ V} - 0.7\text{ V}}{600\text{ k}\Omega + 76(1.2\text{ k}\Omega)}$$

$$= \frac{15.3\text{ V}}{691.2\text{ k}\Omega} = 22.1\ \mu\text{A}$$

$I_E = (1 + \beta)I_B$

$= 76(22.1\ \mu\text{A}) = 1.68\text{ mA}$

$[V_{CE} = V_{CC} - I_C(R_C + R_E) = 16\text{ V} - 1.68\text{ mA}(4.7\text{ k}\Omega + 1.2\text{ k}\Omega) \cong 6.1\text{ V}]$

$$r_e = \frac{26\text{ mV}}{I_E(\text{mA})} = \frac{26\text{ mV}}{1.68\text{ mA}} \cong 15.5\ \Omega$$

$h_{ie} = (1 + \beta)r_e = 76(15.5\ \Omega) = \mathbf{1.18\text{ k}\Omega} = Z_i$

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

$$A_v = \frac{-h_{fe}}{h_{ie} + R_E} = \frac{-75}{1.18\ \text{k}\Omega + 1.2\ \text{k}\Omega} = -31.5 \times 10^{-3}$$

$\beta = R_E = -1.2 \times 10^3$

$(1 + \beta A) = 1 + (-1.2 \times 10^3)(-31.5 \times 10^{-3})$

$= 38.8$

$$A_f = \frac{A_v}{1 + \beta A_v} = \frac{-31.5 \times 10^{-3}}{38.8} = 811.86 \times 10^{-6}$$

$A_{v_f} = -A_f R_C = -(811.86 \times 10^{-6})(4.7 \times 10^3) = \mathbf{-3.82}$

$Z_{i_f} = (1 + \beta A_v)Z_i = (38.8)(1.18\ \text{k}\Omega) = \mathbf{45.8\ k\Omega}$

$Z_{o_f} = (1 + \beta A_v)Z_o = (38.8)(4.7\ \text{k}\Omega) = \mathbf{182.4\ k\Omega}$

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. $$f_o = \frac{1}{2\pi RC} \cdot \frac{1}{\sqrt{6 + 4\ \frac{R_c}{R}}}$$

$$= \frac{1}{2\pi(6 \times 10^3)(1500 \times 10^{-12})} \cdot \frac{1}{\sqrt{6 + 4(18 \times 10^3 / 6 \times 10^3)}}$$

$= 4.17\ \text{kHz} \cong \mathbf{4.2\ kHz}$

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. $f_o = \dfrac{1}{2\pi\sqrt{L_{eq}C}}$,

$L_{eq} = L_1 + L_2 + 2\,M$
$= 1.5\text{ mH} + 1.5\text{ mH} + 2(0.5\text{ mH})$
$= 4\text{ mH}$

$$= \frac{1}{2\pi\sqrt{(4\times10^{-3})(250\times10^{-12})}}$$

$= \mathbf{159.2\ kHz}$

12. $f_o = \dfrac{1}{2\pi\sqrt{LC_{eq}}}$,

where $L_{eq} = L_1 + L_2 + 2\,M$
$= 750\ \mu\text{H} + 750\ \mu\text{H} + 2(150\ \mu\text{H})$
$= 1800\ \mu\text{H}$

$$= \frac{1}{2\pi\sqrt{(1800\mu\text{H})(150\text{ pF})}}$$

$= 306.3\text{ kHz}$

13. See Fig. 14.33a and Fig. 14.34.

14. $f_o = \dfrac{1}{R_T C_T \ln(1/(1-\eta))}$

for $\eta = 0.5$:

$$f_o \cong \frac{1.5}{R_T C_T}$$

(a) Using $R_T = 1\text{ k}\Omega$

$$C_T = \frac{1.5}{R_T f_o} = \frac{1.5}{(1\text{ k}\Omega)(1\text{ kHz})} = \mathbf{1.5\ \mu F}$$

(b) Using $R_T = 10\text{ k}\Omega$

$$C_T = \frac{1.5}{R_T f_o} = \frac{1.5}{(10\text{ k}\Omega)(150\text{ kHz})} = \mathbf{1000\ pF}$$

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**

   $\cong$ **17 V**

8. $V_r = \dfrac{2.4I_{\text{dc}}}{C} = \dfrac{2.4(120)}{200}$ $=$ **1.44 V**

9. $C = 100\ \mu\text{F}$
   $\left.\begin{array}{l} V_{\text{dc}} = 12\text{ V} \\ R_L = 2.4\text{ k}\Omega \end{array}\right\}\quad I_{\text{dc}} = \dfrac{V_{\text{dc}}}{R_L} = \dfrac{12\text{ V}}{2.4\text{ k}\Omega} = 5\text{ mA}$

$V_r(\text{rms}) = \dfrac{2.4I_{dc}}{C} = \dfrac{2.4(5)}{100}$ = **0.12 V**

10. $C = \dfrac{2.4I_{dc}}{rV_{dc}} = \dfrac{2.4(150)}{(0.15)(24)}$ = **100 μF**

11. $C = 500\ \mu F$
$I_{dc} = 200$ mA
$R = 8\% = 0.08$

Using $r = \dfrac{2.4I_{dc}}{CV_{dc}}$

$V_{dc} = \dfrac{2.4I_{dc}}{rC} = \dfrac{2.4(200)}{0.08(500)} = 12$ V

$V_m = V_{dc} + \dfrac{4.17I_{dc}}{C} = 12\text{ V} + \dfrac{(200)(4.17)}{500}$
$= 12\text{ V} + 1.7\text{ V} =$ **13.7 V**

12. $C = \dfrac{2.4I_{dc}}{V_r} = \dfrac{2.4(200)}{(0.07)}$ = **6857 μF**

13. $C = 120\ \mu F$
$I_{dc} = 80$ mA
$V_m = 25$ V
$V_{dc} = V_m - \dfrac{4.17I_{dc}}{C} = 25\text{ V} - \dfrac{4.17(80)}{120}$
$= 22.2$ V

$\%r = \dfrac{2.4I_{dc}}{CV_{dc}} \times 100\% = \dfrac{2.4(80)}{(120)(22.2)} \times 100\%$
= **7.2%**

14. $V_r' = \dfrac{r \cdot V_{dc}'}{100} = \dfrac{2(80)}{100}$ = **1.6 V, rms**

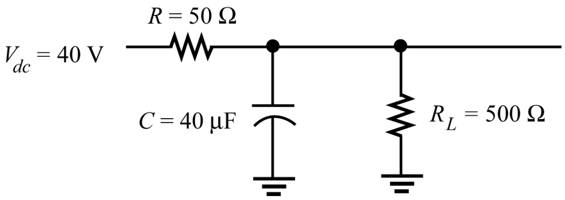
15. $V_r = 2$ V
$V_{dc} = 24$ V
***R* = 33 Ω, *C* = 120 μF**
$X_C = \dfrac{1.3}{C} = \dfrac{1.3}{120} = 10.8\ \Omega$

$V_r' = \dfrac{X_C}{R}V_r = \dfrac{10.8}{33}(2\text{ V}) = 0.65$ V
$V_{dc}' = V_{dc} - I_{dc}R = 24\text{ V} - 33\ \Omega\ (100\text{ mA})$
$= 20.7$ V

$\%r = \dfrac{V_r}{V_{dc}} \times 100\% = \dfrac{2\text{ V}}{24\text{ V}} \times 100\%$
= **8.3%**

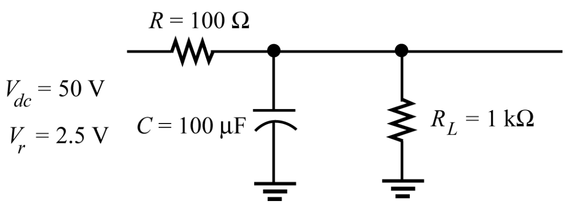
$$\%r' = \frac{V_r'}{V_{\text{dc}}'} \times 100\% = \frac{0.65\text{ V}}{20.7\text{ V}} \times 100\% = \mathbf{3.1\%}$$

16.



$$V_{\text{dc}}' = \frac{R_L}{R+R_L}V_{\text{dc}}$$
$$= \frac{500}{50+500}(40\text{ V})$$
$$= 36.4\text{ V}$$
$$I_{\text{dc}} = \frac{V_{\text{dc}}'}{R_L} = \frac{36.4\text{ V}}{500\ \Omega} = \mathbf{72.8\ mA}$$

17.



$$X_C = \frac{1.3}{C} = \frac{1.3}{100} = 13\ \Omega$$
$$V_r' = \frac{X_C}{R}V_r = \frac{13}{100}(2.5\text{ V})$$
$$= \mathbf{0.325\ V,\ rms}$$

18. $V_{NL} = 60$ 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. $V_o = V_Z - V_{BE} = 8.3\text{ V} - 0.7\text{ V} = \mathbf{7.6\ V}$

$V_{CE} = V_i - V_o = 15\text{ V} - 7.6\text{ V} = 7.4\text{ V}$

$$I_R = \frac{V_i - V_Z}{R} = \frac{15\text{ V} - 8.3\text{ V}}{1.8\text{ k}\Omega} = 3.7\text{ mA}$$
$$I_L = \frac{V_o}{R_L} = \frac{7.6\text{ V}}{2\text{ k}\Omega} = 3.8\text{ mA}$$
$$I_B = \frac{I_C}{\beta} = \frac{3.8\text{ mA}}{100} = 38\ \mu\text{A}$$

$I_Z = I_R - I_B = 3.7 \text{ mA} - 38\ \mu\text{A} = \mathbf{3.66\ mA}$

20. $V_o = \frac{R_1 + R_2}{R_2}(V_z + V_{BE_2})$

$= \frac{33\text{ k}\Omega + 22\text{ k}\Omega}{22\text{ k}\Omega}(10\text{ V} + 0.7\text{ V})$

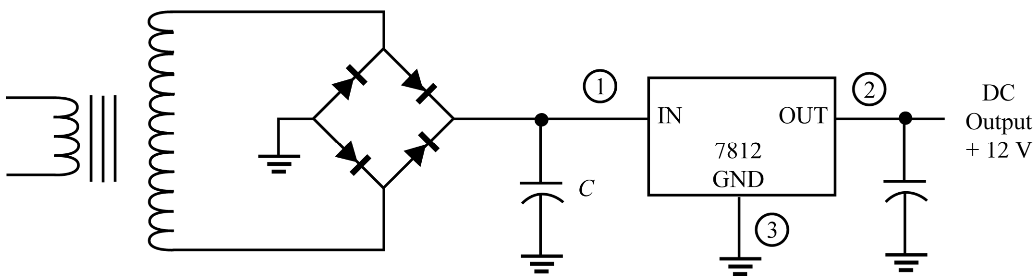
$=$ **26.75 V**

21. $V_o = \; 1+\frac{R_1}{R_2} \; V_Z = \; 1+\frac{12\text{ k}\Omega}{8.2\text{ k}\Omega} \; 10\text{ V}$

$=$ **24.6 V**

22. $V_o = V_L = 10\text{ V} + 0.7\text{ V} =$ **10.7 V**

23.



24. $I_L = 250\text{ mA}$

$V_m = V_r(\text{rms}) \cdot \sqrt{2} = \sqrt{2}\,(20\text{ V}) = 28.3\text{ V}$

$V_{r_{\text{peak}}} = \sqrt{3}\,V_r(\text{rms}) = \sqrt{3}\;\frac{2.4I_{\text{dc}}}{C}$

$= \sqrt{3}\;\frac{2.4(250)}{500} = 2.1\text{ V}$

$V_{\text{dc}} = V_m - V_{r_{\text{peak}}} = 28.3\text{ V} - 2.1\text{ V} = 26.2\text{ V}$

$V_i(\text{low}) = V_{\text{dc}} - V_{r_{\text{peak}}} = 26.2\text{ V} - 2.1\text{ V} =$ **24.1 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

$I_{\text{dc}} = \frac{V_r(\text{rms})C}{2.4} = \frac{(2.7\text{ V})(200)}{2.4} =$ **225 mA**

26. $V_o = V_{\text{ref}}\left(1+\frac{R_2}{R_1}\right) + I_{\text{adj}}R_L$

$= 1.25\text{ V}\left(1+\frac{1.8\text{ k}\Omega}{240\ \Omega}\right) + 100\ \mu\text{A}(2.4\text{ k}\Omega)$

$= 1.25\text{ V}(8.5) + 0.24\text{ V}$

= 10.87 V

27. $V_o = V_{\text{ref}}\left(1+\frac{R_2}{R_1}\right) + I_{\text{adj}}\,R_2$

$= 1.25\text{ V}\left(1+\frac{1.5\text{ k}\Omega}{220\ \Omega}\right) + 100\ \mu\text{A}(1.5\text{ k}\Omega)$

= 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. –

6. (a) $V_F \cong$ **0.7 V**
   (b) $V_F \cong$ **0.5 V**
   (c) As $T\uparrow$, $V_F\downarrow$

7. $$C_D \cong 6.2\ \text{pF},\ X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(1\ \text{MHz})(6.2\ \text{pF})} = \mathbf{25.67\ k\Omega}$$

8. (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) $k = C_T(V_T + V_R)^n$

$= 41.85 \text{ pF}(0.7\ \underbrace{\text{V} + 4.2}_{1.698}\ \text{V})^{1/3}$

$\cong \mathbf{71 \times 10^{-12}}$

9. (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.

10. 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**

11. $C_t \cong 15$ 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

12. $TC_C = \dfrac{\Delta C}{C_o(T_1 - T_0)} \times 100\% \Rightarrow T_1 = \dfrac{\Delta C \times 100\%}{TC_C(C_o)} + T_o$

$= \dfrac{(0.11 \text{ pF})(100)}{(0.02)(22 \text{ pF})} + 25$

= **50°C**

13. 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**

14. $Q(-1\text{ V}) = 82$, $Q(-10\text{ V}) = 5000$

$$\text{Ratio} = \frac{Q(-10\text{ V})}{Q(-1\text{ V})} = \frac{5000}{82} = 60.98$$

$$BW = \frac{f_o}{Q} = \frac{10\times10^6\text{ Hz}}{82} = \mathbf{121.95\ kHz}$$

$$BW = \frac{f_o}{Q} = \frac{10\times10^6\text{ Hz}}{5000} = \mathbf{2\ kHz}$$

15. $$C_t \cong 55\text{ pF},\ C_T = \frac{C_t C_C}{C_t + C_C} = \frac{(55\text{ pF})(40\text{ pF})}{55\text{ pF} + 40\text{ pF}} = 23.16\text{ pF}$$

$$f_r = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{(2\text{mH})(23.16\text{ pF})}} \cong \mathbf{739.5\ kHz}$$

16. $$\eta\% = \frac{P_{\max}}{(A_{\text{cm}^2})(100\text{ mW/cm}^2)} \times 100\%$$

$$9\% = \frac{P_{\max}}{(2\text{ cm}^2)(100\text{ mW/cm}^2)} \times 100\%$$

$P_{\max}$ = **18 mW**

17. 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.

18. (a) $$\frac{\Delta I_{SC}}{\Delta f_c} = \frac{100\text{ mA}}{2(20f_c) - 20f_c} = \frac{100\text{ mA}}{20f_c} = \mathbf{5\ mA}/f_c$$

(b) At $f_{c_1} = 20f_c$, x $I_{SC_1} = 100$ mA

$\Delta I_{SC} = (5\text{ mA}/f_c)(\Delta f_c) = (5\text{ mA}/f_c)(8f_c) = 40$ mA

$I_{SC} = I_{SC_1} + 40$ mA = 100 mA + 40 mA = **140 mA**

19. (a) $\Delta V_{OC} = 0.57\text{ V} - 0.54\text{ V} = 0.03\text{ V}$

$$\frac{\Delta V_{OC}}{\Delta f_c} = \frac{0.03\text{ V}}{80f_c} = \mathbf{0.375\ mV}/f_c$$

(b) $\Delta V_{OC} = (0.375\text{ mV}/f_c)(\Delta f_c) = (0.375\text{ mV}/f_c)(20f_c) = 7.5$ mV

V_{OC} = 0.54 V + 7.5 mV = **547.5 mV**

20. (a) At knee, $I_{SC} \cong$ **90 mA,** $V_{OC} \cong$ **0.5 V**

At $V_{OC} = 0$ V, I_{SC} = **100 mA**

At $I_{SC} = 0$ A, V_{OC} = **0.56 V**

(b) Plotting $P = VI$ we find $P_{\max} = VI = (0.5\text{ V})(90\text{ mA})$ = **45 mW**

(c) $P_{\max}$ = 45 mW vs. $P = VI =$ (0.5 V)(180 mA) = **90 mW** for f_{c_2}

21. (a) $W = \dfrac{\hbar \nu}{\lambda} = \dfrac{(6.624 \times 10^{-34}\text{ Js})(3 \times 10^{8}\text{ m/s})}{470\text{ nm(blue)}}$ **= 422.81 × 10^{-21} J**

(b) $W = \dfrac{\hbar \nu}{\lambda} = \dfrac{(6.624 \times 10^{-3}\text{ Js})(3 \times 10^{8}\text{ m/s})}{650\text{ nm(red)}}$ **= 305.72 × 10^{-21} J**

(c) yes

(d) Yes, higher energy level.

(e) Low wavelength of emitted light has high energy content.

22. $\dfrac{4 \times 10^{-9}\text{ W/m}^2}{1.609 \times 10^{-12}} = 2{,}486\, f_c$

From the intersection of V_A = 30 V and 2,486 f_c we find

$I_\lambda \cong$ **440 μA**

23. 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
$V_R = I_\lambda R = (500 \times 10^{-6}\text{ A})(100 \times 10^{3}\ \Omega)$ = **50 V**

24. Drawing a straight line approximation to the curve through the intersection of the axis will result in

$$m = \frac{\Delta y}{\Delta x} = \frac{200\ \mu\text{A}}{1000 f_c} = 0.2\ \mu\text{A}/f_c$$

$y = mx + b \quad I_\lambda \quad (0.2\ \mu\text{A}/f_c)(f_c) \quad 0$

I_λ = **(0.2 μA/f_c)(f_c)**

25. (a) Extending the curve:

0.1 kΩ → 1000f_c, 1 kΩ → 25f_c

$\dfrac{\Delta R}{\Delta f_c} = \dfrac{(1 - 0.1) \times 10^{3}\ \Omega}{(1000 - 25) f_c}$ **= 0.92 Ω/f_c ≅ 0.9 Ω/f_c**

(b) 1 kΩ → 25f_c, 10 kΩ → 1.3f_c

$\dfrac{\Delta R}{\Delta f_c} = \dfrac{(10 - 1) \times 10^{3}\ \Omega}{(25 - 1.3) f_c}$ **= 379.75 Ω/f_c ≅ 380 Ω/f_c**

(c) $10\text{ k}\Omega \rightarrow 1.3f_c$, $100\text{ k}\Omega \rightarrow 0.15f_c$

$$\frac{\Delta R}{\Delta f_c} = \frac{(100-10)\times 10^3}{(1.3-0.15)f_c} = \mathbf{78{,}260.87\ \Omega/f_c \cong 78\times 10^3\ \Omega/f_c}$$

The greatest rate of change in resistance occurs in the low illumination region.

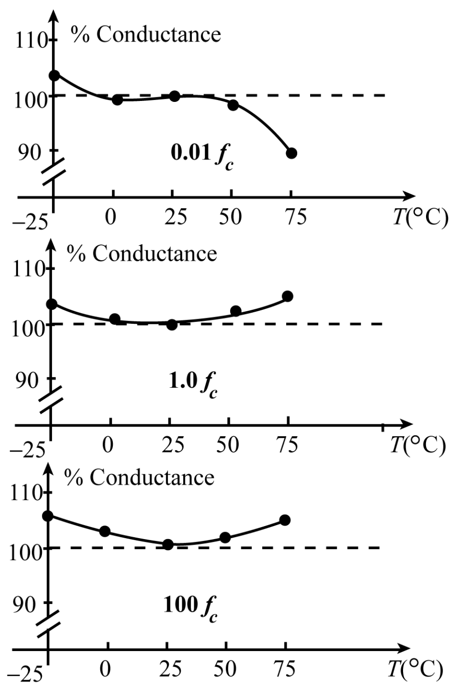
26. The "dark current" of a photodiode is the diode current level when no light is striking the diode. It is essentially the reverse saturation leakage current of the diode, comprised mainly of minority carriers.

27. $10f_c \rightarrow R \cong 2\text{ k}\Omega$

$$V_o = 6\text{ V} = \frac{(2\times 10^3\ \Omega)V_i}{2\times 10^3\ \Omega + 5\times 10^3\ \Omega}$$

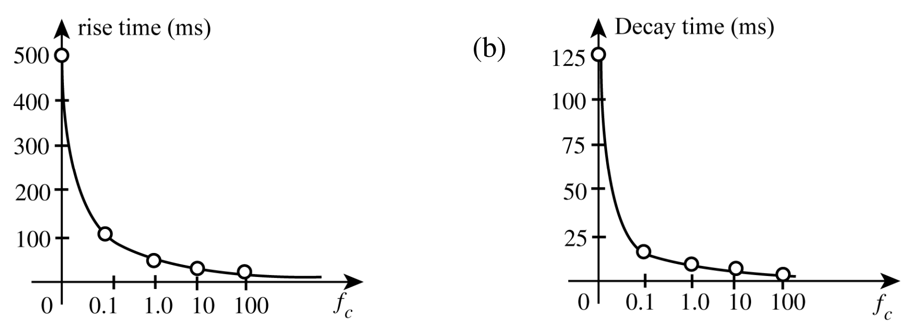
$V_i = \mathbf{21\ V}$

28.



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.

29. (a) (b)



(c) Increased levels of illumination result in reduced rise and decay times.

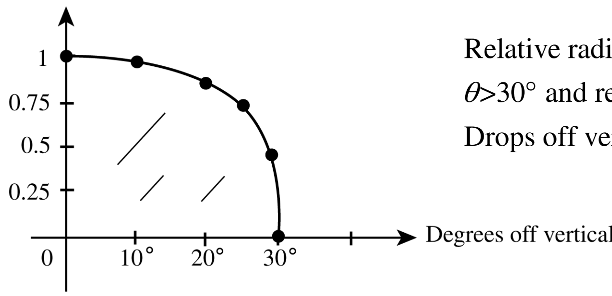
30. The highest % sensitivity occurs between 5250A and 5750A. Fig 16.20 reveals that the CdS unit would be most sensitive to *yellow*. The % sensitivity of the CdS unit of Fig. 16.30 is at the 30% level for the range 4800Å → 7000Å. This range includes green, yellow, and orange in Fig. 16.20.

31. (a) ≅ **5 mW** radiant flux

(b) ≅ 3.5 mW $\dfrac{3.5 \text{ mW}}{1.496\times10^{-13} \text{ W/lm}}$ = $\mathbf{2.34\times10^{10}}$ **lms**

32. (a) Relative radiant intensity ≅ **0.8**.

(b)



Relative radiant vs degrees off vertical

θ>30° and relative radiant intensity essentially zero-

Drops off very sharply after 25°!

33. At I_F = 60 mA, Φ ≅ 4.4 mW
At 5°, relative radiant intensity = 0.8
(0.8)(4.4 mW) = **3.52 mW**

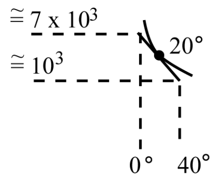
34. 6, 7, 8

35. –

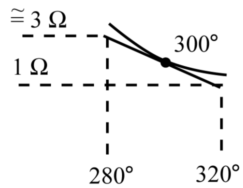
36. The LED generates a light source in response to the application of an electric voltage. The LCD depends on ambient light to utilize the change in either reflectivity or transmissivity caused by the application of an electric voltage.

37. 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.

38. Since log scales are present, the differentials must be as small as possible.



$$\frac{\Delta R}{\Delta T} = \frac{(7000 - 1000)\Omega}{(40 - 0)^\circ} = \frac{6000\ \Omega}{40^\circ} = 150\ \Omega/^\circ\text{C}$$



$$\frac{\Delta R}{\Delta T} = \frac{(3 - 1)\Omega}{40^\circ} = \frac{2\ \Omega}{40^\circ} = 0.05\ \Omega/^\circ\text{C}$$

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.

39. No. 1 Fenwall Electronics Thermistor material.
Specific resistance $\cong 10^4$ = 10,000 Ω cm

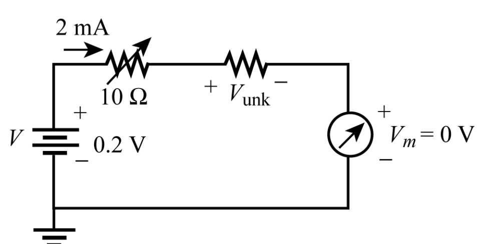
$R = \frac{\rho \ell}{A}$ 2x (twice) $\quad \therefore R = 2 \times (10{,}000\ \Omega) =$ **20 kΩ**

40. (a) $\cong 10^{-5}$ A = **10 μA**

(b) Power ≅ **0.1 mW**, $R \cong 10^7$ Ω = **10 MΩ**

(c) Log scale ≅ **0.3 mW**

41.



$V = IR + IR_{\text{unk}} + V_m$
$V = I(R + R_{\text{unk}}) + 0\ \text{V}$

$$\begin{aligned} R_{\text{unk}} &= \frac{V}{I} - R \\ &= \frac{0.2\ \text{V}}{2\ \text{mA}} - 10\ \Omega \\ &= 100\ \Omega - 10\ \Omega \\ &= \mathbf{90\ \Omega} \end{aligned}$$

42. 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.

43. At 1 MHz: $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(1\times10^6 \text{ Hz})(5\times10^{-12} \text{ F})}$

$= \mathbf{31.83\ k\Omega}$

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: $X_{L_S} = 2\pi fL = 2\pi(1 \times 10^6 \text{ Hz})(6 \times 10^{-9} \text{ H})$

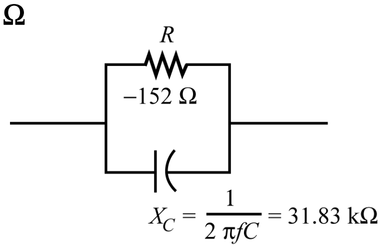
$= \mathbf{0.0337\ \Omega}$

At 100 MHz: $X_{L_S} = 2\pi(100 \times 10^6 \text{ Hz})(6 \times 10^{-9} \text{ H})$

$= \mathbf{3.769\ \Omega}$

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!

44. 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.

45. At V_T = 0.1 V,
$I_F \cong 5.5$ mA
At V_T = 0.3 V
$I_F \cong 2.3$ mA

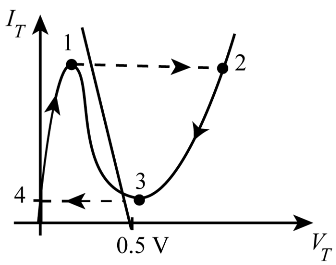
$$R = \frac{\Delta V}{\Delta I} = \frac{0.3\text{ V} - 0.1\text{ V}}{2.3\text{ mA} - 5.5\text{ mA}}$$
$$= \frac{0.2\text{ V}}{-3.2\text{ mA}} = \mathbf{-62.5\ \Omega}$$

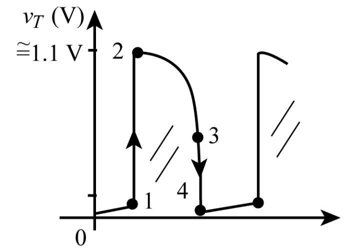
46. $I_{\text{sat}} = \dfrac{E}{R} = \dfrac{2\text{ V}}{0.39\text{ k}\Omega} \cong 5.13$ mA

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**

47. $I_{sat} = \frac{E}{R} = \frac{0.5\text{ V}}{51\ \Omega} = 9.8\text{ mA}$

Draw load line on characteristics.





48. $$f_s = \frac{1}{2\pi\sqrt{LC}}\sqrt{1-\frac{R_l^2 C}{L}}$$

$$= \frac{1}{2\pi\sqrt{(5\times10^{-3}\text{ H})(1\times10^{-6}\text{ F})}}\sqrt{1-\frac{(10\ \Omega)^2(1\times10^{-6}\text{ F})}{5\times10^{-3}\text{ H}}}$$

$= (2250.79\text{ Hz})(0.9899)$

$\cong$ **2228 Hz**

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) $V_P = \dfrac{V_{\text{sec}}(\text{rms})}{2}\sqrt{2}$

   $= \dfrac{117\text{ V}}{2}\left(\sqrt{2}\right) = 82.78\text{ V}$

   $V_{DC} = 0.636(82.78\text{ V})$
   $= \mathbf{52.65\ V}$

   (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) $V_2 \cong \frac{1}{2}V_P = \frac{1}{2}(82.78\text{ V}) = \mathbf{41.39\ V}$

9. (a) Full-wave rectified waveform with peak value of 168.28 V

(b) $P = VI \quad 100\text{ W} \quad (0.707)(168.28\text{ V})(I_{\text{rms}})$
$I_{\text{rms}} = 840.5\text{ mA}, \; I_{\text{peak}} = \mathbf{1.19\ A}$

(c) **1.19 A**

(d) $t_r = \frac{1}{4}T = \frac{1}{4} \; \frac{1}{60\text{ Hz}} \; = \mathbf{4.17\ ms}$

(e) $\tau = RC(510\text{ k}\Omega)(0.1\ \mu\text{F}) = \mathbf{51\ ms}$

(f) open

(g) dc level established = 0.636 (V_{peak}) = 0.636(168.28 V) $\cong$ 107 V
$\upsilon_C = 107\text{ V}(1 - e^{-t/51\text{ ms}}) = 40\text{ V}$
t = **23.86 ms**

(h) turn on

(g) forced commutation

10. (a) $V_{\text{peak}} = (1.414)(6.3\text{ V}) = 8.91\text{ V}$
V_{peak} across 6 V lamp = 8.91 V − 0.7 V = **8.21 V**

(b) $V_{R_2} = \frac{150\ \Omega(6\text{ V})}{150\ \Omega + 1\text{ k}\Omega} = 0.783\text{ V}$
$V_{C_1(\text{peak})} = 8.21\text{ V} - 0.783\text{ V} = \mathbf{7.43\ V}$

(c) V_{peak} = 8.21 V − 0.7 V − 5 V = **2.51 V**

(d) V_{lamp} = 6 V

(e) $P = VI = \quad 2\text{ W} = (6\text{ V})(I)$
$I = \frac{2\text{ W}}{6\text{ V}} = \mathbf{0.333\ A}$

11. –

12. Negative pulse at the cathode terminal.

13. (a) $V_{GK} = -12\text{ V} + V_R',\ V_R' = \dfrac{R'(24\text{ V})}{R' + R_S}$

$$\therefore V_{GK} = -12\text{ V} + \frac{R'(24\text{ V})}{R' + R_S}$$

(b) $R_S = R'$, $V_{GK} = 0$ V, scs off

(c) $V_{GK} = 2\text{ V} = -12\text{ V} + \dfrac{10\text{ k}\Omega(24\text{ V})}{10\text{ k}\Omega + R_S}$

R_S = **14 kΩ**

(d) $I = \dfrac{12\text{ V}}{200\ \Omega}$ = **60 mA**

(e) $I = \dfrac{12\text{ V}}{100\text{ k}\Omega}$ = **0.12 mA**

(f) Inductive element in alarm could establish spikes. Use protective capacitive element.

14. (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) $\tau = R_3C_1 = (20\text{ k}\Omega)(0.1\ \mu\text{F})$
$= 2$ ms
5τ = **10 ms**

(c) $5\tau' = \dfrac{1}{2}(5\tau) = 5\text{ ms} = 5R_{GTO}C_1$

$R_{GTO} = \dfrac{5\text{ ms}}{5C_1} = \dfrac{5\text{ ms}}{5(0.1\times10^{-6}\text{ F})}$ = **10 kΩ** $= \dfrac{1}{2}(20\text{ k}\Omega -$ above)

15. (a) ≅ **0.7 mW/cm²**

(b) $0°\text{C} \rightarrow 0.82\text{ mW/cm}^2$
$100°\text{C} \rightarrow 0.16\text{ mW/cm}^2$
$\dfrac{0.82 - 0.16}{0.82} \times 100\% \cong$ **80.5%**

16. $V_C = V_{BR} + V_{GK} = 6\text{ V} + 3\text{ V} = 9\text{ V}$

$V_C = 40(1 - e^{-t/RC}) = 9$

$40 - 40e^{-t/RC} = 9$

$40e^{-t/RC} = 31$

$e^{-t/RC} = 31/40 = 0.775$

$RC = (10 \times 10^3\ \Omega)(0.2 \times 10^{-6}\text{ F}) = 2 \times 10^{-3}\text{ s}$

$\log_e(e^{-t/RC}) = \log_e 0.775$

$-t/RC = -t/2 \times 10^{-3} = -0.255$

and $t = 0.255(2 \times 10^{-3}) =$ **0.51 ms**

17. –

18. $V_{BR_1} = V_{BR_2} \pm 10\%\ V_{BR_2}$

$= 6.4\text{ V} \pm 0.64\text{ V} \Rightarrow$ **5.76 V → 7.04 V**

19. $$\mathbf{V_G} = \frac{(1\text{ M}\Omega - jX_{C_b})V_i\angle 0°}{10\text{ M}\Omega + 1\text{ M}\Omega - jX_{C_b}} = \frac{(1\text{ M}\Omega - jX_{C_b})V_i\angle 0°}{11\text{ M}\Omega - jX_{C_b}}$$

For 45° shift in denominator $X_{C_b} = 11\text{ M}\Omega$. In the numerator the result is $1\text{ M}\Omega - j11\text{ M}\Omega \cong -j11\text{ M}\Omega = 11\text{ M}\Omega\angle -90°$.

$$\therefore \mathbf{V_G} = \frac{(11\text{ M}\Omega\angle -90°)(V_i\angle 0°)}{15.56\text{ M}\Omega\angle -45°} = 0.707V_i\angle -45°$$

$\therefore$ A 45° shift is established with $X_{C_b} = 11\text{ M}\Omega$

$$X_{C_B} = \frac{1}{2\pi f C_b} \quad C_b \quad \frac{1}{2\pi f X_C} \quad \frac{1}{2\pi(60\text{ Hz})(11\text{ M}\Omega)} \quad \mathbf{241\,pF}$$

20. $$\mathbf{V_{X_C}} = \frac{(X_C\angle -90°)(170\text{ V}\angle 0°)}{R - jX_C} = 12\text{ V}\angle\theta$$

$$\frac{(X_C)((170\text{ V})(\angle -90°)}{\sqrt{R^2 + X_C^2}\angle -\theta'} = 12\text{ V}\angle\theta$$

$$\frac{\therefore (X_C)(170\text{ V})}{\sqrt{R^2 + X_C^2}} = 12\text{ V}$$

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi(60\text{ Hz})(1\ \mu\text{F})} = 2.65\text{ k}\Omega$$

$$\frac{(2.65\text{ k}\Omega)(170\text{ V})}{\sqrt{R^2 + (2.65\text{ k}\Omega)^2}} = 12\text{ V}$$

$R =$ **25.25 kΩ**

21. $\dfrac{V - V_P}{I_P} > R_1$

$\dfrac{40\text{ V} - [0.6(40\text{ V}) + 0.7\text{ V}]}{10 \times 10^{-6}}$ = **1.53 MΩ** > R_1

$\dfrac{V - V_V}{I_V} < R_1 \Rightarrow \dfrac{40\text{ V} - 1\text{ V}}{8\text{ mA}}$ = 4.875 kΩ < R_1

∴ **1.53 MΩ > R_1 > 4.875 kΩ**

22. (a) $\eta = \dfrac{R_{B_1}}{R_{B_1} + R_{B_2}\big|_{I_E=0}} \Rightarrow 0.65 = \dfrac{2\text{ k}\Omega}{2\text{ k}\Omega + R_{B_2}}$ R_{B_2} = **1.08 kΩ**

(b) $R_{BB} = \left(R_{B_1} + R_{B_2}\right)\big|_{I_E=0}$ = 2 kΩ + 1.08 kΩ = **3.08 kΩ**

(c) $V_{R_{B_1}} = \eta V_{BB}$ = 0.65(20 V) = **13 V**

(d) $V_P = \eta V_{BB} + V_D$ = 13 V + 0.7 V = **13.7 V**

23. (a) $\eta = \dfrac{R_{B_1}}{R_{BB}}\Big|_{I_E=0}$

$0.55 = \dfrac{R_{B_1}}{10\text{ k}\Omega}$

R_{B_1} = **5.5 kΩ**

$R_{BB} = R_{B_1} + R_{B_2}$

10 kΩ = 5.5 kΩ + R_{B_2}

R_{B_2} = **4.5 kΩ**

(b) $V_P = \eta V_{BB} + V_D$ = (0.55)(20 V) + 0.7 V = **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 kΩ

ok: 68 kΩ < 166 kΩ

(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 ms

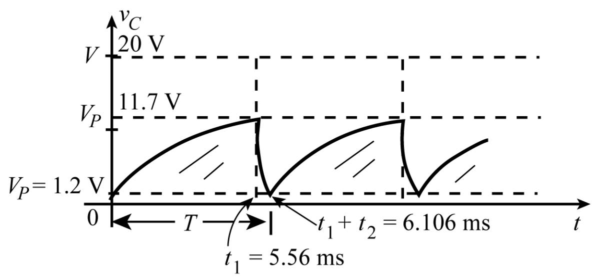
$t_2 = (R_{B_1} + R_2)\, C \log_e \dfrac{V_P}{V_V} = (0.2\text{ k}\Omega + 2.2\text{ k}\Omega)(0.1 \times 10^{-6}) \log_e \dfrac{11.7}{1.2}$

= 0.546 ms

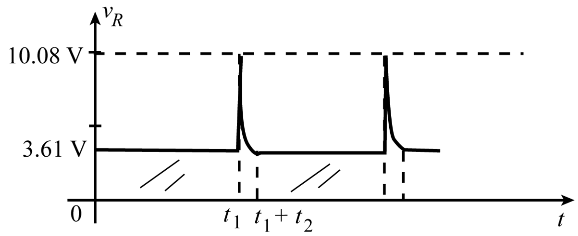
$T = t_1 + t_2$ = 6.106 ms

$f = \dfrac{1}{T} = \dfrac{1}{6.106\text{ ms}}$ = **163.77 Hz**

(e)



(f)



$$V_{R_2} = \frac{R_2 V}{R_2 + R_{BB}} = \frac{2.2\text{ k}\Omega(20\text{ V})}{2.2\text{ k}\Omega + 10\text{ k}\Omega}$$

$= \mathbf{3.61\ V}$

$$V_{R_2} \cong \frac{R_2(V_P - 0.7\text{ V})}{R_2 + R_{B_1}}$$

$$= \frac{2.2\text{ k}\Omega(11.7\text{ V} - 0.7\text{ V})}{2.2\text{ k}\Omega + 0.2\text{ k}\Omega}$$

$= \mathbf{10.08\ V}$

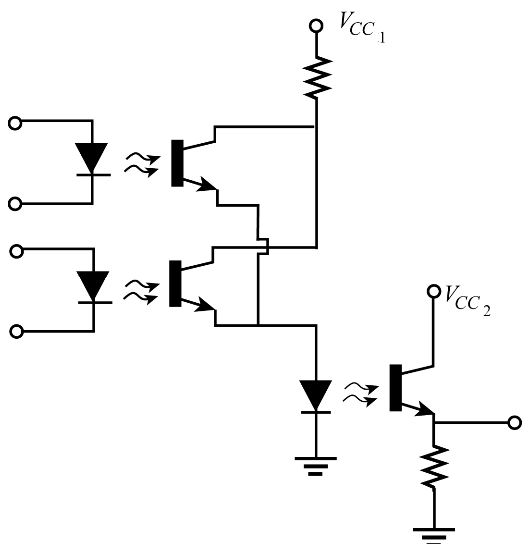
(g) $$f \cong \frac{1}{R_1 C\ \log_e(1/(1-\eta))} = \frac{1}{(6.8\text{ k}\Omega)(0.1\ \mu\text{F})\log_e 2.22} = \mathbf{184.16\ Hz}$$

difference in frequency levels is partly due to the fact that $t_2 \cong 10\%$ of t_1.

24. $I_B = \mathbf{25\ \mu A}$

$I_C = h_{f_e} I_B = (40)(25\ \mu\text{A}) = \mathbf{1\ mA}$

25.



26. (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.

27. (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.

28. $\dfrac{I_o}{I_i} = \dfrac{I_C}{I_F} = \dfrac{20\text{ mA}}{\cong 45\text{ mA}} = \mathbf{0.44}$

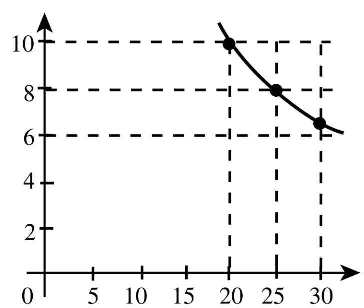
Yes, relatively efficient.

29. (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) $\beta_{dc} = \dfrac{I_C}{I_F} = \dfrac{4\text{ mA}}{10\text{ mA}} = \mathbf{0.4}$, Fig. 17.56 $\dfrac{I_C}{I_F} \cong \dfrac{4\text{ mA}}{10\text{ mA}} = \mathbf{0.4}$

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.

30. (a) $I_C \geq$ **3 mA**

(b) At $I_C = 6$ mA; $R_L = 1$ kΩ, $t = 8.6\ \mu$s
$R_L = 100$ Ω; $t = 2\ \mu$s
1 kΩ:100 Ω = 10:1
8.6 μs:2 μs = 4.3:1
ΔR:$\Delta t \cong$ **2.3:1**

31. $\eta = \dfrac{3R_{B_2}}{3R_{B_2} + R_{B_2}} = \dfrac{3}{4}$ = **0.75**, $V_G = \eta V_{BB} = 0.75(20\text{ V})$ = **15 V**

32. $V_P = 8.7$ V, $I_P = 100\ \mu$A $\qquad Z_P = \dfrac{V_P}{I_P} = \dfrac{8.7\text{ V}}{100\ \mu\text{A}}$ = **87 kΩ** (≅ open)

$V_V = 1$ V, $I_V = 5.5$ mA $\qquad Z_V = \dfrac{V_V}{I_V} = \dfrac{1\text{ V}}{5.5\text{ mA}}$ = **181.8 Ω** (relatively low)

87 kΩ: 181.8 Ω = 478.55:1 ≅ **500:1**

33. 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

34. (a) Minimum V_{BB}:

$$R_{max} = \frac{V_{BB} - V_P}{I_P} \geq 20\text{ k}\Omega$$

$$\frac{V_{BB} - (\eta V_{BB} + V_D)}{I_P} = 20\text{ k}\Omega$$

$$V_{BB} - \eta V_{BB} - V_D = I_P\, 20\text{ k}\Omega$$

$$V_{BB}(1 - \eta) = I_P\, 20\text{ k}\Omega + V_D$$

$$V_{BB} = \frac{I_P\, 20\text{ k}\Omega + V_D}{1 - \eta}$$

$$= \frac{(100\ \mu\text{A})(20\text{ k}\Omega) + 0.7\text{ V}}{1 - 0.67}$$

$$= \mathbf{8.18\text{ V}}$$

10 V OK

(b) $R < \frac{V_{BB} - V_V}{I_V} = \frac{12\text{ V} - 1\text{ V}}{5.5\text{ mA}} = 2\text{ k}\Omega$

$R <$ **2 kΩ**

(c) $T \cong RC \log_e \left(1 + \frac{R_{B_1}}{R_{B_2}}\right)$

$$2 \times 10^{-3} = R(1 \times 10^{-6})\underbrace{\log_e \left(1 + \frac{10\text{ k}\Omega}{5\text{ k}\Omega}\right)}_{\log_e 3 = 1.0986}$$

$$R = \frac{2 \times 10^{-3}}{(1 \times 10^{-6})(1.0986)}$$

$R =$ **1.82 kΩ**