Instructor's Resource Manual to accompany

# Electronic Devices and Circuit Theory

## Eighth Edition

**Containing Solutions to Problems in Text**
**Solutions to Laboratory Experiments**
**Test Item File**

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# Contents

Chapter 1. (Odd)

1. 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.

3. 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).

5. $\rho \cong 50 \times 10^3\ \Omega\cdot\text{cm}\ (Si)$, $\rho \cong 10^{-6}\ \Omega\cdot\text{cm}\ (Cu)$

(a) $R = \rho\dfrac{l}{A} = (50\times10^3\ \Omega\cdot\text{cm})\dfrac{(3\text{cm})}{(1\text{cm}^2)} = \underline{150\text{k}\Omega}$

(b) $R = \rho\dfrac{l}{A} = (50\times10^3\ \Omega\cdot\text{cm})\dfrac{(1\text{cm})}{(4\text{cm}^2)} = \underline{12.5\text{k}\Omega}$

(c) $R = \rho\dfrac{l}{A} = (50\times10^3\ \Omega\cdot\text{cm})\dfrac{(8\text{cm})}{(0.5\text{cm}^2)} = \underline{800\text{k}\Omega}$

(d) $R = \rho\dfrac{l}{A} = (10^{-6}\ \Omega\cdot\text{cm})\dfrac{(3\text{cm})}{(1\text{cm}^2)} = \underline{3\mu\Omega}$

$R_{Si} : R_{Cu} = \underline{50\times10^9 : 1}$

7. 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 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.

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

11. GaP Gallium Phosphide $E_g = 2.24\text{eV}$

ZnS Zinc Sulfide $E_g = 3.67\text{eV}$

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

15. Same basic appearance as Fig. 1.9 since Arsenic also has 5 valence electrons(pentavalent).

17. --

19. For forward bias, the <u>p</u>ositive potential is applied to the <u>p</u>-type material and the <u>n</u>egative potential to the <u>n</u>-type material.

21. $k = 11{,}600/\eta = 11{,}600/2 = 5800$ ($\eta = 2$ for $V_D = 0.6\text{V}$)

$T_K = T_C + 273 = 100 + 273 = 373$

$e^{kV/T_K} = e^{\frac{(5800)(0.6\text{V})}{373}} = e^{9.33} = 11.27\times10^3$

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

23. (a)

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

(b) $y = e^0 = \underline{1}$

(c) For $V = 0V$, $e^0 = 1$ and $I = I_s(1-1) = \underline{0 mA}$

25. 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.

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

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

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

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

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

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

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

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

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

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

$R_{DC} >> r_d$

33. $I_D = 1mA$, $r_d = 2\left(\frac{26mV}{I_D}\right) = 2(26\Omega) = \underline{52\Omega}$ vs $55\Omega$ (#32)

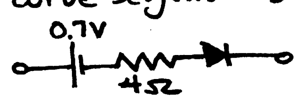
$I_D = 15mA$, $r_d = \frac{26mV}{I_D} = \frac{26mV}{15mA} = \underline{1.73\Omega}$ vs. $2\Omega$ (#32)

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

(relatively close to average value of $24.4\Omega$ (#34))

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

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



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

41. Log scale: $T_A = 25°C$, $I_R = \underline{0.5nA}$

$T_A = 100°C$, $I_R = \underline{60nA}$

The change is significant $60nA : 0.5nA = \underline{120:1}$

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

43. $T = 25°C$: $P_{max} = 500mW$

$T = 100°C$: $P_{max} = 260mW$

$P_{max} = V_F I_F$

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

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

$714.29mA : 371.43mA = \underline{1.92:1} \cong \underline{2:1}$

45. (a) $V_R = -25V$: $C_T \cong \underline{0.75pF}$

$V_R = -10V$: $C_T \cong \underline{1.25pF}$

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

(b) $V_R = -10V$: $C_T \cong \underline{1.25pF}$

$V_R = -1V$: $C_T \cong \underline{3pF}$

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

(c) $0.194pF/V : 0.033pF/V = \underline{5.88:1} \cong \underline{6:1}$

Increased sensitivity near $V_D = 0V$

47. 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.

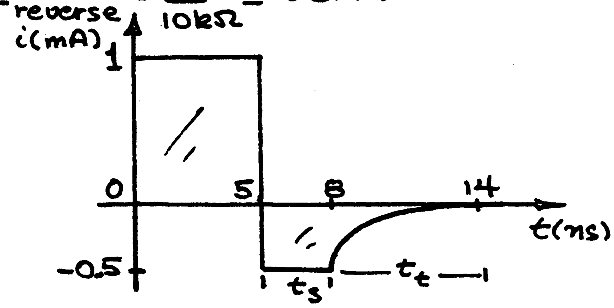
49. $I_f = \dfrac{10V}{10k\Omega} = 1mA$ $\quad I_{reverse} = \dfrac{5V}{10k\Omega} = 0.5mA$

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

$t_s + 2t_s = 9ns$

$t_s = \underline{3ns}$

$t_t = 2t_s = \underline{6ns}$



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

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

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

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

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

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

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

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

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

The 5V Zener is therefore ≅ 44% of the distance between 3.6V and 6.8V measured from the 3.6V characteristic.

At $I_Z = 0.1\text{mA}$, $T_C \cong \underline{-0.025\%/°C}$

55. 24V Zener:

$0.2\text{mA}: \cong 400\Omega$

$1\text{mA}: \cong 95\Omega$

$10\text{mA}: \cong 13\Omega$

the steeper the curve (higher dI/dV) the less the dynamic resistance.

57. Fig. 1.55 (f) $I_F \cong 13\text{mA}$

Fig. 1.55 (e) $V_F \cong \underline{2.3\text{V}}$

59. a. $1\text{ms} = 1000\mu\text{s}$, $f = 300\text{Hz}$

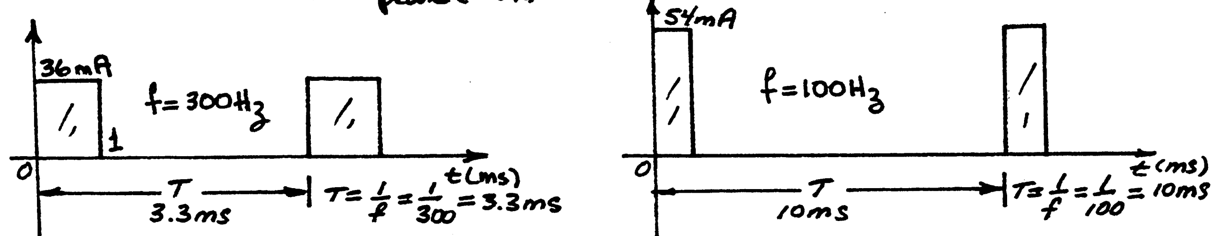
From Fig. 1.55(h) $\dfrac{I_{peak\,(max)}}{I_{dc\,(max)}} = 1.8$

$\therefore I_{peak\,(max)} = 1.8\, I_{dc\,(max)} = 1.8(20\text{mA}) = \underline{36\text{mA}}$

b. $1\text{ms} = 1000\mu\text{s}$, $f = 100\text{Hz}$

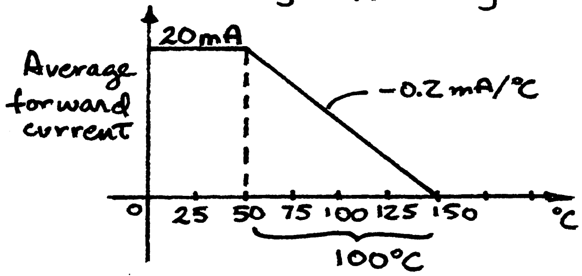
From Fig. 1.55(h) $\dfrac{I_{peak\,(max)}}{I_{dc\,(max)}} \cong 2.7$

$\therefore I_{peak\,(max)} = 2.7\, I_{dc\,(max)} = 2.7(20\text{mA}) = \underline{54\text{mA}}$




The plots above reveal that for the same duration pulse, the lower the frequency the higher the permitted current for the duration of the pulse — concurring with our expectations.

61. For the high efficiency red unit of Fig. 1.55:




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

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

Chapter 1. (even)

2. In the forward-bias region the 0V 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.

4. Semiconductor: materials with conduction characteristics lying between those of a conductor and insulator. Typically materials whose conduction level is a function of the "doping" levels.

Resistivity: that characteristic of materials that will determine level of opposition to the flow of charge (current) through the material.

Bulk resistance: (from additional reading and section 1.7) the actual resistance of a semiconductor material.

Ohmic contact resistance: (from additional reading and section 1.7) the resistance introduced by the connection between the metal lead and the semiconductor material.

6. Copper has 29 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.

8. —

10. $48\text{eV} = 48(1.6\times10^{-19}\text{J}) = 76.8\times10^{-19}\text{J}$

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

$6.4\times10^{-19}$C is the charge associated with 4 electrons

12. 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 then 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.

14. 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.

16. Same basic appearance as Fig. 1.11 since Boron also has 3 valence electrons (trivalent).

18. --

20. $T_K = 20 + 273 = 293$

$k = 11{,}600/\eta = 11{,}600/2$ (low value of $V_D$) $= 5800$

$$I_D = I_s(e^{kV_D/T_K} - 1) = 50\times10^{-9}(e^{\frac{(5800)(0.6)}{293}} - 1)$$

$$= 50\times10^{-9}(e^{11.877} - 1) = \underline{7.197\,mA}$$

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

$k = 11{,}600/\eta = 11{,}600/2 = 5800$

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

$$= 0.1\times10^{-6}(e^{-197.95} - 1) = 0.1\times10^{-6}(1.07\times10^{-86} - 1)$$

$$\cong 0.1\times10^{-6} = 0.1\mu A$$

and $I_D = I_s = \underline{0.1\mu A}$

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

24.

$T = 20°C$ : $I_s = 0.1\mu A$

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

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

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

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

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

26. From Fig. 1.24:

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

$V_F$ decreased with increase in temperature

$1.7V : 0.65V \cong \underline{2.6:1}$

$I_s$ increased with increase in temperature

$2\mu A : 0.1\mu A = \underline{20:1}$

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

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

As the forward diode current increases the static resistance decreases.

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

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

(c) quite close

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

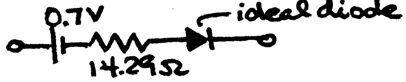
$I_D = 15mA$, $r_d = \dfrac{\Delta V_d}{\Delta I_d} = \dfrac{0.8V - 0.78V}{20mA - 10mA} = \underline{2\Omega}$

34.

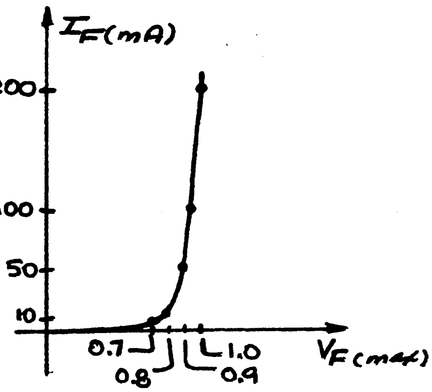
$$r_{av} = \frac{\Delta V_d}{\Delta I_d} = \frac{0.9V - 0.6V}{13.5mA - 1.2mA} = \underline{24.4\Omega}$$

36.

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




38.




40. At $V_D = -25V$, $I_D = -0.2nA$ and at $V_D = -100V$, $I_D \cong -0.45nA$
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.

42. $I_F = 0.1mA$: $r_d \cong \underline{700\Omega}$
$I_F = 1.5mA$: $r_d \cong \underline{70\Omega}$
$I_F = 20mA$: $r_d \cong \underline{6\Omega}$
The results support the fact that the dynamic or ac resistance decreases rapidly with increasing current levels.

44. Using the bottom right graph of Fig. 1.36:
$I_F = 500mA$ @ $T = 25°C$
At $I_F = 250mA$, $T \cong \underline{104°C}$

46. From Fig. 1.37:
$V_D = 0V$, $C_D = \underline{3.3pF}$
$V_D = 0.25V$, $C_D = \underline{9pF}$

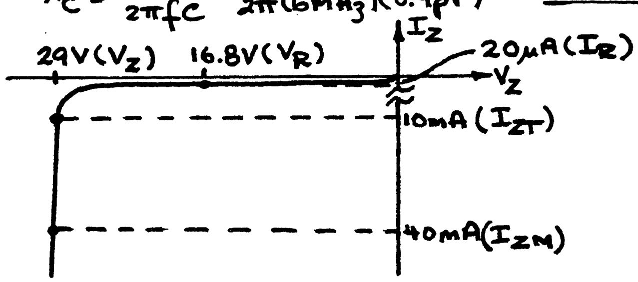
48. $V_D = 0.2V$, $C_D = 7.3pF$

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

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

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

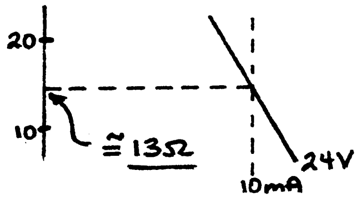
50.



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

$= \dfrac{(5V - 4.8V)}{5V(100° - 25°)} \times 100\% = \underline{0.053\%/°C}$

54.




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

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

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

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

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

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

ratio $\dfrac{1.42}{1.38} = \underline{1.03}$

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

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

From Fig. 1.55(i) $\measuredangle \cong \underline{75°}$

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

Chapter 2 (odd)

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

(a) $V_{D_Q} \cong \underline{0.92V}$

$I_{D_Q} \cong \underline{21.5mA}$

$V_R = E - V_{D_Q} = 8V - 0.92V = \underline{7.08V}$

(b) $V_{D_Q} = \underline{0.7V}$

$I_{D_Q} \cong \underline{22.2mA}$

$V_R = E - V_{D_Q} = 8V - 0.7V = \underline{7.3V}$

(c) $V_{D_Q} = \underline{0V}$

$I_{D_Q} = \underline{24.24mA}$

$V_R = E - V_{D_Q} = 8V - 0V = \underline{8V}$

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

3. Load line through $I_{D_Q} = 10mA$ of characteristics and $V_D = 7V$ will intersect $I_D$ axis at 11.25 mA.

$$I_D = 11.25mA = \frac{E}{R} = \frac{7V}{R}$$

$$\text{with } R = \frac{7V}{11.25mA} = \underline{0.62k\Omega}$$

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

(b) $V_{20\Omega} = 20V - 0.7V = 19.3V$ (Kirchhoff's voltage law)

$$I = \frac{19.3V}{20\Omega} = \underline{0.965A}$$

(c) $I = \frac{10V}{10\Omega} = \underline{1A}$; center branch open

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

$$= \frac{1}{2}(20V - 1V) = \frac{1}{2}(19V) = \underline{9.5V}$$

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

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

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

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

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

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

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

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

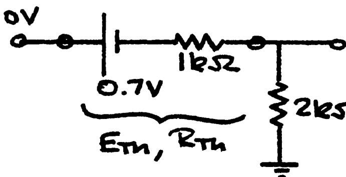
$$I = \frac{10V - 0.3V}{1k\Omega} = \frac{9.7V}{1k\Omega} = \underline{9.7mA}$$

$$V_o = 10V - 0.3V = \underline{9.7V}$$

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

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

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




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

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

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

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

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

19. 0V at one Terminal is "more positive" than −5V at the other input Terminal. Therefore assume lower diode "on" and upper diode "off". The result:

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

The result supports the above assumptions.

21. The Si diode requires more Terminal voltage than the Ge diode To Turn "on". Therefore, with 5V at both input Terminals, assume Si diode "off" and Ge diode "on".

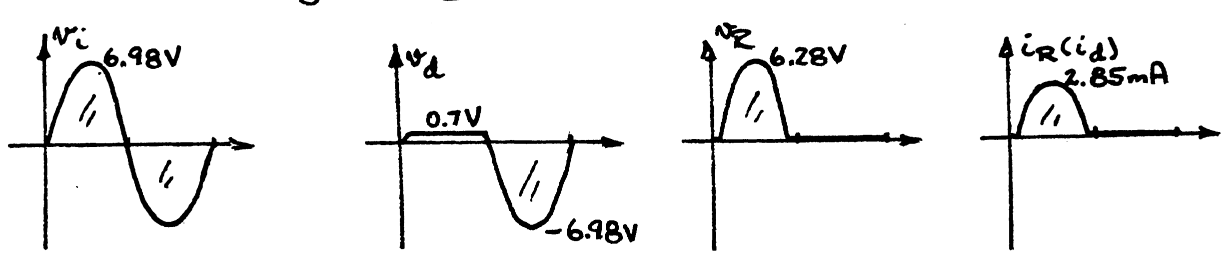
The result: $V_o = 5V - 0.3V = \underline{4.7V}$

The result supports the above assumptions.

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

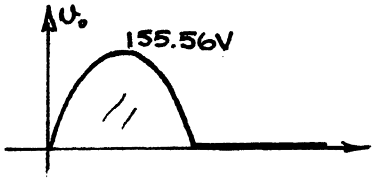
$$2V = 0.318(V_m - 0.7V)$$

Solving: $V_m = \underline{6.98V} \cong 10:1$ for $V_m : V_T$



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

$V_{dc} = 0.318\,V_m = 0.318(155.56V) = \underline{49.47V}$




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

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

(b) $4.7k\Omega \| 56k\Omega = 4.34k\Omega$

$V_R = 160V - 0.7V = 159.3V$

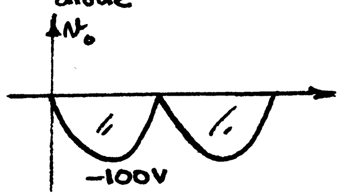
$$I_{max} = \frac{159.3V}{4.34k\Omega} = \underline{36.71mA}$$

(c) $I_{diode} = \dfrac{I_{max}}{2} = \dfrac{36.71mA}{2} = \underline{18.36mA}$

(d) yes $I_D = 20mA > 18.36mA$

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

29.




$PIV = \underline{100V}$

31. Positive pulse of $v_i$:

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

$2.2k\Omega \| 2.2k\Omega = 1.1k\Omega$

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

Negative pulse of $v_i$:

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

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

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

33. (a) Positive pulse of $v_i$:

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

Negative pulse of $v_i$:

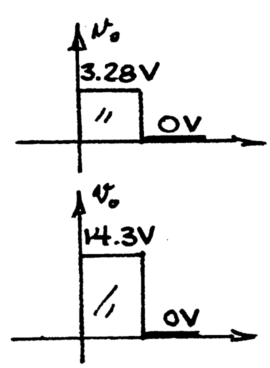
diode "open", $v_o = 0V$

(b) Positive pulse of $v_i$:

$V_o = 10V - 0.7V + 5V = 14.3V$

Negative pulse of $v_i$:

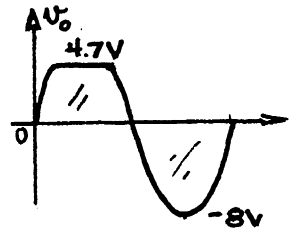
diode "open", $v_o = 0V$



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

For $v_i > 4.7V$, $V_o = 4V + 0.7V = 4.7V$

For $v_i < 4.7V$, diode "off" and $v_o = v_i$




(b) Again, diode "on" for $v_i \geq 4.7V$ but $v_o$ now defined as the voltage across the diode

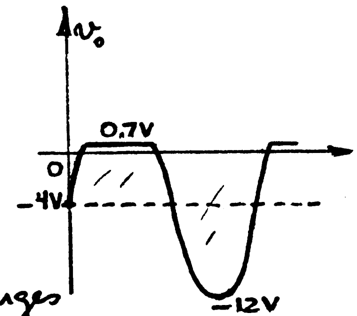
For $v_i \geq 4.7V$, $v_o = 0.7V$

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

therefore, $v_o = v_i - 4V$

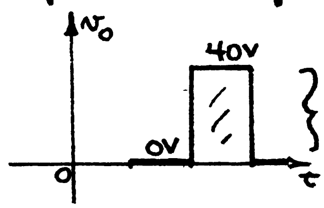
at $v_i = 0V$, $v_o = -4V$

$v_i = -8V$, $v_o = -8V - 4V = -12V$




37 (a) Starting with $v_i = -20V$, the diode is in the "on" state and the capacitor quickly charges to $-20V+$. During this interval of time $v_o$ is across the "on" diode (short-circuit equivalent) and $v_o = 0V$

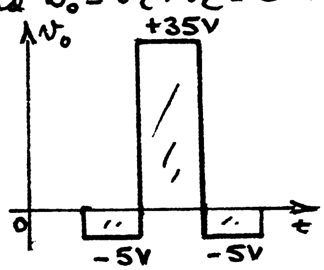
When $v_i$ switches to the +20V level the diode enters the "off" state (open-circuit equivalent) and $v_o = v_i + v_C = 20V + 20V = +40V$




} Total swing of $v_o$ = Total swing of $v_i$

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

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




} 40V swing (= that of $v_i$)

39. (a) $\tau = RC = (56\,k\Omega)(0.1\,\mu F) = 5.6\,ms$

$5\tau = \underline{28\,ms}$

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

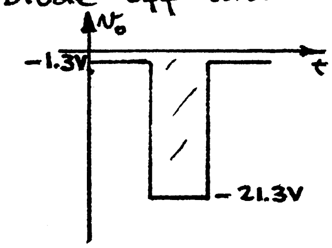
(c) Positive pulse of $v_i$:

Diode "on" and $V_o = -2V + 0.7V = -1.3V$

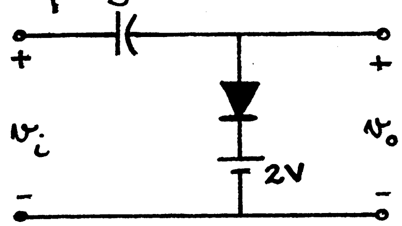
Capacitor charges to $10V + 2V - 0.7V = 11.3V$

Negative pulse of $v_i$:

Diode "off" and $V_o = -10V - 11.3V = -21.3V$




41. Network of Fig. 2.161 with 2V battery reversed.




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

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

$720 + 12R_s = 960$

$12R_s = 240$

$R_s = \underline{20\Omega}$

(b) $P_{Z_{max}} = V_Z I_{Z_{max}}$

$= (12V)(200mA)$

$= \underline{2.4W}$

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

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

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

At 50V $I_{R_s} = \frac{50V - 20V}{0.5k\Omega} = 60mA$, $I_L = \frac{20V}{1k\Omega} = 20mA$

$I_{ZM} = I_{R_s} - I_L = 60mA - 20mA = \underline{40mA}$

47. $V_m = 1.414(120V) = 169.68V$

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

## Chapter 2 (Even)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

6. (a) Diode forward-biased,

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

$V_o = \underline{-4.3V}$

$I_R = I_D = \frac{|V_o|}{R} = \frac{4.3V}{2.2k\Omega} = \underline{1.955mA}$

(b) Diode forward-biased,

$I_D = \frac{8V - 0.7V}{1.2k\Omega + 4.7k\Omega} = \underline{1.24mA}$

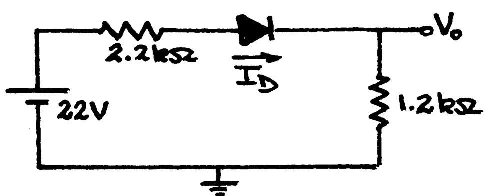
$V_o = V_{4.7k\Omega} + V_D = (1.24mA)(4.7k\Omega) + 0.7V$

$= \underline{6.53V}$

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

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

$R_{Th} = 2.2k\Omega$




Diode forward-biased

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

$V_o = I_D(1.2k\Omega)$

$= (6.26mA)(1.2k\Omega)$

$= \underline{7.51V}$

(b) Diode forward-biased

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

Kirchhoff's voltage law: (CW)

$$+V_o - 0.7\text{V} + 5\text{V} = 0$$
$$V_o = \underline{-4.3\text{V}}$$

10. (a) Both diodes forward-biased.

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

Assuming identical diodes:

$$I_D = \frac{I_R}{2} = \frac{4.106\text{mA}}{2} = \underline{2.05\text{mA}}$$
$$V_o = 20\text{V} - 0.7\text{V} = \underline{19.3\text{V}}$$

(b) Right diode forward-biased:

$$I_D = \frac{15\text{V} + 5\text{V} - 0.7\text{V}}{2.2\text{k}\Omega} = \underline{8.77\text{mA}}$$
$$V_o = 15\text{V} - 0.7\text{V} = \underline{14.3\text{V}}$$

12. Both diodes forward-biased,

$$V_{o_1} = \underline{0.7\text{V}},\ V_{o_2} = \underline{0.3\text{V}}$$
$$I_{1\text{k}\Omega} = \frac{20\text{V} - 0.7\text{V}}{1\text{k}\Omega} = \frac{19.3\text{V}}{1\text{k}\Omega} = 19.3\text{mA}$$
$$I_{0.47\text{k}\Omega} = \frac{0.7\text{V} - 0.3\text{V}}{0.47\text{k}\Omega} = 0.851\text{mA}$$
$$I(\text{Si diode}) = I_{1\text{k}\Omega} - I_{0.47\text{k}\Omega}$$
$$= 19.3\text{mA} - 0.851\text{mA}$$
$$= \underline{18.45\text{mA}}$$

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

$$V_o = \underline{0\text{V}}$$

16. Both diodes "on".

$$V_o = \underline{0.7\text{V}}$$

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

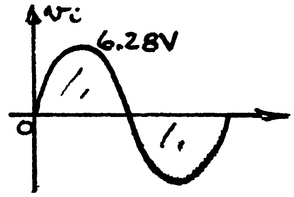
$$V_o = -5\text{V} + 0.7\text{V} = \underline{-4.3\text{V}}$$

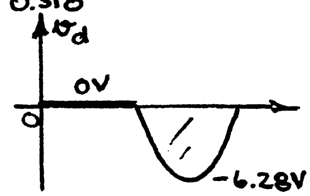
20. Since all the system terminals are at 10V the required difference of 0.7V across either diode cannot be established. Therefore, both diodes are "off" and

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

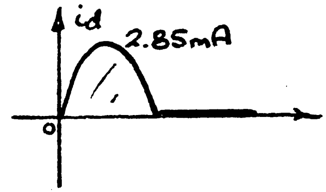
as established by 10V supply connected to 1kΩ resistor.

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

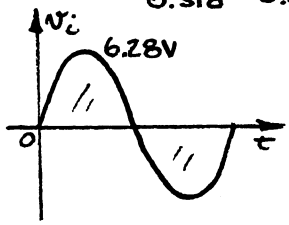


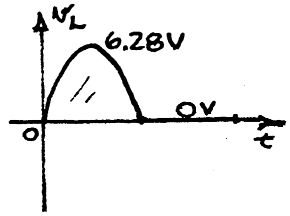



$$I_m = \frac{V_m}{R} = \frac{6.28\text{V}}{2.2\text{k}\Omega} = 2.85\text{mA}$$

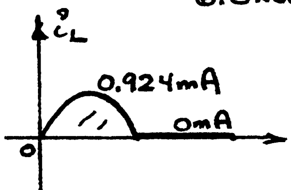



24. $V_m = \frac{V_{dc}}{0.318} = \frac{2\text{V}}{0.318} = 6.28\text{V}$



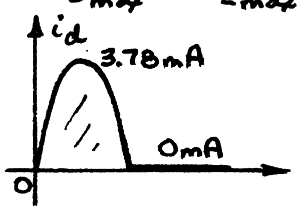




$$I_{L_{max}} = \frac{6.28\text{V}}{6.8\text{k}\Omega} = 0.924\text{mA}$$




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

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




26. Diode will conduct when $v_o = 0.7\text{V}$, that is,

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

Solving: $v_i = 0.77\text{V}$

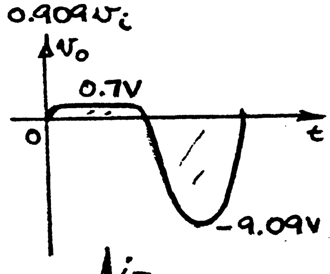
For $v_i \geq 0.77\text{V}$ Si diode is "on" and $v_o = 0.7\text{V}$

For $v_i < 0.77\text{V}$ Si diode open and level of $v_o$ determined by voltage divider rule:

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

For $v_i = -10\text{V}$:

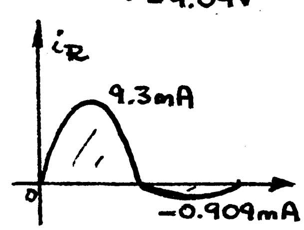
$$v_o = 0.909(-10\text{V}) = -9.09\text{V}$$




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

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

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



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

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

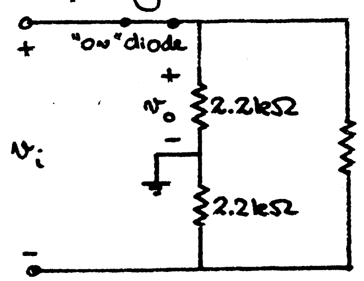
(b) $\text{PIV} = V_m(\text{load}) + V_D = 168.3\text{V} + 0.7\text{V} = \underline{169\text{V}}$

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

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

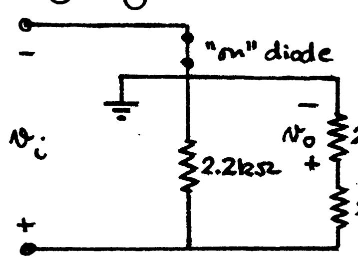
30. Positive half-cycle of $v_i$:

Network redrawn:



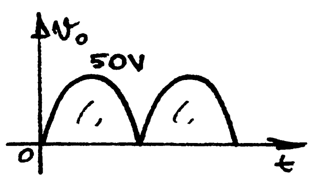

Voltage-divider rule:
$$V_{o_{max}} = \frac{2.2\text{k}\Omega(V_{i_{max}})}{2.2\text{k}\Omega + 2.2\text{k}\Omega}$$
$$= \frac{1}{2}(V_{i_{max}})$$
$$= \frac{1}{2}(100\text{V})$$
$$= \underline{50\text{V}}$$

Negative half-cycle of $v_i$:




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

Voltage-divider rule:
$$V_{o_{max}} = \frac{2.2\text{k}\Omega(V_{i_{max}})}{2.2\text{k}\Omega + 2.2\text{k}\Omega}$$
$$= \frac{1}{2}(V_{i_{max}})$$
$$= \frac{1}{2}(100\text{V})$$
$$= \underline{50\text{V}}$$




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

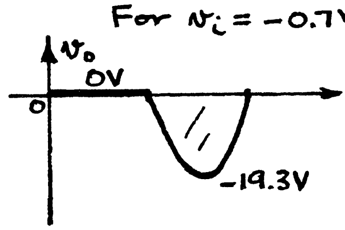
32. (a)

Si diode open for positive pulse of $v_i$ and $v_o = 0\text{V}$

For $-20\text{V} < v_i \leq -0.7\text{V}$ diode "on" and $v_o = v_i + 0.7\text{V}$

For $v_i = -20\text{V}$, $v_o = -20\text{V} + 0.7\text{V} = -19.3\text{V}$

For $v_i = -0.7\text{V}$, $v_o = -0.7\text{V} + 0.7\text{V} = 0\text{V}$



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

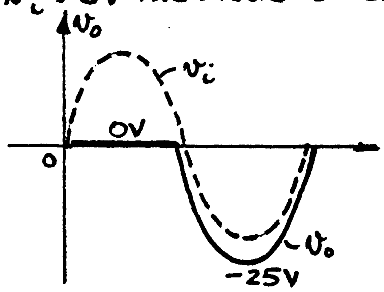
at $v_i = 5V$

$v_o = 5V - 5V = 0V$

at $v_i = -20V$

$v_o = -20V - 5V = -25V$

For $v_i > 5V$ the diode is reverse-biased and $v_o = 0V$




34. (a)

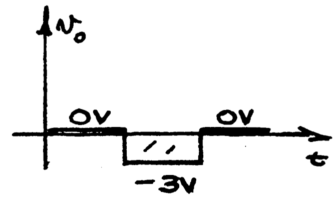
For $v_i = 20V$ the diode is reverse-biased and $v_o = \underline{0V}$.

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

Applying Kirchhoff's voltage law in the clockwise direction:

$$-5V + 2V - v_o = 0$$

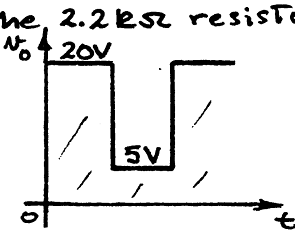
$$v_o = \underline{-3V}$$




(b)

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

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




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 $5.3V + 0.7V = 6V$. In fact, $v_o = 6V$ for $v_i \ge 6V$

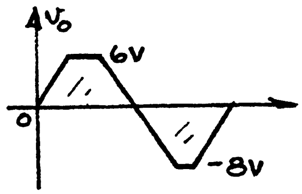
For $v_i < 6V$ both diodes are reverse-biased and $v_o = v_i$.

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 $7.3V + 0.7V = 8V$. In fact, $v_o = -8V$ for $v_i \le -8V$

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




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

For $v_i \geq 6V$

$v_R = v_i - v_o = v_i - 6V$

For $v_i = 10V$, $v_R = 10V - 6V = 4V$

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

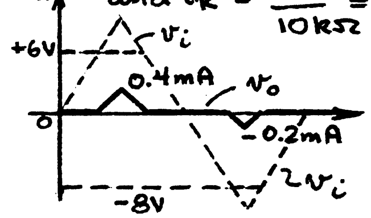
For $v_i \leq -8V$

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

For $v_i = -10V$

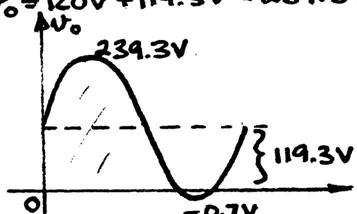
$v_R = -10V + 8V = -2V$

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




38. (a) For negative half cycle capacitor charges to peak value of $120V - 0.7V = 119.3V$ with polarity $(- \dashv\vdash +)$. The output $v_o$ is directly across the "on" diode resulting in $v_o = -0.7V$ as a negative peak value.

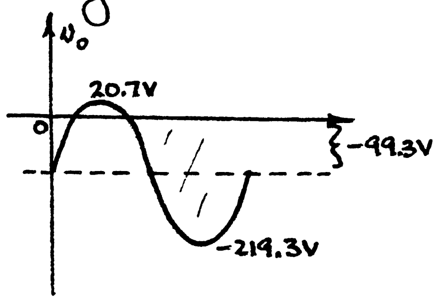
For the next positive half cycle $v_o = v_i + 119.3V$ with a peak value of $v_o = 120V + 119.3V = 239.3V$.




$\uparrow$ vertical shift of 119.3V

(b) For positive half cycle capacitor charges to peak value of $120V - 20V - 0.7V = 99.3V$ with polarity $(+ \dashv\vdash -)$. The output $v_o = 20V + 0.7V = 20.7V$

For next negative half cycle $v_o = v_i - 99.3V$ with negative peak value of $v_o = -120V - 99.3V = -219.3V$




$\downarrow$ vertical shift of -99.3V

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

40. Solution is network of Fig. 2.159(b) using a 10V supply in place of the 5V source.

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

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

$V_L = 9V < V_Z = 10V$ and diode non-conducting

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

with $I_Z = \underline{0\text{ mA}}$

and $V_L = \underline{9V}$

(b) In the absence of the Zener diode

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

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

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

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

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

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

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

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

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

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

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

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

$$10R_L + 2200 = 20R_L$$

$$10R_L = 2200$$

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

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

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

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

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

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

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

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

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

46. For $v_i = +50\text{V}$:

$Z_1$ forward-biased at 0.7V

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

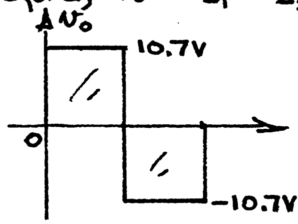
Therefore, $V_o = V_{Z_1} + V_{Z_2} = 0.7\text{V} + 10\text{V} = \underline{10.7\text{V}}$

For $v_i = -50\text{V}$:

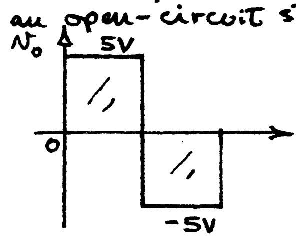
$Z_1$ reverse-biased at the Zener potential and $V_{Z_1} = -10\text{V}$.

$Z_2$ forward-biased at $-0.7\text{V}$

therefore, $V_o = V_{Z_1} + V_{Z_2} = \underline{-10.7\text{V}}$




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




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

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

Chapter 3 (Odd)

1. –
3. forward-and reverse-biased.
5. –
7. –
9. $I_B = \frac{1}{100} I_C \Rightarrow I_C = 100 I_B$

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

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

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

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

$V_{CB} = 10\text{V}$: $V_{BE} = \underline{770\text{mV}}$

$V_{CB} = 20\text{V}$: $V_{BE} = \underline{750\text{mV}}$

The change in $V_{CB}$ is $20\text{V}:1\text{V} = \underline{20:1}$

The resulting change in $V_{BE}$ is $800\text{mV}:750\text{mV} = \underline{1.07:1}$ (very slight)

13. (a) $I_C \cong I_E = \underline{4.5\text{mA}}$

(b) $I_C \cong I_E = \underline{4.5\text{mA}}$

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

(d) $I_C \cong I_E$

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

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

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

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

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

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

$I_L \cong I_i = 25\text{mA}$

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

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

19. –
21. (a) $\beta = \frac{I_C}{I_B} = \frac{2\text{mA}}{17\,\mu\text{A}} = \underline{117.65}$

(b) $\alpha = \frac{\beta}{\beta+1} = \frac{117.65}{117.65+1} = \underline{0.992}$

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

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

$= (1-0.992)(0.3\text{mA}) = \underline{2.4\,\mu\text{A}}$

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

(b) $\beta_{dc} = \frac{I_C}{I_B} = \frac{0.85\text{mA}}{5\,\mu\text{A}} = \underline{170}$

(c) $\beta_{dc} = \frac{I_C}{I_B} = \frac{3.4\text{mA}}{30\,\mu\text{A}} = \underline{113.33}$

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

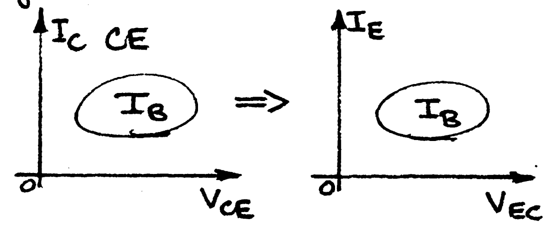
25. $\beta_{dc} = \dfrac{I_C}{I_B} = \dfrac{2.9\text{ mA}}{25\ \mu\text{A}} = \underline{116}$

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

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

27. —

29. Output characteristics:




Curves are essentially the same with new scales as shown.

Input characteristics:

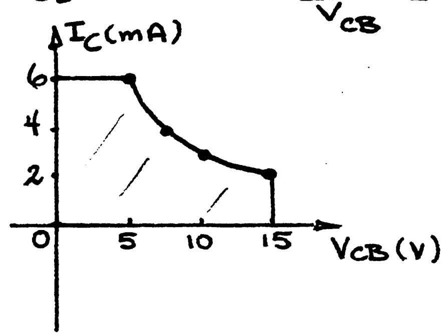
Common-emitter input characteristics may be used directly for common-collector calculations.

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

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

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

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



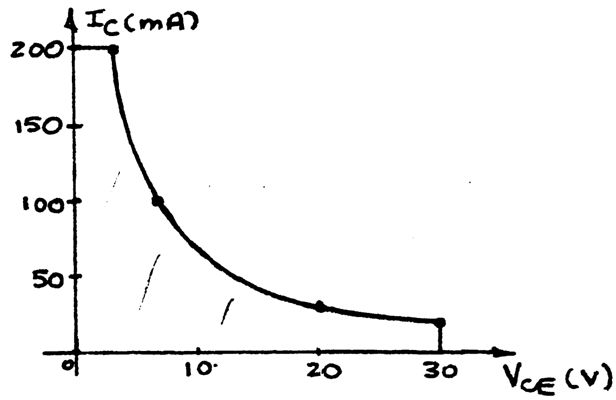

33. $I_{C_{max}} = 200\text{mA}$, $V_{CE_{max}} = 30\text{V}$ $P_{D_{max}} = 625\text{mW}$

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

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

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

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




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

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

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

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

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

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

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

37. (a) at $I_C = 1mA$, $h_{fe} \cong \underline{120}$

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

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

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

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

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

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

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

(f)(g)

In general $\beta_{dc}$ + $\beta_{ac}$ increase with increasing $I_C$ for fixed $V_{CE}$ and both decrease for decreasing levels of $V_{CE}$ for a fixed $I_C$. However, if $I_C$ increases while $V_{CE}$ decreases when moving between two points on the characteristics chances are the level of $\beta_{dc}$ or $\beta_{ac}$ 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 $\beta$ are relatively close.

## Chapter 3 (Even)

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

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

6. —

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

10. —

12. (a) $r_{av} = \dfrac{\Delta V}{\Delta I} = \dfrac{0.9\text{V} - 0.7\text{V}}{8\text{mA} - 0} = \underline{25\,\Omega}$

(b) Yes, since 25Ω is often negligible compared to the other resistance levels of the network.

14. (a) Using Fig. 3.7 first, $I_E \cong 7\text{mA}$
Then Fig. 3.8 results in $I_C \cong \underline{7\text{mA}}$

(b) Using Fig. 3.8 first, $I_E \cong 5\text{mA}$
then Fig. 3.7 results in $V_{BE} \cong \underline{0.78\text{V}}$

(c) Using Fig. 3.10(b) $I_E = 5\text{mA}$ results in $V_{BE} \cong \underline{0.81\text{V}}$

(d) Using Fig. 3.10(c) $I_E = 5\text{mA}$ results in $V_{BE} = \underline{0.7\text{V}}$

(e) Yes, the difference in levels of $V_{BE}$ can be ignored for most applications if voltages of several volts are present in the network.

16. —

18. $I_i = \dfrac{V_i}{R_i + R_s} = \dfrac{200\text{mV}}{20\,\Omega + 100\,\Omega} = \dfrac{200\text{mV}}{120\,\Omega} = 1.67\text{mA}$

$I_L = I_i = 1.67\text{mA}$

$V_L = I_L R = (1.67\text{mA})(5\text{k}\Omega) = 8.35\text{V}$

$A_v = \dfrac{V_o}{V_i} = \dfrac{8.35\text{V}}{0.2\text{V}} = \underline{41.75}$

20. (a) Fig. 3.14(b): $I_B \cong 35\,\mu\text{A}$
Fig. 3.14(a): $I_C \cong \underline{3.6\text{mA}}$

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

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

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

$\beta_{dc} = \dfrac{I_C}{I_B} = \dfrac{1.35\text{mA}}{10\,\mu\text{A}} = \underline{135}$

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

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

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

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

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

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

(e)

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

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

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

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

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

$I_E = I_C + I_B = 2mA + 11.11\mu A$

$= \underline{2.011\ mA}$

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

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

$I_e = \dfrac{V_e}{R_E} = \dfrac{1.9V}{1k\Omega} = \underline{1.9mA}\ (rms)$

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

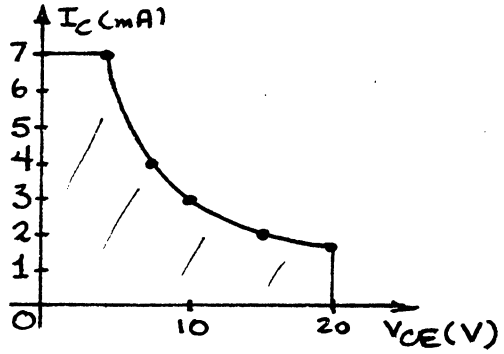
$I_C = I_{C_{max}},\ V_{CE} = \dfrac{P_{C_{max}}}{I_{C_{max}}} = \dfrac{30mW}{7mA} = 4.29V$

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

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

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

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




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

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

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

$$\beta_{avg} = \frac{\beta_{min} + \beta_{max}}{2}$$
$$= \frac{50 + 150}{2} = \frac{200}{2}$$
$$= 100$$
$$\therefore I_{CEO} \cong \beta I_{CBO} = (100)(50\text{ nA})$$
$$= \underline{5\,\mu A}$$

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

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

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

## Chapter 4 (Odd)

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

 (b) $I_{C_Q} = \beta I_{B_Q} = (90)(32.55\mu A) = \underline{2.93mA}$

 (c) $V_{CE_Q} = V_{CC} - I_{C_Q}R_C = 16V-(2.93mA)(2.7k\Omega) = \underline{8.09V}$

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

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

 (f) $V_E = \underline{0V}$

3. (a) $I_C = I_E - I_B = 4mA - 20\mu A = \underline{3.98mA} \cong 4mA$

 (b) $V_{CC} = V_{CE} + I_C R_C = 7.2V + (3.98mA)(2.2k\Omega)$
 $= \underline{15.96V} \cong 16V$

 (c) $\beta = \dfrac{I_C}{I_B} = \dfrac{3.98mA}{20\mu A} = \underline{199} \cong 200$

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

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

 (b) $I_B = 25\mu A$: $R_B = \dfrac{V_{CC}-V_{BE}}{I_B} = \dfrac{21V-0.7V}{25\mu A} = \underline{812k\Omega}$

 (c) $I_{C_Q} \cong \underline{3.4mA}$, $V_{CE_Q} \cong \underline{10.75V}$

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

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

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

 (g) –

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

 (i) $P_s = V_{CC}(I_C + I_B) = 21V(3.4mA + 25\mu A) = \underline{71.92mW}$

 (j) $P_R = P_s - P_D = 71.92mW - 36.55mW = \underline{35.37mW}$

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

 (b) $I_E \cong I_C$: $R_E = \dfrac{V_E}{I_E} = \dfrac{2.4V}{2mA} = \underline{1.2k\Omega}$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$\% \Delta V_{CE} = \left|\dfrac{4.67\text{V} - 8.61\text{V}}{8.61\text{V}}\right| \times 100\% = \underline{45.76\%}$

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

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

(b) $V_E = I_E R_E \cong I_C R_E = (1.28\text{mA})(1.2\text{k}\Omega) = 1.54\text{V}$

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

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

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

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

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

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

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

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

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

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

(b) $V_{CE} = V_{CC} - I_C(R_C + R_E) = 18\text{V} - (2.28\text{mA})(3.3\text{k}\Omega + 1\text{k}\Omega)$

$= 18\text{V} - 9.8\text{V} = \underline{8.2\text{V}}$ (vs. 7.55V #16)

(c) $19.02\mu A$ (vs. $20.25\mu A$ #16)

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

(e) $V_B = V_{BE} + V_E = 0.7V + 2.28V = \underline{2.98V}$ (vs. 3.13V #16)

The results suggest that the approximate approach is valid if Eq. 4.33 is satisfied.

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

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

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

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

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

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

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

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

(f) $\beta R_E \geq 10R_2$

$(129.8)(0.8k\Omega) \geq 10(5.84k\Omega)$

$103.84k\Omega \geq 58.4k\Omega$ (checks)

21. I. (a) Problem 16: Approximate approach: $I_{C_Q} = 2.\underline{43mA}$, $V_{CE_Q} = \underline{7.55V}$

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

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

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

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

$$= 12.94\mu A$$

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

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

$$= \underline{7.98V}$$

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

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

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

(d) $\%\Delta I_C = 2.19\%$ vs. 49.83% for problem 11.

$\%\Delta V_{CE} = 2.68\%$ vs. 49.70% for problem 11.

(e) Voltage-divider configuration considerably less sensitive.

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

23. (a) $I_B = \dfrac{V_{CC} - V_{BE}}{R_B + \beta(R_C + R_E)} = \dfrac{30V - 0.7V}{690k\Omega + 100(6.2k\Omega + 1.5k\Omega)} = 20.07\mu A$

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

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

$= 30V - (2.01mA)(6.2k\Omega) = 30V - 12.462V = \underline{17.54V}$

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

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

$= \underline{14.52V}$

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

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

$= 7.11\mu A$

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

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

$= \underline{5.98V}$

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

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

$= 4.36\mu A$

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

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

$= \underline{8.31V}$

$V_C$ range from $\underline{5.98V \text{ to } 8.31V}$

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

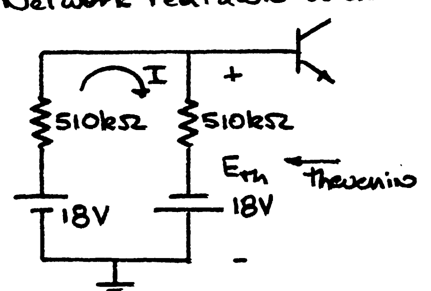
(b) $I_C = \dfrac{V_{CC} - V_C}{R_C} = \dfrac{18V - 8V}{3.9k\Omega} = \dfrac{10V}{3.9k\Omega} = \underline{2.56mA}$

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

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

29. $\beta R_E > 10R_2$ not satisfied ∴ Use Exact Approach:

Network redrawn to determine the Thevenin equivalent:

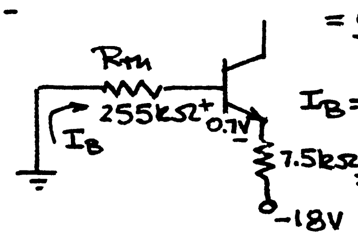



$R_{Th} = \dfrac{510k\Omega}{2} = \underline{255k\Omega}$

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

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

$= \underline{0V}$




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

$= \underline{13.95\mu A}$

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

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

$= -18V + 13.58V$

$= \underline{-4.42V}$

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

$= 36V - 30.05V = \underline{5.95V}$

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

(b) $V_C = 10V - (3.32mA)(1.8k\Omega) = 10V - 5.976$

$= \underline{4.02V}$

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

$= 18V - 13.28V$

$= \underline{4.72V}$

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

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

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

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

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

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

$= \underline{415.17k\Omega}$

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

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

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

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

$V_{RC} = V_{CC} - V_C = 28V - 19.6V = 8.4V$

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

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

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

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

$\beta R_E = 10R_2$

$(135.14)(1.12k\Omega) = 10(R_2)$

$R_2 = 15.14k\Omega$ (use 15kΩ)

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

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

Standard values:

$R_E = \underline{1.1\,k\Omega}$

$R_C = \underline{1.6\,k\Omega}$

$R_1 = \underline{51\,k\Omega}$

$R_2 = \underline{15\,k\Omega}$

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

$R_C = \dfrac{5V}{8mA} = \underline{0.625\,k\Omega}$

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

use $1.2(80\,\mu A) = 96\,\mu A$

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

Standard values:

$R_B = \underline{43\,k\Omega}$

$R_C = \underline{0.62\,k\Omega}$

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

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

(c) Open-circuit in base circuit
Open transistor

41. (a) $R_B\uparrow, I_B\downarrow, I_C\downarrow, V_C\uparrow$

(b) $\beta\downarrow, I_C\downarrow$

(c) unchanged, $I_{C_{sat}}$ not a function of $\beta$

(d) $V_{CC}\downarrow, I_B\downarrow, I_C\downarrow$

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

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

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

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

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

(e) open in the base circuit.

45. $\beta R_E \geq 10 R_2$

$(220)(0.75\,k\Omega) \geq 10(16\,k\Omega)$

$165\,k\Omega \geq 160\,k\Omega$ (checks)

Use approximate approach:

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

$V_E = V_B + 0.7V = -3.59V + 0.7V = -2.89V$

$I_C \cong I_E = V_E/R_E = 2.89/0.75\,k\Omega = 3.85\,mA$

$I_B = \dfrac{I_C}{\beta} = \dfrac{3.85mA}{220} = \underline{17.5\,\mu A}$

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

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

(b) $S(V_{BE}) = \dfrac{-\beta}{R_B} = \dfrac{-90}{470\text{k}\Omega} = -1.92\times10^{-4}\text{S}$

(c) $S(\beta) = \dfrac{I_{C_1}}{\beta_1} = \dfrac{2.93\text{mA}}{90} = 32.56\times10^{-6}\text{A}$

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

$$= (91)(10\mu\text{A} - 0.2\mu\text{A}) + (-1.92\times10^{-4}\text{S})(0.5\text{V} - 0.7\text{V}) + (32.56\times10^{-6}\text{A})(112.5 - 90)$$
$$= (91)(9.8\mu\text{A}) + (1.92\times10^{-4}\text{S})(0.2\text{V}) + (32.56\times10^{-6}\text{A})(22.5)$$
$$= 8.92\times10^{-4}\text{A} + 0.384\times10^{-4}\text{A} + 7.326\times10^{-4}\text{A}$$
$$= 16.63\times10^{-4}\text{A}$$
$$\cong \underline{1.66\text{mA}}$$

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

$$S(I_{CO}) = (\beta+1)\frac{1 + R_{Th}/R_E}{(\beta+1) + R_{Th}/R_E} = (80+1)\frac{(1 + 7.94\text{k}\Omega/0.68\text{k}\Omega)}{(80+1) + 7.94\text{k}\Omega/0.68\text{k}\Omega}$$
$$= \frac{(81)(1+11.68)}{81 + 11.68} = \underline{11.08}$$

(b) $$S(V_{BE}) = \frac{-\beta}{R_{Th} + (\beta+1)R_E} = \frac{-80}{7.94\text{k}\Omega + (81)(0.68\text{k}\Omega)}$$
$$= \frac{-80}{7.94\text{k}\Omega + 55.08\text{k}\Omega} = \underline{-1.27\times10^{-3}\text{S}}$$

(c) $$S(\beta) = \frac{I_{C_1}(1 + R_{Th}/R_E)}{\beta_1(1 + \beta_2 + R_{Th}/R_E)} = \frac{1.71\text{mA}(1 + 7.94\text{k}\Omega/0.68\text{k}\Omega)}{80(1 + 100 + 7.94\text{k}\Omega/0.68\text{k}\Omega)}$$
$$= \frac{1.71\text{mA}(12.68)}{80(112.68)} = \underline{2.41\times10^{-6}\text{A}}$$

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

$$= (11.08)(10\mu\text{A} - 0.2\mu\text{A}) + (-1.27\times10^{-3}\text{S})(0.5\text{V} - 0.7\text{V}) + (2.41\times10^{-6}\text{A})(100 - 80)$$
$$= (11.08)(9.8\mu\text{A}) + (-1.27\times10^{-3}\text{S})(-0.2\text{V}) + (2.41\times10^{-6}\text{A})(20)$$
$$= 1.09\times10^{-4}\text{A} + 2.54\times10^{-4}\text{A} + 0.482\times10^{-4}\text{A}$$
$$= 4.11\times10^{-4}\text{A} = \underline{0.411\text{mA}}$$

51.

| Type | $S(I_{CO})$ | $S(V_{BE})$ | $S(\beta)$ |
|---|---|---|---|
| Collector Feedback | 83.69 | $-1.476\times10^{-4}$S | $4.84\times10^{-6}$A |
| Emitter-bias | 78.1 | $-1.51\times10^{-4}$S | $21\times10^{-6}$A |
| Voltage-divider | 11.08 | $-12.7\times10^{-4}$S | $2.41\times10^{-6}$A |
| Fixed-bias | 91 | $-1.92\times10^{-4}$S | $32.56\times10^{-6}$A |

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

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

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

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

## Chapter 4 (Even)

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

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

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

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

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

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

$= \underline{29.18\mu A}$

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

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

$= 20V - 11.388V$

$= \underline{8.61V}$

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

$= \underline{13V}$

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

$= 20V - 14.882V = \underline{5.12V}$

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

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

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

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

$= (3.09mA)(2.7k\Omega) + 7.3V + 2.1V = 8.34V + 7.3V + 2.1V$

$= \underline{17.74V}$

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

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

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

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

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

(b) $\beta = \frac{I_C}{I_B} = \frac{4\,mA}{30\,\mu A} = \underline{133.33}$

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

$= \frac{18.5V}{30\,\mu A} = \underline{616.67\,k\Omega}$

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

$= (10V)(4mA) = \underline{40\,mW}$

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

$= \underline{37.28\,mW}$

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

$(80)(0.68k\Omega) \geq 10(9.1k\Omega)$

$54.4k\Omega \not\geq 91k\Omega$ (No!)

(a) Use Exact approach:

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

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

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

$= \underline{21.42\,\mu A}$

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

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

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

$= \underline{8.17V}$

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

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

$= \underline{9.33V}$

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

$= \underline{1.16V}$

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

$= \underline{1.86V}$

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

(b) $I_E = I_C + I_B = 2mA + 20\,\mu A$

$= 2.02mA$

$V_E = I_E R_E = (2.02mA)(1.2k\Omega)$

$= \underline{2.42V}$

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

$= 10.6V + 5.4V$

$= \underline{16V}$

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

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

(f) $I_{R_1} = I_{R_2} + I_B$
$= \dfrac{3.12\text{V}}{8.2\text{k}\Omega} + 20\mu\text{A} = 380.5\mu\text{A} + 20\mu\text{A} = 400.5\mu\text{A}$

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

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

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

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

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

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

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

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

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

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

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

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

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

$V_{CE_Q} = V_{CC} - I_C(R_C + R_E)$
$= 16\text{V} - (1.99\text{mA})(3.9\text{k}\Omega + 0.68\text{k}\Omega)$
$= 16\text{V} - 9.$
$= \underline{6.89\text{V}}$

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

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

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

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

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

$$I_B = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta+1)R_E} = \frac{2.05\text{ V} - 0.7\text{ V}}{7.94\text{ k}\Omega + (121)(0.68\text{ k}\Omega)}$$
$$= 14.96\ \mu\text{A}$$
$$I_C = \beta I_B = (120)(14.96\ \mu\text{A}) = \underline{1.8\text{ mA}}$$
$$V_{CE} = V_{CC} - I_C(R_C + R_E)$$
$$= 16\text{ V} - (1.8\text{ mA})(3.9\text{ k}\Omega + 0.68\text{ k}\Omega)$$
$$= \underline{7.76\text{ V}}$$

(c) $$\% \Delta I_C = \left| \frac{1.8\text{ mA} - 1.71\text{ mA}}{1.71\text{ mA}} \right| \times 100\% = \underline{5.26\%}$$
$$\% \Delta V_{CE} = \left| \frac{7.76\text{ V} - 8.17\text{ V}}{8.17\text{ V}} \right| \times 100\% = \underline{5.02\%}$$

(d)

| | 11c | 11f | 20c |
|---|---|---|---|
| $\% \Delta I_C$ | 49.83% | 34.59% | 5.26% |
| $\% \Delta V_{CE}$ | 48.70% | 46.76% | 5.63% |
| | fixed-bias | Emitter feedback | Voltage-divider |

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

22. (a) $$I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta(R_C + R_E)} = \frac{16\text{ V} - 0.7\text{ V}}{470\text{ k}\Omega + (120)(3.6\text{ k}\Omega + 0.51\text{ k}\Omega)}$$
$$= \underline{15.88\ \mu\text{A}}$$

(b) $$I_C = \beta I_B = (120)(15.88\ \mu\text{A})$$
$$= \underline{1.91\text{ mA}}$$

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

24. (a) $$I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta(R_C + R_E)} = \frac{22\text{ V} - 0.7\text{ V}}{470\text{ k}\Omega + (90)(9.1\text{ k}\Omega + 9.1\text{ k}\Omega)}$$
$$= 10.09\ \mu\text{A}$$
$$I_C = \beta I_B = (90)(10.09\ \mu\text{A}) = \underline{0.91\text{ mA}}$$
$$V_{CE} = V_{CC} - I_C(R_C + R_E) = 22\text{ V} - (0.91\text{ mA})(9.1\text{ k}\Omega + 9.1\text{ k}\Omega)$$
$$= \underline{5.44\text{ V}}$$

(b) $\beta = 135$ $$I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta(R_C + R_E)} = \frac{22\text{ V} - 0.7\text{ V}}{470\text{ k}\Omega + (135)(9.1\text{ k}\Omega + 9.1\text{ k}\Omega)}$$
$$= 7.28\ \mu\text{A}$$

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

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

$= \underline{4.11V}$

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

$\% \Delta V_{CE} = \left| \frac{4.11V - 5.44V}{5.44V} \right| \times 100\% = \underline{24.45\%}$

(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 $\beta$.

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

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

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

$= \underline{11.95V}$

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

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

(f) $\beta = \frac{I_C}{I_B} = \frac{2.75 mA}{24.09\mu A} = \underline{114.16}$

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

$= \underline{6.2\mu A}$

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

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

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

$= \underline{7.91V}$

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

$= \underline{7.07V}$

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

$= 23.78\mu A$

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

$= \underline{2.88 mA}$

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

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

$= \underline{-2.54V}$

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

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

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

$$= \underline{2.4\text{k}\Omega}$$

Standard values:

$R_B = \underline{360\text{k}\Omega}$

$R_C = \underline{2.4\text{k}\Omega}$

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

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

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

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

$V_B = \frac{R_2 V_{CC}}{R_2 + R_1} \Rightarrow 3.7\text{V} = \frac{R_2(24\text{V})}{R_2 + R_1}$ } 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 $R_2 = \underline{7.5\text{k}\Omega}$

Substituting in the above equation:

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

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

Standard values:

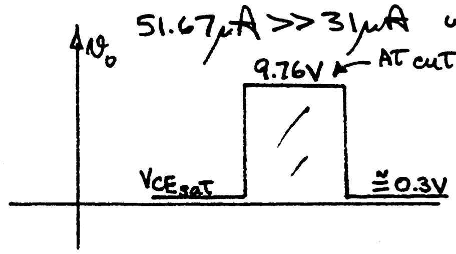
$R_E = \underline{0.75\text{k}\Omega}$, $R_C = \underline{3.3\text{k}\Omega}$, $R_2 = \underline{7.5\text{k}\Omega}$, $R_1 = \underline{43\text{k}\Omega}$

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

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

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

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




AT cutoff $I_C \cong 0.1\text{mA} = I_{CEO}$

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

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

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

38. (a) From Fig. 3.23c:

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

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

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

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

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

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

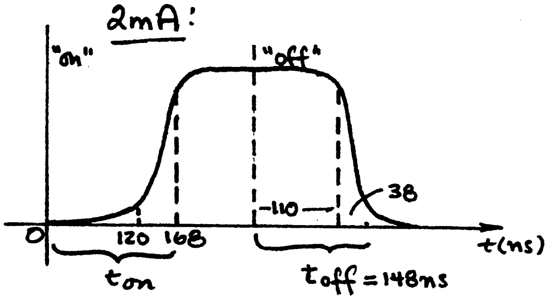
The turn-on time has dropped dramatically

$$168\text{ns} : 37\text{ns} = \underline{4.54} : 1$$

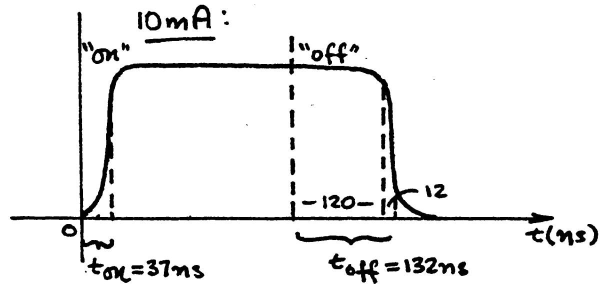
while the turn-off time is only slightly smaller

$$148\text{ns} : 132\text{ns} = \underline{1.12} : 1$$

2mA:




10mA:




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

If operating properly:

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

As an emitter feedback bias circuit:

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

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

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

$$= \underline{9.4\text{V}}$$

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

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

∴ Assume base circuit "open"

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

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

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

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

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

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

and $\underline{V_C\downarrow}$

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

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

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

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

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

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

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

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

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

$= \underline{-4.69\text{V}}$

$V_{CE} = V_C = \underline{-4.69\text{V}}$

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

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

$= \underline{-3.37\text{V}}$

48. For the emitter-bias:

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

$= \underline{78.1}$

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

$= \underline{-1.512\times10^{-4}\,S}$

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

$= \underline{21.37\times10^{-6}\text{A}}$

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

$= (78.1)(9.8\mu A) + (-1.512\times10^{-4}S)(-0.2V) + (21.37\times10^{-6}A)(25)$

$= 0.7654mA + 0.0302mA + 0.5343mA$

$= \underline{1.33mA}$

50. For collector-feedback bias:

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

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

$= \underline{83.69}$

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

$= \underline{-1.477\times10^{-4}S}$

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

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

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

$= (83.69)(9.8\mu A) + (-1.477\times10^{-4}S)(-0.2V) + (4.83\times10^{-6}A)(49.1)$

$= 8.20\times10^{-4}A + 0.295\times10^{-4}A + 2.372\times10^{-4}A$

$= 10.867\times10^{-4}A = \underline{1.087mA}$

52. (a) Fixed-bias:

$S(I_{CO}) = 91$, $\Delta I_C = 0.892mA$

$S(V_{BE}) = -1.92\times10^{-4}S$, $\Delta I_C = 0.0384mA$

$S(\beta) = 32.56\times10^{-6}A$, $\Delta I_C = 0.7326mA$

(b) Voltage-divider bias:

$S(I_{CO}) = 11.08$, $\Delta I_C = 0.1090mA$

$S(V_{BE}) = -1.27\times10^{-3}S$, $\Delta I_C = 0.2540mA$

$S(\beta) = 2.41\times10^{-6}A$, $\Delta I_C = 0.0482mA$

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

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

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

## Chapter 5 (Odd)

1. –

3. (a) $V_{DS} \cong 1.4\text{V}$

(b) $r_d = \dfrac{V}{I} = \dfrac{1.4\text{V}}{6\text{mA}} = 233.33\Omega$

(c) $V_{DS} \cong 1.6\text{V}$

(d) $r_d = \dfrac{V}{I} = \dfrac{1.6\text{V}}{3\text{mA}} = 533.33\Omega$

(e) $V_{DS} \cong 1.4\text{V}$

(f) $r_d = \dfrac{V}{I} = \dfrac{1.4\text{V}}{1.5\text{mA}} = 933.33\Omega$

(g) $r_o = 233.33\Omega$

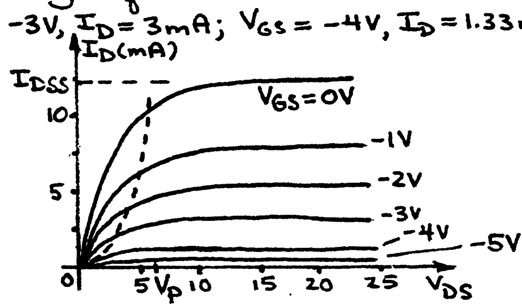
$$r_d = \frac{r_o}{[1 - V_{GS}/V_P]^2} = \frac{233.33\Omega}{[1 - (-1\text{V})/(-4\text{V})]^2} = \frac{233.33\Omega}{0.5625}$$
$$= 414.81\Omega$$

(h) $r_d = \dfrac{233.33\Omega}{[1-(-2\text{V})/(-4\text{V})]^2} = \dfrac{233.33\Omega}{0.25} = 933.2\Omega$

(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 (5.1) is valid!

5. The collector characteristics of a BJT transistor are a plot of the output current versus the output voltage for different levels of input current. The drain characteristics of a JFET transistor are also a plot of the output current versus output voltage. However, the curves are for different levels of 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 $V_{GS}$. $V_{Csat}$ and $V_P$ define the region of nonlinearity for each device. That is, operation at voltage levels less than either quantity will result in a distorted, nonlinear response.

7. $V_{GS} = 0\text{V}$, $I_D = I_{DSS} = 12\text{mA}$
$V_{GS} = V_P = -6\text{V}$, $I_D = 0\text{mA}$
Shockley's equation: $V_{GS} = -1\text{V}$, $I_D = 8.33\text{mA}$; $V_{GS} = -2\text{V}$, $I_D = 5.33\text{mA}$;
$V_{GS} = -3\text{V}$, $I_D = 3\text{mA}$; $V_{GS} = -4\text{V}$, $I_D = 1.33\text{mA}$; $V_{GS} = -5\text{V}$, $I_D = 0.333\text{mA}$



9. (b) $I_{DSS} = 10\text{ mA}$, $V_P = -6\text{ V}$

11. (a) $I_D = I_{DSS} = \underline{9\text{ mA}}$

(b) $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$

$= 9\text{ mA}(1 - (-2\text{ V})/(-3.5\text{ V}))^2$

$= \underline{1.653\text{ mA}}$

(c) $V_{GS} = V_P = -3.5\text{ V}$, $I_D = \underline{0\text{ mA}}$

(d) $V_{GS} < V_P = -3.5\text{ V}$, $I_D = \underline{0\text{ mA}}$

13. $V_{GS} = 0\text{ V}$, $I_D = I_{DSS} = \underline{7.5\text{ mA}}$

$V_{GS} = 0.3V_P = (0.3)(4\text{ V}) = \underline{1.2\text{ V}}$, $I_D = I_{DSS}/2 = 7.5\text{ mA}/2 = \underline{3.75\text{ mA}}$

$V_{GS} = 0.5V_P = (0.5)(4\text{ V}) = \underline{2\text{ V}}$, $I_D = I_{DSS}/4 = 7.5\text{ mA}/4 = \underline{1.875\text{ mA}}$

$V_{GS} = V_P = 4\text{ V}$, $I_D = \underline{0\text{ mA}}$

15. $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$

$3\text{ mA} = I_{DSS}(1 - (-3\text{ V})/(-6\text{ V}))^2$

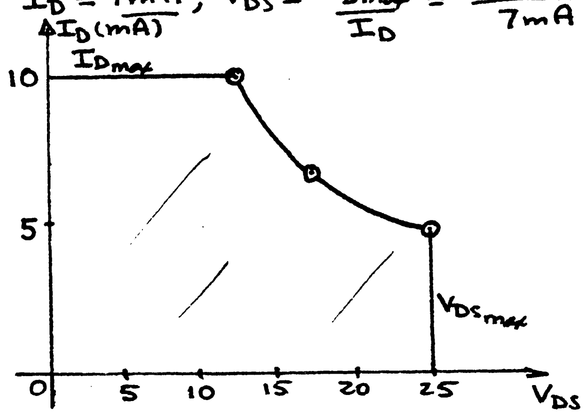
$3\text{ mA} = I_{DSS}(0.25)$

$I_{DSS} = \underline{12\text{ mA}}$

17. $V_{DS} = V_{DS_{max}} = \underline{25\text{ V}}$, $I_D = \dfrac{P_{D_{max}}}{V_{DS_{max}}} = \dfrac{120\text{ mW}}{25\text{ V}} = \underline{4.8\text{ mA}}$

$I_D = I_{DSS} = \underline{10\text{ mA}}$, $V_{DS} = \dfrac{P_{D_{max}}}{I_{DSS}} = \dfrac{120\text{ mW}}{10\text{ mA}} = \underline{12\text{ V}}$

$I_D = \underline{7\text{ mA}}$, $V_{DS} = \dfrac{P_{D_{max}}}{I_D} = \dfrac{120\text{ mW}}{7\text{ mA}} = \underline{17.14\text{ V}}$




19. Yes, All knees of $V_{GS}$ curves at or below $|V_P| = 3\text{ V}$

21. $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$

$= 9\text{ mA}(1 - (-1\text{ V})/(-3\text{ V}))^2$

$= \underline{4\text{ mA}}$ which compares very well with the level obtained using Fig. 5.21.

23. —

25. —

27. $V_{GS} = 0\text{ V}$, $I_D = I_{DSS} = 12\text{ mA}$; $V_{GS} = -8\text{ V}$, $I_D = 0\text{ mA}$; $V_{GS} = \frac{V_P}{2} = -4\text{ V}$, $I_D = 3\text{ mA}$;
$V_{GS} = 0.3V_P = -2.4\text{ V}$, $I_D = 6\text{ mA}$; $V_{GS} = -6\text{ V}$, $I_D = 0.75\text{ mA}$

29. $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$

$$I_{DSS} = \frac{I_D}{(1 - V_{GS}/V_P)^2} = \frac{4\text{mA}}{(1-(-2V)/(-5V))^2} = \underline{11.11\text{mA}}$$

31. From Fig. 5.30, $P_{D_{max}} = 200\text{mW}$, $I_D = 8\text{mA}$

$P = VI$

$$\text{a } V_{DS} = \frac{P_{max}}{I} = \frac{200\text{mW}}{8\text{mA}} = \underline{25V}$$

33. (a) $I_D = k(V_{GS} - V_T)^2 = 0.4\times10^{-3}(V_{GS} - 3.5)^2$

| $V_{GS}$ | $I_D$ |
|---|---|
| 3.5V | 0 |
| 4V | 0.1mA |
| 5V | 0.9mA |
| 6V | 2.5mA |
| 7V | 4.9mA |
| 8V | 8.1mA |

(b) $I_D = 0.8\times10^{-3}(V_{GS} - 3.5)^2$

| $V_{GS}$ | $I_D$ |
|---|---|
| 3.5V | 0 |
| 4V | 0.2mA |
| 5V | 1.8mA |
| 6V | 5.0mA |
| 7V | 9.8mA |
| 8V | 16.2mA |

For same levels of $V_{GS}$, $I_D$ attains twice the current level as part (a). Transfer curve has steeper slope. For both curves, $I_D = 0$mA for $V_{GS} < 3.5$ V.

35. From Fig. 5.47, $V_T = 2.0V$

At $I_D = 6.5\text{mA}$, $V_{GS} = 5.5V$ : $I_D = k(V_{GS} - V_T)^2$

$6.5\text{mA} = k(5.5V - 2V)^2$

$k = \underline{5.31\times10^{-4}}$

$$I_D = \underline{5.31\times10^{-4}(V_{GS} - 2)^2}$$

37. $I_D = k(V_{GS} - V_T)^2$

$$\frac{I_D}{k} = (V_{GS} - V_T)^2$$

$$\sqrt{\frac{I_D}{k}} = V_{GS} - V_T$$

$$V_{GS} = V_T + \sqrt{\frac{I_D}{k}} = 5V + \sqrt{\frac{30\text{mA}}{0.06\times10^{-3}}}$$

$$= \underline{27.36V}$$

39. $I_D = k(V_{GS} - V_T)^2 = 0.45\times10^{-3}(V_{GS} - (-5V))^2$

$= 0.45\times10^{-3}(V_{GS} + 5V)^2$

$V_{GS} = -5V$, $I_D = 0$mA; $V_{GS} = -6V$, $I_D = 0.45$mA; $V_{GS} = -7V$, $I_D = 1.8$mA;
$V_{GS} = -8V$, $I_D = 4.05$mA; $V_{GS} = -9V$, $I_D = 7.2$mA; $V_{GS} = -10V$, $I_D = 11.25$mA.

41. —

43. —

Chapter 5 (Even)

2. From Fig. 5.10:

$V_{GS} = 0V,\ I_D = \underline{8mA}$

$V_{GS} = -1V,\ I_D = \underline{4.5mA}$

$V_{GS} = -1.5V,\ I_D = \underline{3.25mA}$

$V_{GS} = -1.8V,\ I_D = \underline{2.5mA}$

$V_{GS} = -4V,\ I_D = \underline{0mA}$

$V_{GS} = -6V,\ I_D = \underline{0mA}$

4. (a) $V_{GS} = 0V,\ I_D = 8mA$ (for $V_{DS} > V_P$)

$V_{GS} = -1V,\ I_D = 4.5mA$

$\Delta I_D = \underline{3.5mA}$

(b) $V_{GS} = -1V,\ I_D = 4.5mA$

$V_{GS} = -2V,\ I_D = 2mA$

$\Delta I_D = \underline{2.5mA}$

(c) $V_{GS} = -2V,\ I_D = 2mA$

$V_{GS} = -3V,\ I_D = 0.5mA$

$\Delta I_D = \underline{1.5mA}$

(d) $V_{GS} = -3V,\ I_D = 0.5mA$

$V_{GS} = -4V,\ I_D = 0mA$

$\Delta I_D = \underline{0.5mA}$

(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 1V the change in $I_D$ drops from a maximum of 3.5mA to a minimum of 0.5mA – a 7:1 change in $\Delta I_D$.

6. (a) The input current $I_G$ for a JFET is effectively zero since the JFET gate-source junction is reverse-biased for linear operation, and a reverse-biased junction has a very high resistance.

(b) The input impedance of the JFET is high due to the reverse-biased junction between the gate and source.

(c) The terminology is appropriate since it is the electric field established by the applied gate to source voltage that controls the level of drain current. The term "field" is appropriate due to the absence of a conductive path between gate and source(or drain).

8. For a p-channel JFET, all the voltage polarities in the network are reversed as compared to an n-channel device. In addition, the drain current has reversed direction.

10. $V_{GS} = 0V,\ I_D = I_{DSS} = 12mA$

$V_{GS} = V_P = -4V,\ I_D = 0mA$

$V_{GS} = \frac{V_P}{2} = -2V,\ I_D = \frac{I_{DSS}}{4} = 3mA$

$V_{GS} = 0.3V_P = -1.2V,\ I_D = 6mA$

$V_{GS} = -3V,\ I_D = 0.75mA$ (Shockley's Eq.)

12. $V_{GS} = \underline{0V}$, $I_D = \underline{16mA}$

$V_{GS} = 0.3V_P = 0.3(-5V) = \underline{-1.5V}$, $I_D = I_{DSS}/2 = \underline{8mA}$

$V_{GS} = 0.5V_P = 0.5(-5V) = -\underline{2.5V}$, $I_D = I_{DSS}/4 = \underline{4mA}$

$V_{GS} = V_P = \underline{-5V}$, $I_D = \underline{0mA}$

14. (a) $I_D = I_{DSS}(1 - V_{GS}/V_P)^2 = 6mA(1 - (-2V)/(-4.5V))^2$

$= \underline{1.852mA}$

$I_D = I_{DSS}(1 - V_{GS}/V_P)^2 = 6mA(1 - (-3.6V)/(-4.5V))^2$

$= \underline{0.24mA}$

(b) $V_{GS} = V_P\left(1 - \sqrt{\dfrac{I_D}{I_{DSS}}}\right) = (-4.5V)\left(1 - \sqrt{\dfrac{3mA}{6mA}}\right)$

$= \underline{-1.318V}$

$V_{GS} = V_P\left(1 - \sqrt{\dfrac{I_D}{I_{DSS}}}\right) = (-4.5V)\left(1 - \sqrt{\dfrac{5.5mA}{6mA}}\right)$

$= -\underline{0.192V}$

16. From Fig. 5.18:

$-0.5V < V_P < -6V$

$1mA < I_{DSS} < 5mA$

For $I_{DSS} = 5mA$ and $V_P = -6V$:

$V_{GS} = 0V$, $I_D = 5mA$

$V_{GS} = 0.3V_P = -1.8V$, $I_D = 2.5mA$

$V_{GS} = V_P/2 = -3V$, $I_D = 1.25mA$

$V_{GS} = V_P = -6V$, $I_D = 0mA$

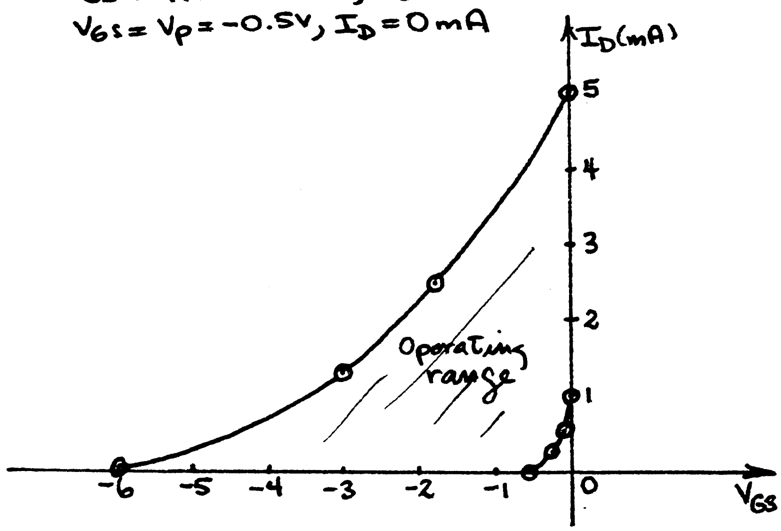
For $I_{DSS} = 1mA$ and $V_P = -0.5V$:

$V_{GS} = 0V$, $I_D = 1mA$

$V_{GS} = 0.3V_P = -0.15V$, $I_D = 0.5mA$

$V_{GS} = V_P/2 = -0.25V$, $I_D = 0.25mA$

$V_{GS} = V_P = -0.5V$, $I_D = 0mA$



18. $V_{GS} = -0.5V$, $I_D = 6.5mA$
$V_{GS} = -1V$, $I_D = 4mA$ $\Big\} 2.5mA$

Determine $\Delta I_D$ above 4mA line

$$\frac{2.5mA}{0.5V} = \frac{x}{0.3V} \Rightarrow x = 1.5mA$$

$I_D = 4mA + 1.5mA = \underline{5.5mA}$ corresponding with value determined from a purely graphical approach

20. From Fig. 5.21, $I_{DSS} \cong 9mA$
At $V_{GS} = -1V$, $I_D = 4mA$

$$I_D = I_{DSS}(1 - V_{GS}/V_P)^2$$

$$\sqrt{\frac{I_D}{I_{DSS}}} = 1 - V_{GS}/V_P$$

$$\frac{V_{GS}}{V_P} = 1 - \sqrt{\frac{I_D}{I_{DSS}}}$$

$$V_P = \frac{V_{GS}}{1 - \sqrt{\frac{I_D}{I_{DSS}}}} = \frac{-1V}{1 - \sqrt{\frac{4mA}{9mA}}}$$

$= \underline{-3V}$ (an exact match)

22. (a) $V_{DS} \cong 0.7V$ @ $I_D = 4mA$ (for $V_{GS} = 0V$)

$$r = \frac{\Delta V_{DS}}{\Delta I_D} = \frac{0.7V - 0V}{4mA - 0mA} = \underline{175\Omega}$$

(b) For $V_{GS} = -0.5V$, @ $I_D = 3mA$, $V_{DS} = 0.7V$

$$r = \frac{0.7V}{3mA} = \underline{233\Omega}$$

(c)
$$r_d = \frac{r_o}{(1 - V_{GS}/V_P)^2} = \frac{175\Omega}{(1 - (-0.5V)/(-3V))^2}$$

$= \underline{252\Omega}$ vs $233\Omega$ from part (b)

24. The construction of a depletion-type MOSFET and an enhancement-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.

26. At $V_{GS} = 0V$, $I_D = \underline{6mA}$
At $V_{GS} = -1V$, $I_D = 6mA(1 - (-1V)/(-3V))^2 = \underline{2.66mA}$
At $V_{GS} = +1V$, $I_D = 6mA(1 - (+1V)/(-3V))^2 = 6mA(1.333)^2 = \underline{10.667mA}$
At $V_{GS} = +2V$, $I_D = 6mA(1 - (+2V)/(-3V))^2 = 6mA(1.667)^2 = \underline{16.67mA}$

| $V_{GS}$ | $I_D$ | |
|---|---|---|
| $-1V$ | 2.66mA | $\Delta I_D = 3.34mA$ |
| 0 | 6.0mA | $\Delta I_D = 4.67mA$ |
| $+1V$ | 10.67mA | $\Delta I_D = 6mA$ |
| $+2V$ | 16.67mA | |

From $-1V$ to $0V$, $\Delta I_D = 3.34mA$
while from $+1V$ to $+2V$, $\Delta I_D = 6mA$ – 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.

28. From problem 20:

$$V_P = \frac{V_{GS}}{1-\sqrt{\frac{I_D}{I_{DSS}}}} = \frac{+1V}{1-\sqrt{\frac{14mA}{9.5mA}}} = \frac{+1V}{1-\sqrt{1.473}} = \frac{+1V}{1-1.21395}$$

$$= \frac{1}{-0.21395} \cong \underline{-4.67V}$$

30. From problem 14(b),

$$V_{GS} = V_P\left(1-\sqrt{\frac{I_D}{I_{DSS}}}\right) = (-5V)\left(1-\sqrt{\frac{20mA}{2.9mA}}\right)$$

$$= (-5V)(1-2.626) = (-5V)(-1.626)$$

$$= \underline{8.13V}$$

32. (a) In a depletion-type MOSFET the channel exists in the device and the applied voltage $V_{GS}$ controls the size of the channel. In an enhancement-type MOSFET the channel is not established by the construction pattern but induced by the applied control voltage $V_{GS}$.

(b) -

(c) Briefly, an applied gate to source voltage greater than $V_T$ will establish a channel between drain and source for the flow of charge in the output circuit.

34. (a) $k = \dfrac{I_{D(on)}}{(V_{GS(on)} - V_T)^2} = \dfrac{4mA}{(6V-4V)^2} = 1mA/V^2$

$$I_D = k(V_{GS}-V_T)^2 = \underline{1\times10^{-3}(V_{GS}-4V)^2}$$

(b) For $V_{GS} < V_T = 4V$, $I_D = 0mA$

| $V_{GS}$ | $I_D$ |
|---|---|
| 4V | 0mA |
| 5V | 1mA |
| 6V | 4mA |
| 7V | 9mA |
| 8V | 16mA |

(c)

| $V_{GS}$ | $I_D$ |
|---|---|
| 2V | 0mA ($V_{GS} < V_T$) |
| 5V | 1mA |
| 10V | 36mA |

36. $I_D = k(V_{GS(on)} - V_T)^2$

and $(V_{GS(on)} - V_T)^2 = \frac{I_D}{k}$

$$V_{GS(on)} - V_T = \sqrt{\frac{I_D}{k}}$$

$$V_T = V_{GS(on)} - \sqrt{\frac{I_D}{k}}$$

$$= 4V - \sqrt{\frac{3mA}{0.4\times10^{-3}}} = 4V - \sqrt{7.5}\,V$$

$$= 4V - 2.739$$

$$= \underline{1.261V}$$

38. Enhancement-Type MOSFET:

$$I_D = k(V_{GS} - V_T)^2$$

$$\frac{dI_D}{dV_{GS}} = 2k(V_{GS} - V_T)\left[\frac{d}{dV_{GS}}(\underbrace{V_{GS}}_{1} - V_T)\right]$$

$$\frac{dI_D}{dV_{GS}} = \underline{2k(V_{GS} - V_T)}$$

Depletion-type MOSFET:

$$I_D = I_{DSS}(1 - V_{GS}/V_P)^2$$

$$\frac{dI_D}{dV_{GS}} = I_{DSS}\frac{d}{dV_{GS}}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

$$= I_{DSS}\,2\left(1 - \frac{V_{GS}}{V_P}\right)\frac{d}{dV_{GS}}\left(\underbrace{1}_{0} - \underbrace{\frac{V_{GS}}{V_P}}_{-\frac{1}{V_P}}\right)$$

$$= 2I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)\left(-\frac{1}{V_P}\right)$$

$$= -\frac{2I_{DSS}}{V_P}\left(1 - \frac{V_{GS}}{V_P}\right)$$

$$= -\frac{2I_{DSS}}{V_P}\left(\frac{V_P}{V_P}\right)\left(1 - \frac{V_{GS}}{V_P}\right)$$

$$\frac{dI_D}{dV_{GS}} = \underline{\frac{2I_{DSS}}{V_P^2}(V_{GS} - V_P)}$$

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. (a) —

(b) For the "on" transistor: $R = \frac{V}{I} = \frac{0.1V}{4mA} = \underline{25\text{ ohms}}$

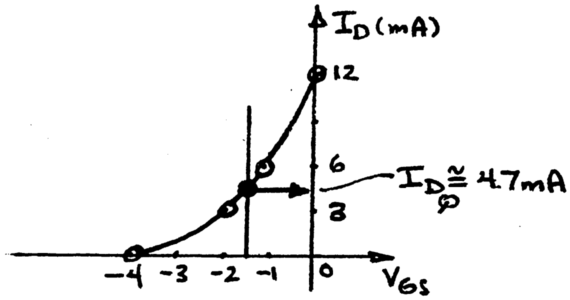
For the "off" transistor: $R = \frac{V}{I} = \frac{4.9V}{0.5\mu A} = \underline{9.8M\Omega}$

Absolutely, the high resistance of the "off" resistance will insure $V_o$ is very close to 5V.

# Chapter 6 (Odd)

1. (a) $V_{GS} = 0\text{V}, I_D = I_{DSS} = 12\text{mA}$
$V_{GS} = V_P = -4\text{V}, I_D = 0\text{mA}$
$V_{GS} = V_P/2 = -2\text{V}, I_D = I_{DSS}/4 = 3\text{mA}$
$V_{GS} = 0.3V_P = -1.2\text{V}, I_D = I_{DSS}/2 = 6\text{mA}$

(b)




(c) $I_{D_Q} \cong \underline{4.7\text{mA}}$,
$V_{DS_Q} = V_{DD} - I_{D_Q}R_D = 12\text{V} - (4.7\text{mA})(1.2\text{k}\Omega)$
$= \underline{6.36\text{V}}$

(d) $I_{D_Q} = I_{DSS}(1 - V_{GS}/V_P)^2 = 12\text{mA}(1 - (-1.5\text{V})/(-4\text{V}))^2$
$= \underline{4.69\text{mA}}$
$V_{DS_Q} = V_{DD} - I_{D_Q}R_D = 12\text{V} - (4.69\text{mA})(1.2\text{k}\Omega)$
$= \underline{6.37\text{V}}$
excellent comparison

3. (a) $I_{D_Q} = \dfrac{V_{DD} - V_D}{R_D} = \dfrac{14\text{V} - 9\text{V}}{1.6\text{k}\Omega} = \underline{3.125\text{mA}}$

(b) $V_{DS} = V_D - V_S = 9\text{V} - 0\text{V} = \underline{9\text{V}}$

(c) $I_D = I_{DSS}(1 - V_{GS}/V_P)^2 \Rightarrow V_{GS} = V_P\left(1 - \sqrt{\dfrac{I_D}{I_{DSS}}}\right)$
$V_{GS} = (-4\text{V})\left(1 - \sqrt{\dfrac{3.125\text{mA}}{8\text{mA}}}\right)$
$= -1.5\text{V}$
$\therefore V_{GG} = \underline{1.5\text{V}}$

5. $V_{GS} = V_P = -4\text{V}$
$\therefore I_{D_Q} = 0\text{mA}$
and $V_D = V_{DD} - I_{D_Q}R_D = 18\text{V} - (0)(2.2\text{k}\Omega)$
$= \underline{18\text{V}}$

7. $I_D = I_{DSS}(1 - V_{GS}/V_P)^2 = I_{DSS}\left(1 + \dfrac{2I_DR_S}{V_P} + \dfrac{I_D^2R_S^2}{V_P^2}\right)$
$\left(\dfrac{I_{DSS}R_S^2}{V_P^2}\right)I_D^2 + \left(\dfrac{2I_{DSS}R_S}{V_P} - 1\right)I_D + I_{DSS} = 0$
Substituting: $351.56\,I_D^2 - 4.75I_D + 10\text{mA} = 0$

$$I_D = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A} = \cancel{10.91\text{mA}}, 2.60\text{mA}$$

$I_{D_Q} = \underline{2.6\text{mA}}$ (exact match #6)

$V_{GS} = -I_D R_S = -(2.60\text{mA})(0.75\text{k}\Omega)$
$= \underline{-1.95\text{V}}$ vs $-2$V #6

9. (a) $I_{D_Q} = I_S = \dfrac{V_S}{R_S} = \dfrac{1.7\text{V}}{0.51\text{k}\Omega} = \underline{3.33\text{mA}}$

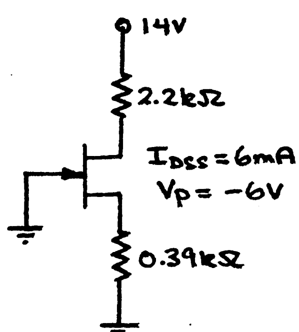
(b) $V_{GS_Q} = -I_{D_Q} R_S = -(3.33\text{mA})(0.51\text{k}\Omega)$
$\cong \underline{-1.7\text{V}}$

(c) $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$
$3.33\text{mA} = I_{DSS}(1 - (-1.7\text{V})/(-4\text{V}))^2$
$3.33\text{mA} = I_{DSS}(0.331)$
$I_{DSS} = \underline{10.06\text{mA}}$

(d) $V_D = V_{DD} - I_{D_Q} R_D$
$= 18\text{V} - (3.33\text{mA})(2\text{k}\Omega) = 18\text{V} - 6.66\text{V}$
$= \underline{11.34\text{V}}$

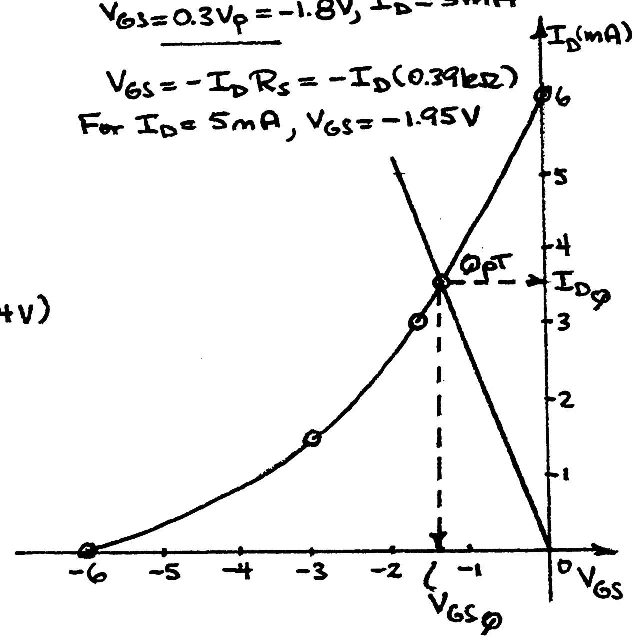
(e) $V_{DS} = V_D - V_S = 11.34\text{V} - 1.7\text{V}$
$= \underline{9.64\text{V}}$

11. Network redrawn:




$V_{GS} = 0\text{V}, I_D = I_{DSS} = 6\text{mA}$
$V_{GS} = V_P = -6\text{V}, I_D = 0\text{mA}$
$V_{GS} = \dfrac{V_P}{2} = -3\text{V}, I_D = 1.5\text{mA}$
$\underline{V_{GS} = 0.3V_P} = -1.8\text{V}, I_D = 3\text{mA}$

$V_{GS} = -I_D R_S = -I_D(0.39\text{k}\Omega)$
For $I_D = 5\text{mA}$, $V_{GS} = -1.95\text{V}$




From graph $I_{D_Q} \cong 3.55\text{mA}$
$V_{GS_Q} \cong -1.4\text{V}$
$V_S = -(V_{GS_Q}) = -(-1.4\text{V})$
$= \underline{+1.4\text{V}}$

13. (a) $I_D = I_{DSS} = 10\text{mA}$, $V_P = -3.5\text{V}$

$V_{GS} = 0\text{V}$, $I_D = I_{DSS} = 10\text{mA}$

$V_{GS} = V_P = -3.5\text{V}$, $I_D = 0\text{mA}$

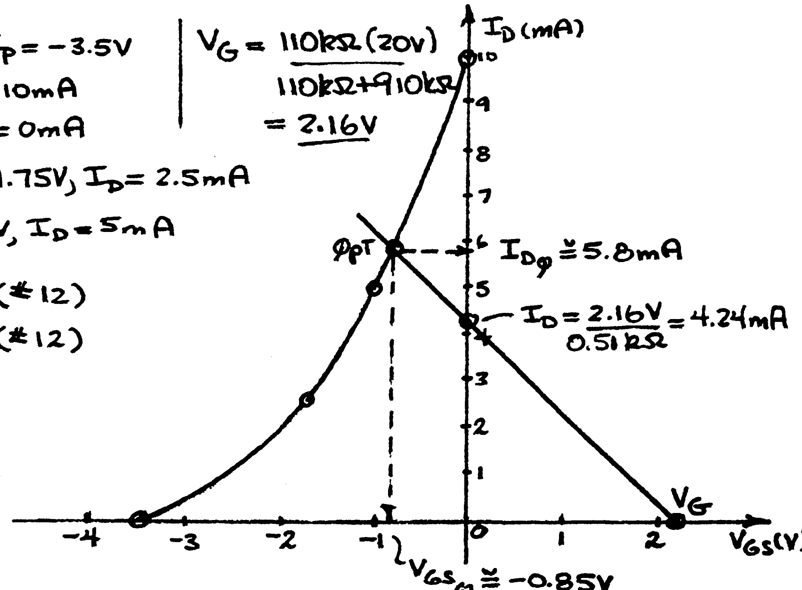
$V_{GS} = \dfrac{V_P}{2} = -\dfrac{3.5\text{V}}{2} = -1.75\text{V}$, $I_D = 2.5\text{mA}$

$V_{GS} = 0.3V_P = -1.05\text{V}$, $I_D = 5\text{mA}$

$V_G = \dfrac{110\text{k}\Omega(20\text{V})}{110\text{k}\Omega + 910\text{k}\Omega} = \underline{2.16\text{V}}$

$I_{D_Q} \cong \underline{5.8\text{mA}}$ vs 3.3mA (#12)

$V_{GS_Q} \cong \underline{-0.85\text{V}}$ vs −1.5V (#12)




(b) As $R_S$ decreases the intersection on the vertical axis increases. The maximum occurs at $I_D = I_{DSS} = 10\text{mA}$

$$\therefore R_{S_{min}} = \frac{V_G}{I_{DSS}} = \frac{2.16\text{V}}{10\text{mA}} = \underline{216\Omega}$$

15. (a) $V_{GS} = 0\text{V}$, $I_D = I_{DSS} = 6\text{mA}$

$V_{GS} = V_P = -6\text{V}$, $I_D = 0\text{mA}$

$V_{GS} = V_P/2 = -3\text{V}$, $I_D = 1.5\text{mA}$

$V_{GS} = 0.3V_P = -1.8\text{V}$, $I_D = 3\text{mA}$

$V_{GS} = V_{SS} - I_D R_S$

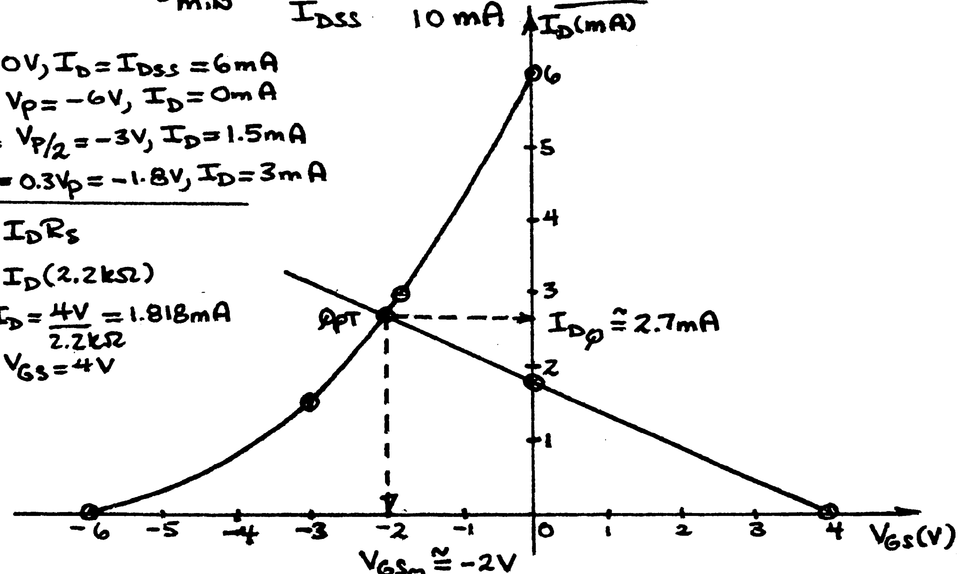
$V_{GS} = 4\text{V} - I_D(2.2\text{k}\Omega)$

$V_{GS} = 0\text{V}$, $I_D = \dfrac{4\text{V}}{2.2\text{k}\Omega} = 1.818\text{mA}$

$I_D = 0\text{mA}$, $V_{GS} = 4\text{V}$

$I_{D_Q} \cong \underline{2.7\text{mA}}$

$V_{GS_Q} \cong \underline{-2\text{V}}$




(b) $V_{DS} = V_{DD} + V_{SS} - I_D(R_D + R_S)$

$= 16\text{V} + 4\text{V} - (2.7\text{mA})(4.4\text{k}\Omega)$

$= \underline{8.12\text{V}}$

$V_S = -V_{SS} + I_D R_S = -4\text{V} + (2.7\text{mA})(2.2\text{k}\Omega)$

$= 1.94\text{V}$

or $V_S = -(V_{GS_Q}) = -(-2\text{V}) = \underline{+2\text{V}}$

17. $V_{GS} = 0\text{V}$, $I_D = I_{DSS} = 6\text{mA}$

$V_{GS} = V_P = -4\text{V}$, $I_D = 0\text{mA}$

$V_{GS} = V_P/2 = -2\text{V}$, $I_D = I_{DSS}/4 = 1.5\text{mA}$

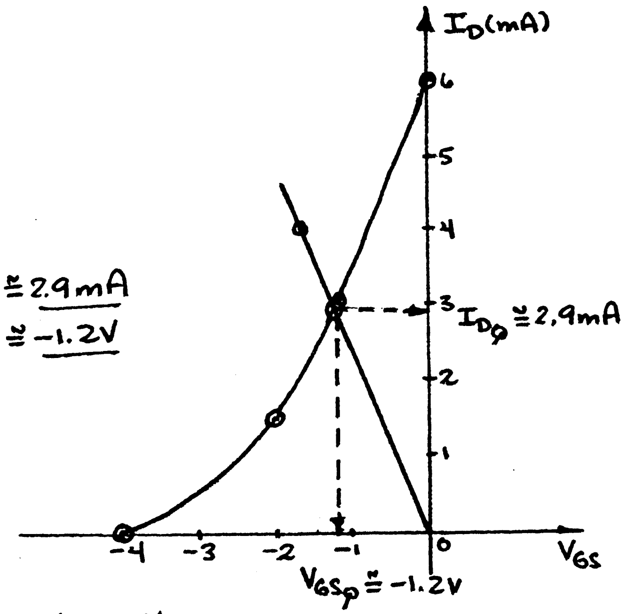
$V_{GS} = 0.3V_P = -1.2\text{V}$, $I_D = I_{DSS}/2 = 3\text{mA}$

$V_{GS} = -I_D R_S = -I_D(0.43\text{k}\Omega)$

$I_D = 4\text{mA}$, $V_{GS} = -1.72\text{V}$

$I_{DQ} \cong \underline{2.9\,mA}$

$V_{GSQ} \cong \underline{-1.2\,V}$




(b) $V_{DS} = V_{DD} - I_D(R_D + R_S)$

$= 14\,V - 2.9\,mA(1.2\,k\Omega + 0.43\,k\Omega)$

$= \underline{9.27\,V}$

$V_D = V_{DD} - I_D R_D$

$= 14\,V - (2.9\,mA)(1.2\,k\Omega)$

$= \underline{10.52\,V}$

19. $I_D = k(V_{GS} - V_T)^2$

$k = \dfrac{I_{D(on)}}{(V_{GS(on)} - V_{Th})^2} = \dfrac{5\,mA}{(7\,V - 4\,V)^2} = \dfrac{5\,mA}{9\,V^2}$

$= 0.556 \times 10^{-3}\,A/V^2$

and $I_D = 0.556 \times 10^{-3}(V_{GS} - 4\,V)^2$

$V_{DS} = V_{DD} - I_D(R_D + R_S)$

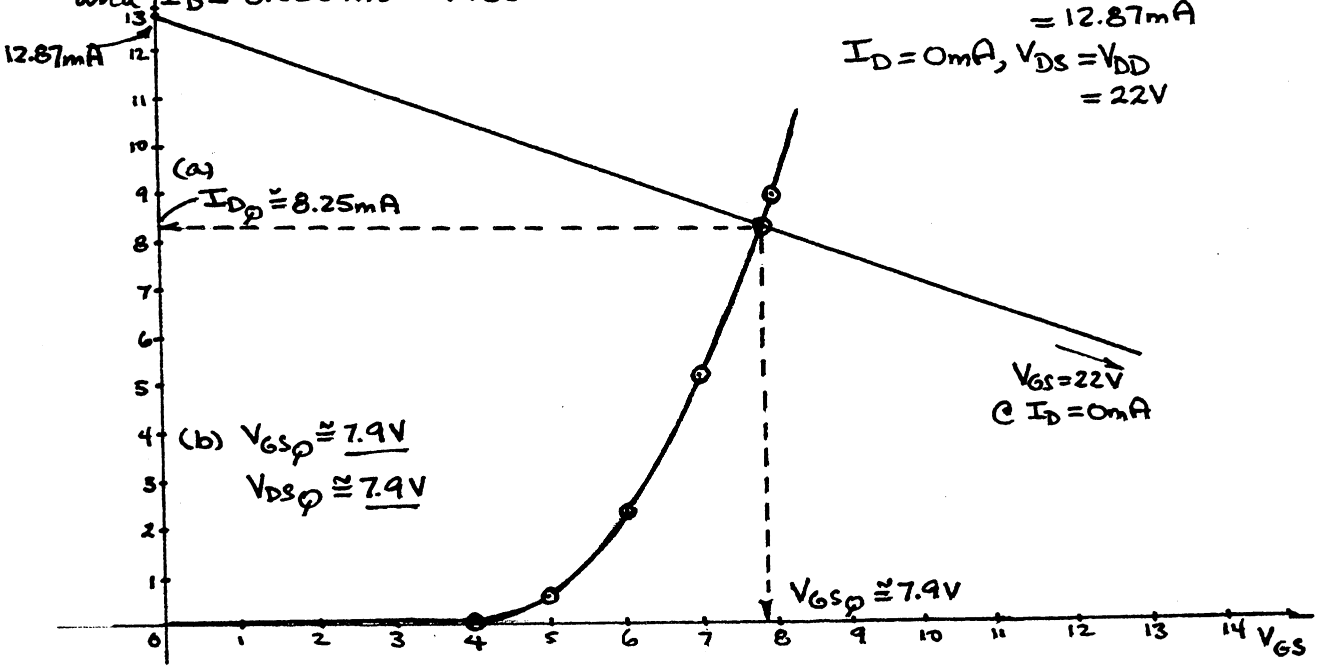
$V_{DS} = 0\,V;\ I_D = \dfrac{V_{DD}}{R_D + R_S}$

$= \dfrac{22\,V}{1.2\,k\Omega + 0.51\,k\Omega}$

$= 12.87\,mA$

$I_D = 0\,mA,\ V_{DS} = V_{DD}$

$= 22\,V$



(c) $V_D = V_{DD} - I_D R_D$

$= 22V - (8.25mA)(1.2k\Omega)$

$= \underline{12.1V}$

$V_S = I_S R_S = I_D R_S$

$= (8.25mA)(0.51k\Omega)$

$= \underline{4.21V}$

(d) $V_{DS} = V_D - V_S$

$= 12.1V - 4.21V$

$= \underline{7.89V}$

vs 7.9V obtained graphically

21. (a) $V_G = \dfrac{R_2}{R_1+R_2} V_{CC} = \dfrac{18k\Omega}{91k\Omega + 18k\Omega}(20V)$

$= \underline{3.3V}$

(b) $V_{GS} = 0V, I_D = I_{DSS} = 6mA$

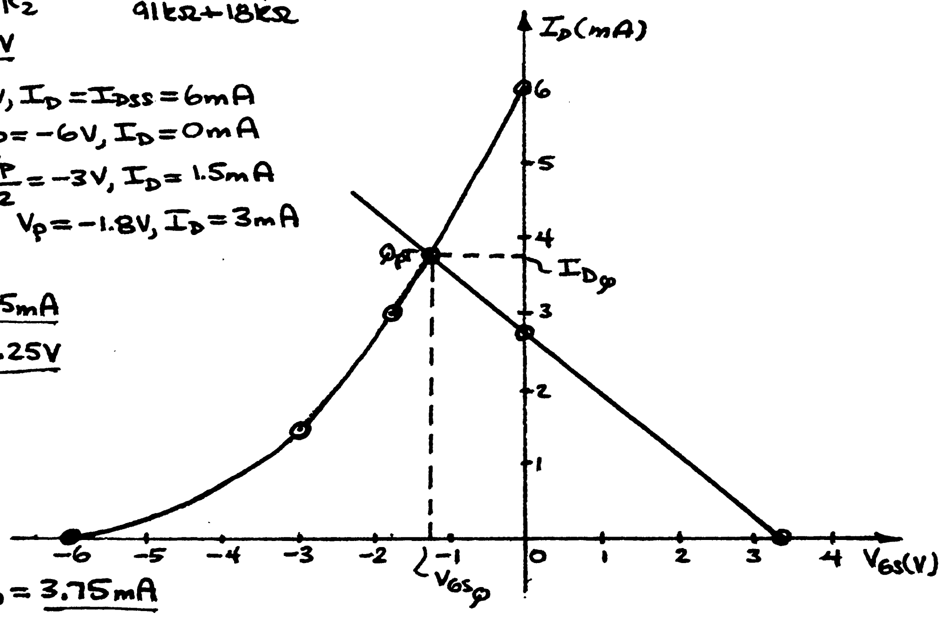
$V_{GS} = V_P = -6V, I_D = 0mA$

$V_{GS} = \dfrac{V_P}{2} = -3V, I_D = 1.5mA$

$V_{GS} = \quad V_P = -1.8V, I_D = 3mA$

$I_{D_Q} \cong \underline{3.75mA}$

$V_{GS_Q} \cong \underline{-1.25V}$




(c) $I_E = I_D = \underline{3.75mA}$

(d) $I_B = \dfrac{I_C}{\beta} = \dfrac{3.75mA}{160} = 23.44\mu A$

(e) $V_D = V_E = V_B - V_{BE} = V_{CC} - I_B R_B - V_{BE} = 20V - (23.44\mu A)(330k\Omega) - 0.7V$

$= \underline{11.56V}$

(f) $V_C = V_{CC} - I_C R_C = 20V - (3.75mA)(1.1k\Omega)$

$= \underline{15.88V}$

23. $V_{GS} = V_P\left(1 - \sqrt{\dfrac{I_D}{I_{DSS}}}\right) = (-6V)\left(1 - \sqrt{\dfrac{4mA}{8mA}}\right)$

$= -1.75V$

$V_{GS} = -I_D R_S : R_S = -\dfrac{V_{GS}}{I_D} = -\dfrac{(-1.75V)}{4mA} = \underline{0.44k\Omega}$

$R_D = 3R_S = 3(0.44k\Omega) = \underline{1.32k\Omega}$

Standard values: $R_S = \underline{0.43k\Omega}$

$R_D = \underline{1.3k\Omega}$

25. $I_D = k(V_{GS} - V_T)^2$

$\dfrac{I_D}{k} = (V_{GS} - V_T)^2$

$$\sqrt{\frac{I_D}{k}} = V_{GS} - V_T$$

and $V_{GS} = V_T + \sqrt{\frac{I_D}{k}} = 4V + \sqrt{\frac{6mA}{0.5\times10^{-3}A/V^2}} = 7.46V$

$$R_D = \frac{V_{R_D}}{I_D} = \frac{V_{DD}-V_{DS}}{I_D} = \frac{V_{DD}-V_{GS}}{I_D} = \frac{16V-7.46V}{6mA} = \frac{8.54V}{6mA}$$

$= 1.42\,k\Omega$

Standard value: $R_D = \underline{0.75\,k\Omega}$

$R_G = \underline{10\,M\Omega}$

27. $V_G = \dfrac{75k\Omega(20V)}{75k\Omega + 330k\Omega} = 3.7V$ — seems correct!

$V_{GS} = 3.7V - 6.25V = -2.55V$ (possibly okay)

$I_D = I_{DSS}(1 - V_{GS}/V_P)^2$

$= 10mA(1-(-2.55V)/(-6V))^2$

$= 3.3mA$ (reasonable)

However, $I_S = \dfrac{V_S}{R_S} = \dfrac{6.25V}{1k\Omega} = 6.25mA \neq 3.3mA$

$V_{R_D} = I_D R_D = I_S R_D = (6.25mA)(2.2k\Omega)$

$= 13.75V$

and $V_{R_S} + V_{R_D} = 6.25V + 13.75V$

$= \underline{20V} = V_{DD}$

$\therefore V_{DS} = 0V$

1. Possible short-circuit from D-S.

2. Actual $I_{DSS}$ and/or $V_P$ may be larger in magnitude than specified.

29. (a) $V_{GS} = 0V$, $I_D = I_{DSS} = 8mA$

$V_{GS} = V_P = +4V$, $I_D = 0mA$

$V_{GS} = \frac{V_P}{2} = +2V$, $I_D = 2mA$

$V_{GS} = 0.3V_P = 1.2V$, $I_D = 4mA$

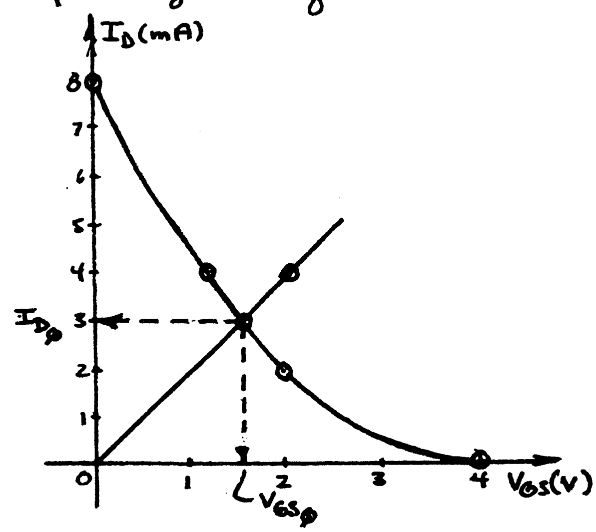
$V_{GS} = I_D R_S$

$I_D = 4mA$;

$V_{GS} = (4mA)(0.51k\Omega)$

$= 2.04V$

$I_{D_Q} = \underline{3mA}$, $V_{GS_Q} = \underline{1.55V}$




(b) $V_{DS} = V_{DD} + I_D(R_D + R_S)$

$= -18V + (3mA)(2.71k\Omega)$

$= \underline{-9.87V}$

(c) $V_D = V_{DD} - I_D R_D$

$= -18V - (3mA)(2.2k\Omega)$

$= \underline{-11.4V}$

31. $\frac{V_{GS}}{|V_p|} = \frac{-1.5\text{V}}{4\text{V}} = -0.375$

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.

$$\frac{I_D}{I_{DSS}} = 0.39$$

$$I_D = 0.39(12\text{mA}) = \underline{4.68\text{mA}} \text{ vs } 4.69\text{mA} \#1$$

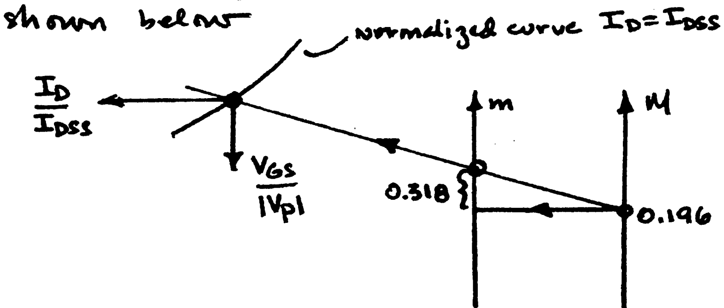
$$V_{DS_Q} = V_{DD} - I_D R_D = 12\text{V} - (4.68\text{mA})(1.2\text{k}\Omega)$$
$$= \underline{6.38\text{V}} \text{ vs } 6.37\text{V} \#1$$

33. $V_{GG} = \frac{R_2 V_{DD}}{R_1 + R_2} = \frac{110\text{k}\Omega(20\text{V})}{110\text{k}\Omega + 910\text{k}\Omega} = 2.16\text{V}$

$$m = \frac{|V_p|}{I_{DSS} R_S} = \frac{3.5\text{V}}{(10\text{mA})(1.1\text{k}\Omega)} = 0.318$$

$$M = m \times \frac{V_{GG}}{|V_p|} = 0.318\,\frac{(2.16\text{V})}{3.5} = 0.196$$

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.

$$\frac{I_D}{I_{DSS}} = 0.33 \text{ and } I_{D_Q} = 0.33(10\text{mA}) = \underline{3.3\text{mA}}$$
vs. 3.3mA #12

$$\frac{V_{GS}}{|V_p|} = -0.425 \text{ and } V_{GS_Q} = -0.425(3.5\text{V})$$
$$= \underline{-1.49\text{V}}$$
vs. 1.5V #12

## Chapter 6 (Even)

2. (a) $I_{D_Q} = I_{DSS}(1 - V_{GS}/V_P)^2$

$= 10\text{mA}(1-(-3\text{V})/(-4.5\text{V}))^2$

$= 10\text{mA}(0.333)^2$

$I_{D_Q} = \underline{1.11\text{mA}}$

(b) $\underline{V_{GS_Q}} = \underline{-3\text{V}}$

(c) $V_{DS} = V_{DD} - I_D(R_D + R_S)$

$= 16\text{V} - (1.11\text{mA})(2.2\text{k}\Omega)$

$= 16\text{V} - 2.444\text{V}$

$= \underline{13.56\text{V}}$

$V_D = V_{DS} = \underline{13.56\text{V}}$

$V_G = V_{GS_Q} = \underline{-3\text{V}}$

$V_S = \underline{0\text{V}}$

4. $V_{GS_Q} = 0\text{V}$, $I_D = I_{DSS} = 5\text{mA}$

$V_D = V_{DD} - I_D R_D$

$= 20\text{V} - (5\text{mA})(2.2\text{k}\Omega)$

$= 20\text{V} - 11\text{V}$

$= \underline{9\text{V}}$

6. $V_{GS} = 0\text{V}$, $I_D = 10\text{mA}$

$V_{GS} = V_P = -4\text{V}$, $I_D = 0\text{mA}$

$V_{GS} = \frac{V_P}{2} = -2\text{V}$, $I_D = 2.5\text{mA}$

$V_{GS} = 0.3V_P = -1.2\text{V}$, $I_D = 5\text{mA}$

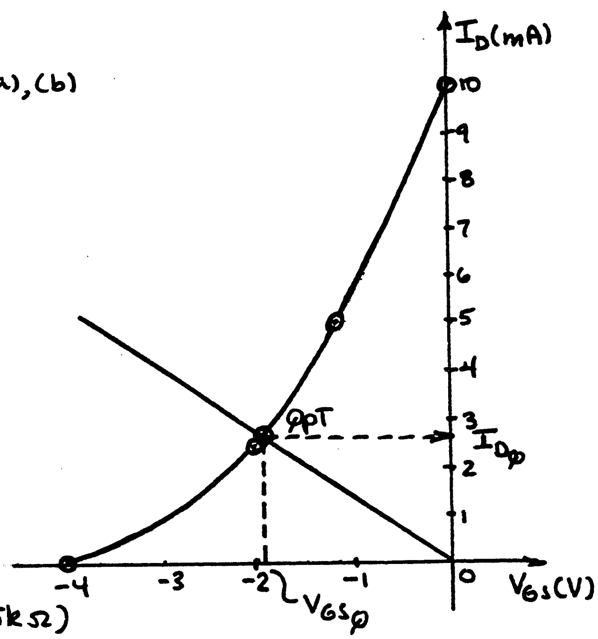
$V_{GS} = -I_D R_S$

$I_D = 5\text{mA}$:

$V_{GS} = -(5\text{mA})(0.75\text{k}\Omega)$

$= -3.75\text{V}$

(a),(b)




(c) $I_{D_Q} \cong \underline{2.7\text{mA}}$

$V_{GS_Q} \cong \underline{-1.9\text{V}}$

(d) $V_{DS} = V_{DD} - I_D(R_D + R_S)$

$= 18\text{V} - (2.7\text{mA})(1.5\text{k}\Omega + .75\text{k}\Omega)$

$= \underline{11.93\text{V}}$

$V_D = V_{DD} - I_D R_D$

$= 18\text{V} - (2.7\text{mA})(1.5\text{k}\Omega)$

$= \underline{13.95\text{V}}$

$V_G = \underline{0\text{V}}$

$V_S = I_S R_S = I_D R_S$

$= (2.7\text{mA})(0.75\text{k}\Omega)$

$= \underline{2.03\text{V}}$

8. $V_{GS} = 0V$, $I_D = I_{DSS} = 6mA$

$V_{GS} = V_P = -6V$, $I_D = 0mA$

$V_{GS} = \frac{V_P}{2} = -3V$, $I_D = 1.5mA$

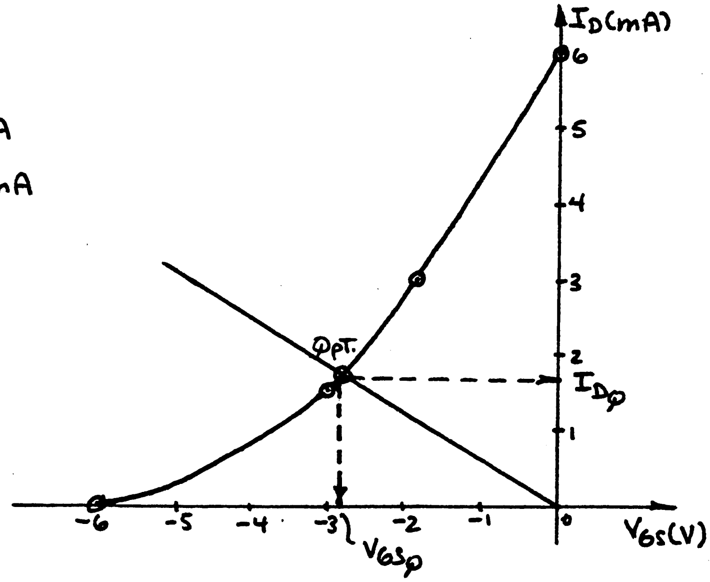
$V_{GS} = 0.3V_P = -1.8V$, $I_D = 3mA$

$V_{GS} = -I_D R_S$

$I_D = 2mA$,

$V_{GS} = -(2mA)(1.6k\Omega)$

$= -3.2V$




(a) $I_{D_Q} = \underline{1.7mA}$

$V_{GS_Q} = \underline{-2.8V}$

(b) $V_{DS} = V_{DD} - I_D(R_D + R_S)$

$= 12V - (1.7mA)(2.2k\Omega + 1.6k\Omega)$

$= \underline{5.54V}$

$V_D = V_{DD} - I_D R_D$

$= 12V - (1.7mA)(2.2k\Omega)$

$= \underline{8.26V}$

$V_G = \underline{0V}$

$V_S = I_S R_S = I_D R_S$

$= (1.7mA)(1.6k\Omega)$

$= \underline{2.72V}$ (vs. 2.8V from $V_S = -(V_{GS_Q})$)

10. (a) $V_{GS} = 0V$

$\therefore I_D = I_{DSS} = \underline{4.5mA}$

(b) $V_{DS} = V_{DD} - I_D(R_D + R_S)$

$= 20V - (4.5mA)(2.2k\Omega + 0.68k\Omega)$

$= 20V - 12.96$

$= \underline{7.04V}$

(c) $V_D = V_{DD} - I_D R_D$

$= 20V - (4.5mA)(2.2k\Omega)$

$= \underline{10.1V}$

(d) $V_S = I_S R_S = I_D R_S$

$= (4.5mA)(0.68k\Omega)$

$= \underline{3.06V}$

12. (a) $V_G = \frac{R_2}{R_1 + R_2} V_{DD} = \frac{110k\Omega(20V)}{910k\Omega + 110k\Omega}$

$= \underline{2.16V}$

$V_{GS} = 0V,\ I_D = I_{DSS} = 10mA$

$V_{GS} = V_P = -3.5V,\ I_D = 0mA$

$V_{GS} = V_P/2 = -1.75V,\ I_D = 2.5mA$

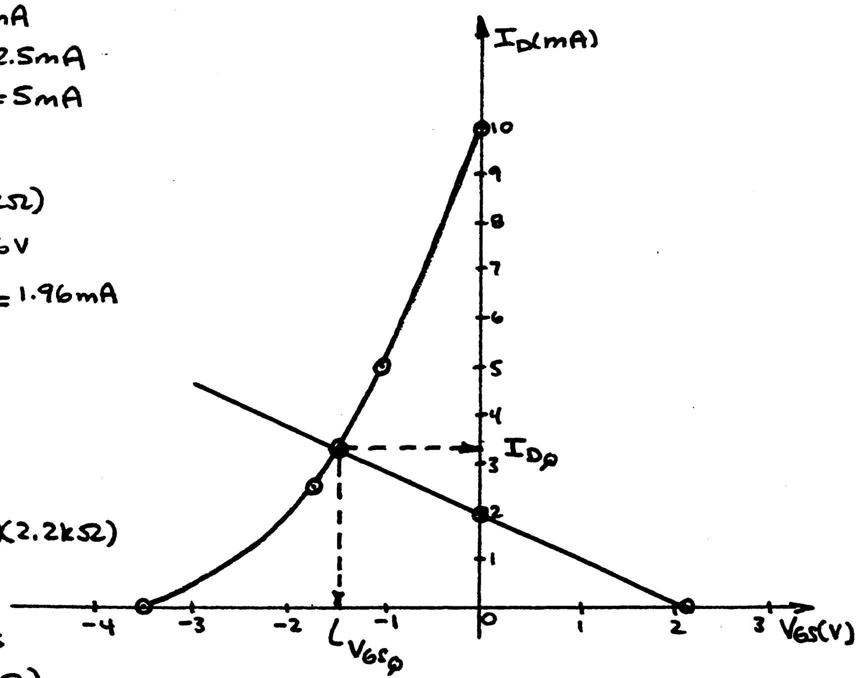
$V_{GS} = 0.3V_P = -1.05V,\ I_D = 5mA$

$V_{GS_Q} = V_G - I_D R_S$

$V_{GS_Q} = 2.16 - I_D(1.1k\Omega)$

$I_D = 0:\ V_{GS_Q} = V_G = 2.16V$

$V_{GS_Q} = 0V,\ I_D = \dfrac{2.16V}{1.1k\Omega} = 1.96mA$




(b) $I_{D_Q} \cong \underline{3.3mA}$

$V_{GS_Q} \cong \underline{-1.5V}$

(c) $V_D = V_{DD} - I_{D_Q} R_D$

$= 20V - (3.3mA)(2.2k\Omega)$

$= \underline{12.74V}$

$V_S = I_S R_S = I_D R_S$

$= (3.3mA)(1.1k\Omega)$

$= \underline{3.63V}$

(d) $V_{DS_Q} = V_{DD} - I_{D_Q}(R_D + R_S)$

$= 20V - (3.3mA)(2.2k\Omega + 1.1k\Omega)$

$= 20V - 10.89V$

$= \underline{9.11V}$

14. (a) $I_D = \dfrac{V_{R_D}}{R_D} = \dfrac{V_{DD} - V_D}{R_D} = \dfrac{18V - 9V}{2k\Omega} = \dfrac{9V}{2k\Omega} = \underline{4.5mA}$

(b) $V_S = I_S R_S = I_D R_S = (4.5mA)(0.68k\Omega)$

$= \underline{3.06V}$

$V_{DS} = V_{DD} - I_D(R_D + R_S)$

$= 18V - (4.5mA)(2k\Omega + 0.68k\Omega)$

$= 18V - 12.06V$

$= \underline{5.94V}$

(c) $V_G = \dfrac{R_2}{R_1 + R_2} V_{DD} = \dfrac{91k\Omega(18V)}{750k\Omega + 91k\Omega} = \underline{1.95V}$

$V_{GS} = V_G - V_S = 1.95V - 3.06V = \underline{-1.11V}$

(d) $V_P = \dfrac{V_{GS}}{\sqrt{1 - \sqrt{\dfrac{I_D}{I_{DSS}}}}} = \dfrac{-1.11V}{\sqrt{1 - \sqrt{\dfrac{4.5mA}{8mA}}}}$

$= \underline{-1.48V}$

16. (a) $I_D = \dfrac{V}{R} = \dfrac{V_{DD} + V_{SS} - V_{DS}}{R_D + R_S} = \dfrac{12V + 3V - 4V}{3k\Omega + 2k\Omega} = \dfrac{11V}{5k\Omega} = \underline{2.2mA}$

(b) $V_D = V_{DD} - I_D R_D = 12\text{V} - (2.2\text{mA})(3\text{k}\Omega)$
$= \underline{5.4\text{V}}$

$V_S = I_S R_S + V_{SS} = I_D R_S + V_{SS}$
$= (2.2\text{mA})(2\text{k}\Omega) + (-3\text{V})$
$= 4.4\text{V} - 3\text{V}$
$= \underline{1.4\text{V}}$

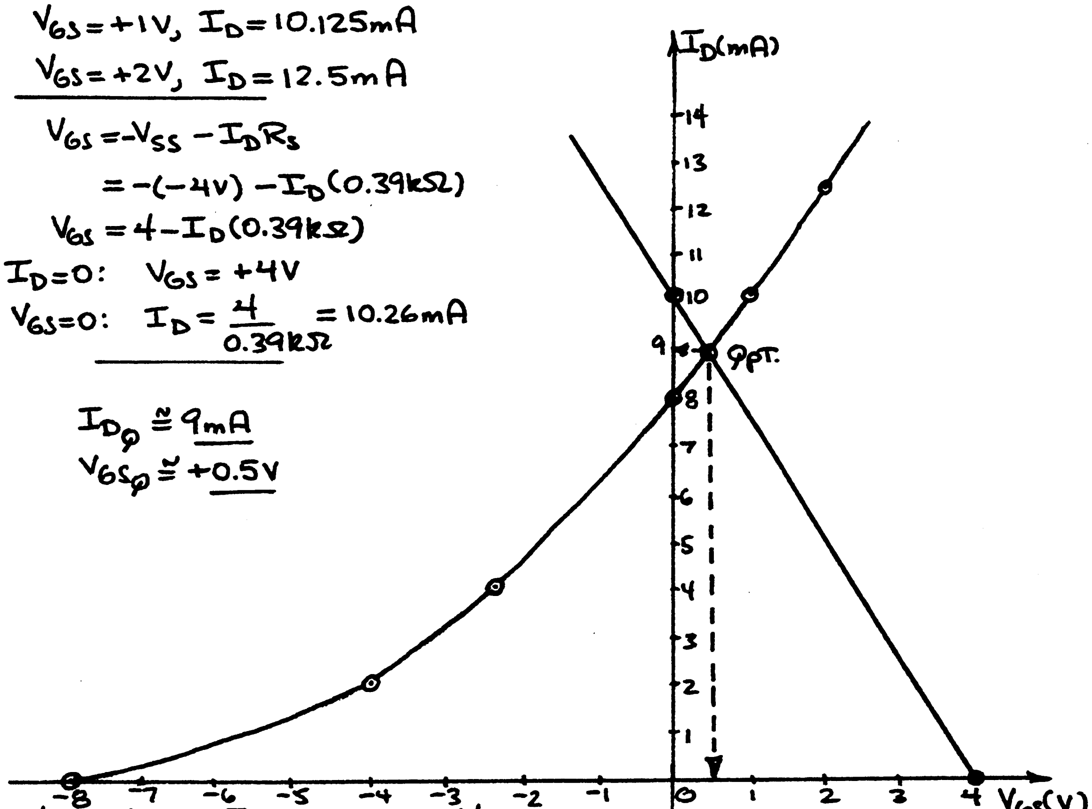
(c) $V_{GS} = V_G - V_S$
$= 0\text{V} - 1.4\text{V}$
$= \underline{-1.4\text{V}}$

18. (a)

$V_{GS} = 0\text{V},\ I_D = I_{DSS} = 8\text{mA}$
$V_{GS} = V_P = -8\text{V},\ I_D = 0\text{mA}$
$V_{GS} = \frac{V_P}{2} = -4\text{V},\ I_D = 2\text{mA}$
$V_{GS} = 0.3V_P = -2.4\text{V},\ I_D = 4\text{mA}$
$V_{GS} = +1\text{V},\ I_D = 10.125\text{mA}$
$V_{GS} = +2\text{V},\ I_D = 12.5\text{mA}$

$V_{GS} = -V_{SS} - I_D R_S$
$= -(-4\text{V}) - I_D(0.39\text{k}\Omega)$
$V_{GS} = 4 - I_D(0.39\text{k}\Omega)$
$I_D = 0$: $V_{GS} = +4\text{V}$
$V_{GS} = 0$: $I_D = \frac{4}{0.39\text{k}\Omega} = 10.26\text{mA}$

$I_{D_Q} \cong \underline{9\text{mA}}$
$V_{GS_Q} \cong \underline{+0.5\text{V}}$




(b) $V_{DS} = V_{DD} - I_D(R_D + R_S) + V_{SS}$
$= 18\text{V} - 9\text{mA}(1.2\text{k}\Omega + 0.39\text{k}\Omega) + 4\text{V}$
$= 22\text{V} - 14.31\text{V}$
$= \underline{7.69\text{V}}$

$V_S = -(V_{GS_Q}) = \underline{-0.5\text{V}}$

20. (a)

$$V_G = \frac{R_2}{R_1+R_2} V_{DD} = \frac{6.8M\Omega}{10M\Omega + 6.8M\Omega}(24V) = 9.71V$$

$V_{GS} = V_G - I_D R_S$

$V_{GS} = 9.71 - I_D(0.75k\Omega)$

At $I_D = 0mA$, $V_{GS} = 9.71V$

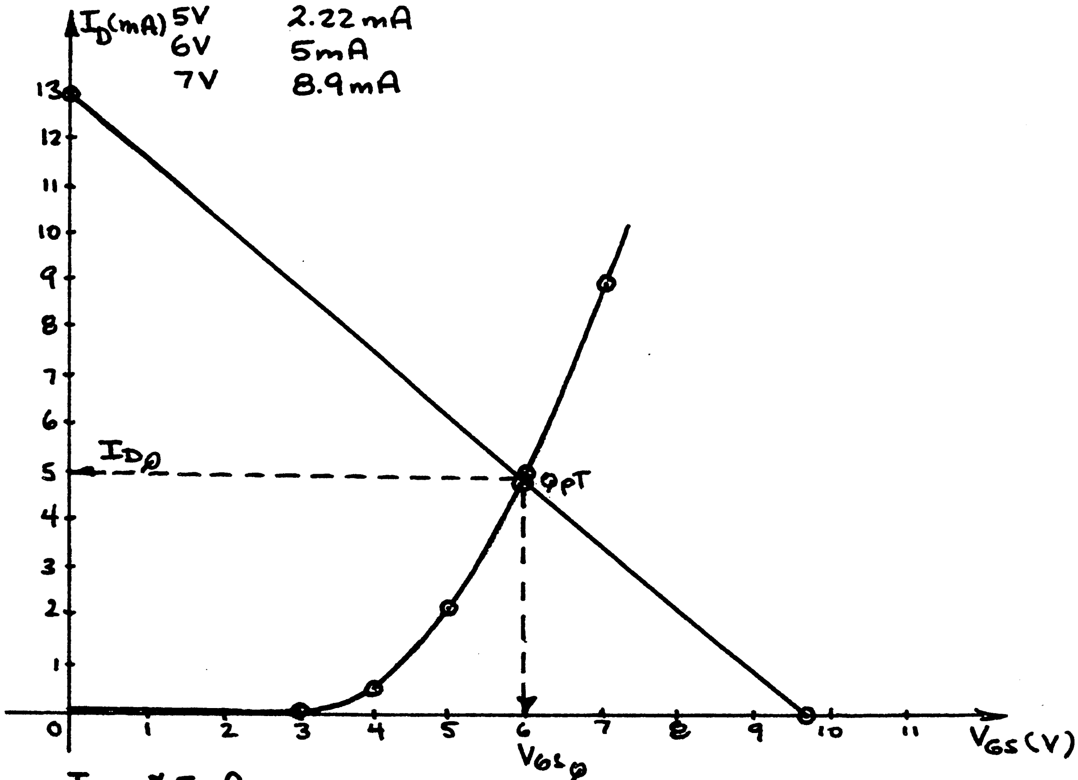
At $V_{GS} = 0V$, $I_D = \frac{9.71V}{0.75k\Omega} = 12.95mA$

$$k = \frac{I_{D(on)}}{(V_{GS(on)} - V_{GS(TH)})^2} = \frac{5mA}{(6V-3V)^2} = \frac{5mA}{(3V)^2}$$

$= 0.556 \times 10^{-3} A/V^2$

$\therefore I_D = 0.556 \times 10^{-3}(V_{GS} - 3V)^2$

| $V_{GS}$ | $I_D$ |
|---|---|
| 3V | 0mA |
| 4V | 0.556mA |
| 5V | 2.22mA |
| 6V | 5mA |
| 7V | 8.9mA |




$I_{DQ} \cong \underline{5mA}$

$V_{GSQ} \cong \underline{6V}$

(b) $V_D = V_{DD} - I_D R_D = 24V - (5mA)(2.2k\Omega)$

$= \underline{13V}$

$V_S = I_S R_S = I_D R_S$

$= (5mA)(0.75k\Omega)$

$= \underline{3.75V}$

22. 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) $V_B = V_G = \dfrac{R_2 V_{DD}}{R_1+R_2} = \dfrac{10\text{k}\Omega(16\text{V})}{40\text{k}\Omega+10\text{k}\Omega}$

$= \underline{3.2\text{V}}$

(b) $V_E = V_B - V_{BE} = 3.2\text{V} - 0.7\text{V} = \underline{2.5\text{V}}$

(c) $I_E = \dfrac{V_E}{R_E} = \dfrac{2.5\text{V}}{1.2\text{k}\Omega} = \underline{2.08\text{mA}}$

$I_C \cong I_E = \underline{2.08\text{mA}}$

$I_D = I_C = \underline{2.08\text{mA}}$

(d) $I_B = \dfrac{I_C}{\beta} = \dfrac{2.08\text{mA}}{100} = \underline{20.8\mu\text{A}}$

(e) $V_C = V_G - V_{GS}$

$V_{GS} = V_P\left(1 - \sqrt{\dfrac{I_D}{I_{DSS}}}\right)$

$= (-6\text{V})\left(1 - \sqrt{\dfrac{2.08\text{mA}}{6\text{mA}}}\right)$

$= -2.47\text{V}$

$V_C = 3.2 - (-2.47\text{V})$

$= \underline{5.67\text{V}}$

$V_S = V_C = \underline{5.67\text{V}}$

$V_D = V_{DD} - I_D R_D$

$= 16\text{V} - (2.08\text{mA})(2.2\text{k}\Omega)$

$= \underline{11.42\text{V}}$

(f) $V_{CE} = V_C - V_E = 5.67\text{V} - 2.5\text{V}$

$= \underline{3.17\text{V}}$

(g) $V_{DS} = V_D - V_S = 11.42\text{V} - 5.67\text{V}$

$= \underline{5.75\text{V}}$

24. $V_{GS} = V_P\left(1 - \sqrt{\dfrac{I_D}{I_{DSS}}}\right) = (-4\text{V})\left(1 - \sqrt{\dfrac{2.5\text{mA}}{10\text{mA}}}\right)$

$= -2\text{V}$

$V_{GS} = V_G - V_S$

and $V_S = V_G - V_{GS} = 4\text{V} - (-2\text{V})$

$= 6\text{V}$

$R_S = \dfrac{V_S}{I_D} = \dfrac{6\text{V}}{2.5\text{mA}} = \underline{2.4\text{k}\Omega}$ (a standard value)

$R_D = 2.5R_S = 2.5(2.4\text{k}\Omega) = 6\text{k}\Omega \Rightarrow$ use $\underline{6.2\text{k}\Omega}$

$V_G = \dfrac{R_2 V_{DD}}{R_1+R_2} \Rightarrow 4\text{V} = \dfrac{R_2(24\text{V})}{22\text{M}\Omega+R_2} \Rightarrow 88\text{M}\Omega + 4R_2 = 24R_2$

$20R_2 = 88\text{M}\Omega$

$R_2 = 4.4\text{M}\Omega$

Use $R_2 = \underline{4.3\text{M}\Omega}$

26. (a) $I_D = I_S = \frac{V_S}{R_S} = \frac{4V}{1k\Omega} = 4mA$

$V_{DS} = V_{DD} - I_D(R_D + R_S) = 12V - (4mA)(2k\Omega + 1k\Omega)$
$= 12V - (4mA)(3k\Omega)$
$= 12V - 12V$
$= 0V$

JFET in saturation!

(b) $V_S = 0V$ 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 $1k\Omega$ resistor.

(c) Typically, the voltage across the $1M\Omega$ resistor is $\cong 0V$. That fact that the voltage across the $1M\Omega$ resistor is equal to $V_{DD}$ suggests that there is a short-circuit connection from gate to drain with $I_D = 0mA$. Either the JFET is defective or an improper circuit connection was made.

28. $I_D = I_S = \frac{V_S}{R_S} = \frac{6.25V}{1k\Omega} = 6.25mA$

$V_{DS} = V_{DD} - I_D(R_D + R_S)$
$= 20V - (6.25mA)(2.2k\Omega + 1k\Omega)$
$= 20V - 20V$
$= 0V$ (saturation condition)

$V_G = \frac{R_2 V_{DD}}{R_1 + R_2} = \frac{75k\Omega(20V)}{330k\Omega + 75k\Omega} = 3.7V$ (as it should be)

$V_{GS} = V_G - V_S = 3.7V - 6.25V = -2.55V$

$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2 = 10mA(1 - (-2.55V)/(-6V))^2$
$= 3.3mA \neq 6.25mA$

In all probability, an open-circuit exists between the voltage divider network and the gate terminal of the JFET with the transistor exhibiting saturation conditions.

30. $k = \frac{I_{D(on)}}{(V_{GS(on)} - V_{GS(TH)})^2} = \frac{4mA}{(-7V - (-3V))^2} = \frac{4mA}{(-4V)^2}$
$= 0.25 \times 10^{-3} A/V^2$

$I_D = 0.25 \times 10^{-3}(V_{GS} + 3V)^2$

| $V_{GS}$ | $I_D$ |
|---|---|
| $-3V$ | $0mA$ |
| $-4V$ | $0.25mA$ |
| $-5V$ | $1mA$ |
| $-6V$ | $2.25mA$ |
| $-7V$ | $4mA$ |
| $-8V$ | $6.25mA$ |

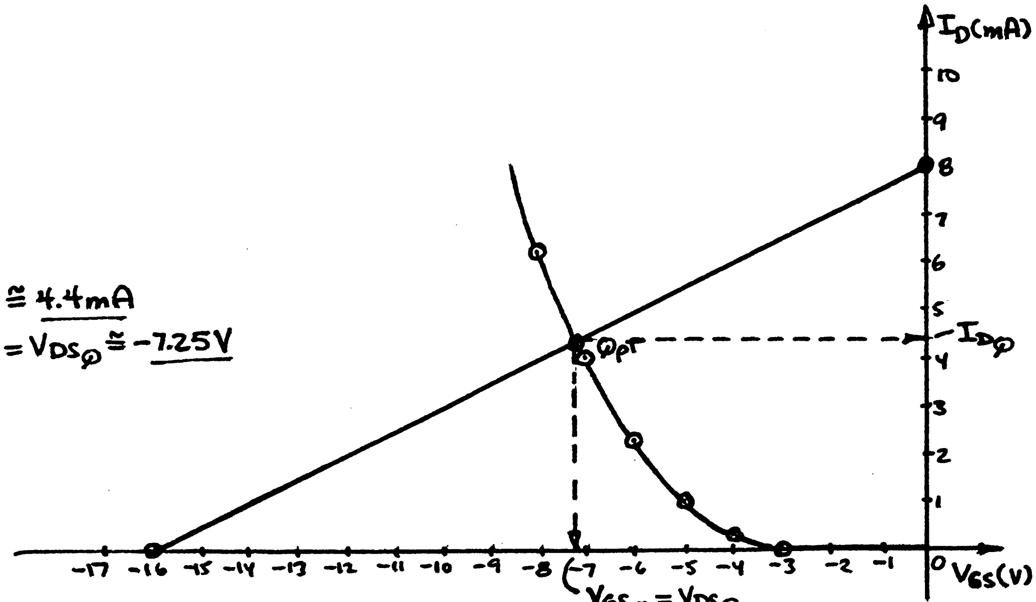
$V_{GS} = V_{DS} = V_{DD} + I_D R_D$

At $I_D = 0mA$, $V_{GS} = V_{DD} = -16V$

At $V_{GS} = 0V$, $I_D = \frac{V_{DD}}{R_D} = \frac{16V}{2k\Omega} = 8mA$

$I_{D_Q} \cong \underline{4.4mA}$

$V_{GS_Q} = V_{DS_Q} \cong -\underline{7.25V}$




(b) $V_{DS} = V_{GS} = -\underline{7.25V}$

(c) $V_D = V_{DS} = -\underline{7.25V}$

or $V_{DS} = V_{DD} + I_D R_D$

$= -16V + (4.4mA)(2k\Omega)$

$= -16V + 8.8V$

$V_{DS} = -\underline{7.2V} = V_D$

32. $m = \dfrac{|V_P|}{I_{DSS} R_S} = \dfrac{4V}{(10mA)(0.75k\Omega)}$

$= \underline{0.533}$

$M = m \dfrac{V_{GG}}{|V_P|} = 0.533 \dfrac{(0)}{4V}$

$= \underline{0}$

Draw a straight line from $M = 0$ through $m = 0.533$ until it crosses the normalized curve of $I_D = I_{DSS}(1 - \frac{V_{GS}}{V_P})^2$. At the intersection with the curve drop a line down to determine

$$\frac{V_{GS}}{|V_P|} = -0.49$$

so that $V_{GS_Q} = -0.49\, V_P = -0.49(4V)$

$= -\underline{1.96V}$ (vs. $-1.9V$ #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 $I_D = 0.27(I_{DSS}) = 0.27(10mA) = \underline{2.7mA}$

(vs. 2.7mA from #6)

(a) $V_{GS_Q} = -\underline{1.96V}$, $I_{D_Q} = \underline{2.7mA}$

(b) —

(c) —

(d) $V_{DS} = V_{DD} - I_D(R_D + R_S) = \underline{11.93V}$ (like #6)

$V_D = V_{DD} - I_D R_D = \underline{13.95V}$ (like #6)

$V_G = \underline{0V}$, $V_S = I_D R_S = \underline{2.03}$ (like #6)

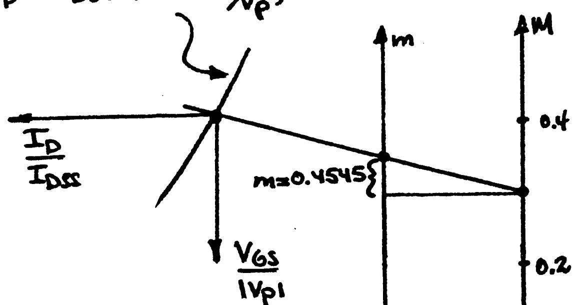
34. $m = \dfrac{|V_P|}{I_{DSS}R_S} = \dfrac{6V}{(6mA)(2.2k\Omega)}$

$= \underline{0.4545}$

$M = m\dfrac{V_{GG}}{|V_P|} = 0.4545\dfrac{(4V)}{(6V)}$

$= \underline{0.303}$

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

$$\frac{V_{GS}}{|V_P|} = -0.34$$

$$\text{\& } V_{GS_Q} = -0.34(6V)$$

$$= \underline{-2.04V} \text{ (vs. } -2V \text{ from Prob. 15)}$$

At the intersection draw a horizontal line to the $I_D/I_{DSS}$ axis to determine

$$\frac{I_D}{I_{DSS}} = 0.46$$

$$\text{\& } I_{D_Q} = 0.46(6mA)$$

$$= \underline{2.76mA} \text{ (vs. 2.7mA from Prob. 15)}$$

(a) $I_{D_Q} = \underline{2.76mA}$, $V_{GS_Q} = \underline{-2.04V}$

(b) $V_{DS} = V_{DD} + V_{SS} - I_D(R_D + R_S)$

$= 16V + 4V - (2.76mA)(4.4k\Omega)$

$= \underline{7.86V}$ (vs 8.12V from Prob. 15)

$V_S = -V_{SS} + I_D R_S = -4V + (2.76mA)(2.2k\Omega)$

$= -4V + 6.07V$

$= \underline{2.07V}$ (vs. 1.94V from Prob. 15)

Chapter 7 (Odd)

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) $P_o = I^2R = (5mA)^2 2.2k\Omega = 55mW$

$P_i = V_{CC}I = (18V)(3.8mA) = 68.4mW$

$$\eta = \frac{P_{o(ac)}}{P_{i(dc)}} = \frac{55mW}{68.4mW} = 0.804 \Rightarrow \underline{80.4\%}$$

3. $X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(1kHz)(10\mu F)} = \underline{15.92\Omega}$

$f = 100kHz: X_C = \underline{0.159\Omega}$

Yes, better at 100kHz

5. (a) The primary difference between the $r_e$ model and the hybrid parameter model is how the model is derived. The $r_e$ model is based on the internal transistor parameters of beta and the effective internal resistance of the base-emitter junction. The hybrid model is based on the terminal characteristics of the transistor under specific operating conditions. In practice, the two models are very closely related, the major difference being that the $r_e$ model does not include the output impedance of the transistor, but this parameter is often included from the hybrid model to correct the deficiency. Once one model is known the important parameters of the other can be determined from that model.

(b) Application depends on the available data, operating conditions, and suitability of a linearized approximation as the result of the calculations.

7. (a) $V_{Z_o} = V - I_o R_{sense}$

$= 600mV - (10\mu A)(10k\Omega)$

$= 600mV - 100mV$

$= 500mV$

$$Z_o = \frac{V_{Z_o}}{I_o} = \frac{500mV}{10\mu A} = \underline{50k\Omega}$$

(b) Current-divider rule:

$$I_L = \frac{Z_o(I_{amp})}{Z_o + R_L} = \frac{50k\Omega(6mA)}{50k\Omega + 2.2k\Omega}$$

$= \underline{5.747mA}$

9. (a) $I_i = \frac{V_s - V_i}{1k\Omega} = \frac{12mV - 4mV}{1k\Omega} = \frac{8mV}{1k\Omega} = \underline{8\mu A}$

(b) $Z_i = \frac{V_i}{I_i} = \frac{4mV}{8\mu A} = \underline{500\Omega}$

(c) $A_v = \dfrac{V_o}{V_i} = -180$

$V_o = (-180)(4\,mV) = \underline{-720\,mV}$

(d) $I_o = \dfrac{V_o}{R_L} = \dfrac{720\,mV}{0.51\,k\Omega} = \underline{1.41\,mA}$

(e) $A_i = \dfrac{I_o}{I_i} = \dfrac{1.41\,mA}{8\,\mu A} = \underline{176.25}$

(f) $A_i = -A_v \dfrac{Z_i}{R_L} = -\dfrac{(-180)(500\,\Omega)}{0.51\,k\Omega} = \underline{176.47}$

11. (a) $r_e = \dfrac{V_i}{I_i} = \dfrac{48\,mV}{3.2\,mA} = \underline{15\,\Omega}$

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

(c) $I_c = \alpha I_e = (0.99)(3.2\,mA) = \underline{3.168\,mA}$

(d) $V_o = I_c R_L = (3.168\,mA)(2.2\,k\Omega)$

$= \underline{6.97\,V}$

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

(f) $I_b = (1-\alpha)I_e = (1-0.99)I_e = (0.01)(3.2\,mA)$

$= \underline{32\,\mu A}$

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

$r_e = \dfrac{1200}{140}$

$= \underline{8.571\,\Omega}$

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

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

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

$A_i = \dfrac{I_L}{I_i} = \dfrac{3.321\,mA}{25\,\mu A} = \underline{132.84}$

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

$= \underline{-298.89}$

15. —

17. —

19. (a) $A_v = \dfrac{V_o}{V_i} = -160$

$V_o = \underline{-160 V_i}$

(b) $I_b = \dfrac{V_i - h_{re} V_o}{h_{ie}} = \dfrac{V_i - h_{re} A_v V_i}{h_{ie}} = \dfrac{V_i(1 - h_{re} A_v)}{h_{ie}}$

$$= V_i\frac{(1-(2\times10^{-4})(160))}{1\,k\Omega}$$

$$I_B = \underline{9.68\times10^{-4}\,V_i}$$

(c) $I_b = \frac{V_i}{1\,k\Omega} = \underline{1\times10^{-3}V_i}$

(d) $\%\text{ Difference} = \frac{1\times10^{-3}V_i - 9.68\times10^{-4}V_i}{1\times10^{-3}\,V_i}\times100\%$

$$= \underline{3.2\%}$$

(e) Valid first approximation

21. (a) $V_o = \underline{-180\,V_i}$ $\quad(h_{ie} = 4\,k\Omega,\ h_{re} = 4.05\times10^{-4})$

(b) $I_b = \frac{V_i - (4.05\times10^{-4})(180V_i)}{4\,k\Omega}$

$$= \underline{2.32\times10^{-4}\,V_i}$$

(c) $I_b = \frac{V_i}{h_{ie}} = \frac{V_i}{4\,k\Omega} = \underline{2.5\times10^{-4}\,V_i}$

(d) $\%\text{ Difference} = \frac{2.5\times10^{-4}V_i - 2.32\times10^{-4}V_i}{2.5\times10^{-4}V_i}\times100\%$

$$= \underline{7.2\%}$$

(e) Yes, less than 10%

23. (a) $h_{fe} = \left.\frac{\Delta I_c}{\Delta I_b}\right|_{V_{CE}=\text{constant}} = \frac{6.5\,mA - 5.5\,mA}{60\,\mu A - 50\,\mu A} = \frac{1\,mA}{10\,\mu A} = \underline{100}$

(b) $h_{fe} = \left.\frac{\Delta I_c}{\Delta I_b}\right|_{V_{CE}=\text{constant}} = \frac{2.3\,mA - 1.7\,mA}{5\,\mu A - 0\,\mu A} = \frac{0.6\,mA}{5\,\mu A} = \underline{120}$

25. (a) $h_{ie} = \frac{\Delta V_{be}}{\Delta I_b} = \frac{0.740\,V - 0.725\,V}{25\,\mu A - 15\,\mu A} = \frac{15\,mV}{10\,\mu A} = \underline{1.5\,k\Omega}$

(b) $h_{ie} = \frac{\Delta V_{be}}{\Delta I_b} = \frac{0.725\,V - 0.66\,V}{10\,\mu A - 0\,\mu A} = \frac{0.065\,V}{10\,\mu A} = \underline{6.5\,k\Omega}$

27. $h_{fe} = \left.\frac{\Delta I_c}{\Delta I_b}\right|_{V_{CE}=\text{const.}} = \frac{3.8\,mA - 2.8\,mA}{30\,\mu A - 20\,\mu A} = \frac{1\,mA}{10\,\mu A} = \underline{100}$

$h_{ie} = \left.\frac{\Delta V_{be}}{\Delta I_b}\right|_{V_{CE}=\text{const.}} = \frac{0.75\,V - 0.73\,V}{30\,\mu A - 20\,\mu A} = \underline{2\,k\Omega}$

$h_{oe} = \left.\frac{\Delta I_c}{\Delta V_{ce}}\right|_{I_B=\text{const.}} = \frac{2.4\,mA - 1.8\,mA}{20\,V - 5\,V} = \underline{40\,\mu S}$

29. $h_{ie} = \beta r_e = h_{fe} r_e = 1.5\,k\Omega$

$$r_e = \frac{1.5\,k\Omega}{h_{fe}} = \frac{1.5\,k\Omega}{100} = \underline{15\,\Omega}$$

$\beta = h_{fe} = \underline{100}$

$r_o = \frac{1}{h_{oe}} = \frac{1}{33\,\mu A/V} = \underline{30.3\,k\Omega}$

31. Log-log scale!

(a) $I_C = 0.2\,mA$, $h_{ie} = 4$ (normalized)

$I_C = 1\,mA$, $h_{ie} = 1$ ( " )

$\% \text{ change} = \left| \frac{4-1}{4} \right| \times 100\% = \underline{75\%}$

(b) $I_C = 5\,mA$, $h_{ie} = 0.3$ (normalized)

$\% \text{ change} = \left| \frac{1-0.3}{1} \right| \times 100\% = \underline{70\%}$

33. (a) $I_C = 10\,mA$, $h_{oe} = 10(20\,\mu S) = \underline{200\,\mu S}$

(b) $r_o = \frac{1}{h_{oe}} = \frac{1}{200\,\mu S} = 5\,k\Omega$ vs $8.6\,k\Omega$

Not a good approximation

35. (a) $h_{fe}$

(b) $h_{oe}$

(c) $h_{oe} \cong 30$ (normalized) to

$h_{oe} \cong 0.1$ ( " ) at low levels of $I_C$

(d) mid-region

# Chapter 7 (Even)

2. –

4. –

6. (a) $V_i = V_s - I_i R_{sense}$

$= 40\text{mV} - (20\mu\text{A})(0.5\text{k}\Omega)$

$= 40\text{mV} - 10\text{mV}$

$= 30\text{mV}$

$$Z_i = \frac{V_i}{I_i} = \frac{30\text{mV}}{20\mu\text{A}} = \underline{1.5\text{k}\Omega}$$

(b) Voltage-divider rule:

$$V_i = \frac{Z_i}{R_{sense} + Z_i}(V_s)$$

$$= \frac{1.5\text{k}\Omega}{0.4\text{k}\Omega + 1.5\text{k}\Omega}(12\text{mV})$$

$$= \underline{9.474\text{mV}}$$

8. (a) $V_i = V_s - I_i R_s$

$= 18\text{mV} - (10\mu\text{A})(0.6\text{k}\Omega)$

$= \underline{12\text{mV}}$

(b) $Z_i = \dfrac{V_i}{I_i} = \dfrac{12\text{mV}}{10\mu\text{A}}$

$= \underline{1.2\text{k}\Omega}$

(c) $A_{v_{NL}} = \dfrac{V_o}{V_i} = \dfrac{3.6\text{V}}{12\text{mV}}$

$= \underline{300}$

(d) $A_{v_s} = \dfrac{V_o}{V_s} = \dfrac{3.6\text{V}}{18\text{mV}}$

$= \underline{200}$

10. (a) $Z_i = \dfrac{V_i}{I_i} = \dfrac{10\text{mV}}{0.5\text{mA}}$

$= \underline{20\Omega}$ $(= r_e)$

(b) $V_o = I_c R_L$

$= \alpha I_e R_L$

$= (0.98)(0.5\text{mA})(1.2\text{k}\Omega)$

$= \underline{0.588\text{V}}$

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

$= \underline{58.8}$

(d) $Z_o = \underline{\infty\,\Omega}$

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

(f) $I_b = I_e - I_c$

$= 0.5\text{mA} - 0.49\text{mA}$

$= \underline{10\mu\text{A}}$

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

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

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

$$= \frac{2\text{ mA}}{81} = \underline{24.69\,\mu\text{A}}$$

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

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

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

$$= \frac{40\text{ k}\Omega}{40\text{ k}\Omega + 1.2\text{ k}\Omega}(80)$$

$$= \underline{77.67}$$

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

$$= -\frac{1.165\text{ k}\Omega}{13\,\Omega}$$

$$= \underline{-89.6}$$

14. $r_e = \dfrac{26\text{ mV}}{I_E(dc)} = \dfrac{26\text{ mV}}{1.2\text{ mA}} = \underline{21.67\,\Omega}$

$$\beta r_e = (120)(21.67\,\Omega) = \underline{2.6\text{ k}\Omega}$$

16. —

18. —

20. % Difference in Total load $= \dfrac{R_L - R_L \| 1/h_{oe}}{R_L} \times 100\%$

$$= \frac{2.2\text{ k}\Omega - (2.2\text{ k}\Omega \| 50\text{ k}\Omega)}{2.2\text{ k}\Omega} \times 100\%$$

$$= \frac{2.2\text{ k}\Omega - 2.1073\text{ k}\Omega}{2.2\text{ k}\Omega} \times 100\%$$

$$= \underline{4.2\%}$$

In this case the effect of $1/h_{oe}$ can be ignored.

22. From Fig. 7.28

$h_{oe}$: min $1\,\mu S$, max $30\,\mu S$ $\quad$ Avg $= \dfrac{(1+30)\,\mu S}{2} = 15.5\,\mu S$

$$\% \text{ Difference in Total load} = \frac{R_L - R_L \| 1/h_{oe}}{R_L} \times 100\%$$

$$= \frac{3.3\text{k}\Omega - 3.3\text{k}\Omega \| 1/15.5\mu\text{S}}{3.3\text{k}\Omega} \times 100\%$$

$$= \frac{3.3\text{k}\Omega - 3.3\text{k}\Omega \| 64.52\text{ k}\Omega}{3.3\text{k}\Omega} \times 100\%$$

$$= \frac{3.3\text{k}\Omega - 3.139\text{k}\Omega}{3.3\text{k}\Omega} \times 100\%$$

$$= 4.86\%$$

Again the effect of $1/h_{oe}$ can be ignored as a good first approximation

24. (a) $$h_{oe} = \left.\frac{\Delta I_c}{\Delta V_{ce}}\right|_{I_B = \text{const}}$$

$$= \frac{6.3\text{mA} - 5.8\text{mA}}{10\text{V} - 1\text{V}} = \frac{0.5\text{mA}}{9\text{V}}$$

$$= \underline{55.56 \times 10^{-6}\text{ A/V}}$$

(b) $$h_{oe} = \left.\frac{\Delta I_c}{\Delta V_{ce}}\right|_{I_B = \text{const.}}$$

$$= \frac{1.2\text{mA} - 0.8\text{mA}}{20\text{V} - 10\text{V}} = \frac{0.4\text{mA}}{10\text{V}}$$

$$= \underline{40 \times 10^{-6}\text{A/V}}$$

26. (a) $$h_{re} = \left.\frac{\Delta V_{be}}{\Delta V_{ce}}\right|_{I_B = \text{const.}}$$

$$= \frac{0.75\text{V} - 0.73\text{V}}{20\text{V} - 0\text{V}} = \frac{0.02\text{V}}{20\text{V}} =$$

$$= \underline{1 \times 10^{-3}}$$

(b) $$h_{re} = \left.\frac{\Delta V_{be}}{\Delta V_{ce}}\right|_{I_B = \text{const.}}$$

$$= \frac{0.765\text{V} - 0.725\text{V}}{20\text{V} - 0\text{V}} = \frac{0.04\text{V}}{20\text{V}} =$$

$$= \underline{2 \times 10^{-3}}$$

28. $$h_{ie} = \left.\frac{\Delta V_{be}}{\Delta I_b}\right|_{V_{ce} = \text{const}}$$

$$= \frac{0.755\text{V} - 0.735}{30\mu\text{A} - 20\mu\text{A}} = \frac{0.02\text{V}}{10\mu\text{A}} = \underline{2\text{k}\Omega}$$

$$h_{fe} = \left.\frac{\Delta I_c}{\Delta I_b}\right|_{V_{CE} = \text{const}}$$

$$= \frac{3.8\text{mA} - 2.9\text{mA}}{30\mu\text{A} - 20\mu\text{A}} = \frac{0.9\text{mA}}{10\mu\text{A}} = \underline{90}$$

$$h_{oe} = \left.\frac{\Delta I_c}{\Delta V_{ce}}\right|_{I_B = \text{const.}}$$

$$= \frac{3.4\,\text{mA} - 3.2\,\text{mA}}{15\,\text{V} - 10\,\text{V}} = \frac{0.2\,\text{mA}}{5\,\text{V}} = 40\times10^{-6}\,\text{S} = 40\,\mu\text{S}$$

$$h_{ie} = \beta r_e \Rightarrow r_e = \frac{h_{ie}}{\beta} = \frac{2{,}000\,\Omega}{90} = \underline{22.22\,\Omega}$$

$$\beta = h_{fe} = \underline{90}$$

$$r_o = \frac{1}{h_{oe}} = \frac{1}{40\,\mu\text{S}} = \underline{25\,\text{k}\Omega}$$

30. (a) $h_{fe}(0.2\,\text{mA}) \cong 0.6$ (normalized)

$h_{fe}(1\,\text{mA}) = 1.0$

$$\%\text{ change} = \left|\frac{h_{fe}(0.2\,\text{mA}) - h_{fe}(1\,\text{mA})}{h_{fe}(0.2\,\text{mA})}\right| \times 100\%$$

$$= \left|\frac{0.6 - 1}{0.6}\right| \times 100\%$$

$$= \underline{66.7\%}$$

(b) $h_{fe}(1\,\text{mA}) = 1.0$

$h_{fe}(5\,\text{mA}) \cong 1.5$

$$\%\text{ change} = \left|\frac{h_{fe}(1\,\text{mA}) - h_{fe}(5\,\text{mA})}{h_{fe}(1\,\text{mA})}\right| \times 100\%$$

$$= \left|\frac{1 - 1.5}{1}\right| \times 100\%$$

$$= \underline{50\%}$$

32. (a) $h_{oe} = 20\,\mu\text{S}$ @ 1 mA

$I_C = 0.2\,\text{mA}$, $h_{oe} = 0.2(h_{oe}\text{ @ }1\,\text{mA})$

$$= 0.2(20\,\mu\text{S})$$

$$= \underline{4\,\mu\text{S}}$$

(b) $r_o = \dfrac{1}{h_{oe}} = \dfrac{1}{4\,\mu\text{S}} = 250\,\text{k}\Omega \gg 6.8\,\text{k}\Omega$

Ignore $1/h_{oe}$

34. (a) $h_{re}(0.1\,\text{mA}) = 4(h_{re}(1\,\text{mA}))$

$$= 4(2\times10^{-4})$$

$$= \underline{8\times10^{-4}}$$

(b) $h_{re}V_{ce} = h_{re}A_v \cdot V_i$

$$= (8\times10^{-4})(210)V_i$$

$$= 0.168\,V_i$$

In this case $h_{re}V_{ce}$ too large a factor to be ignored.

36. (a) $h_{ie}$ is the most temperature sensitive parameter of Fig. 7.47.

(b) $h_{oe}$ exhibited the smallest change

(c) Normalized: $h_{fe(max)} = \underline{1.5}$, $h_{fe(min)} = \underline{0.5}$

For $h_{fe} = 100$ the range would extend from 50 to 150 is 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 $0° \rightarrow 100°C$.

## Chapter 8 (Odd)

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

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

$= 3.13\text{ mA}$

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

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

$= \underline{497.47\Omega}$

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

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

$A_i \cong \beta = \underline{60}$

(c) $Z_i = 497.47\Omega$ (the same)

$Z_o = r_o \| R_C = 20\text{k}\Omega \| 2.2\text{k}\Omega = \underline{1.98\text{k}\Omega}$

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

$A_i = -A_v Z_i / R_C = -(-238.27)(497.47\Omega)/2.2\text{k}\Omega$

$= \underline{53.88}$

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

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

$r_e = \dfrac{26\text{mV}}{I_E} = \dfrac{26\text{mV}}{2.41\text{mA}} = \underline{10.79\Omega}$

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

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

$= \underline{1.08\text{k}\Omega}$

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

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

$A_i \cong \beta = \underline{100}$

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

$A_i = -A_v \dfrac{Z_i}{R_C} = -(-348.47)\dfrac{(1.08\text{k}\Omega)}{4.3\text{k}\Omega} = \underline{87.52}$

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

$(100)(1\text{k}\Omega) \geq 10(5.6\text{k}\Omega)$

$100\text{k}\Omega > 56\text{k}\Omega$ (checks!) & $r_o \geq 10R_C$

Use approximate approach:

$A_v = -\dfrac{R_C}{r_e} \Rightarrow r_e = -\dfrac{R_C}{A_v} = -\dfrac{(3.3\text{k}\Omega)}{-160} = 20.625\Omega$

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

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

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

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

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

$V_{CC} = \underline{30.68\text{V}}$

7. (a) $I_B = \dfrac{V_{CC} - V_{BE}}{R_B + (\beta+1)R_E} = \dfrac{20\text{V} - 0.7\text{V}}{390\text{k}\Omega + (141)(1.2\text{k}\Omega)}$

$= \dfrac{19.3\text{V}}{559.2\text{k}\Omega} = 34.51\mu\text{A}$

$I_E = (\beta+1)I_B = (140+1)(34.51\mu\text{A}) = 4.866\text{mA}$

$r_e = \dfrac{26\text{mV}}{I_E} = \dfrac{26\text{mV}}{4.866\text{mA}} = \underline{5.34\Omega}$

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

$= (140)(5.34\Omega) + (140+1)(1.2\text{k}\Omega) = 747.6\Omega + 169.2\text{k}\Omega$

$= 169.95\text{k}\Omega$

$Z_i = R_B \| Z_b = 390\text{k}\Omega \| 169.95\text{k}\Omega = \underline{118.37\text{k}\Omega}$

$Z_o = R_C = 2.2\text{k}\Omega$

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

$A_i = -\dfrac{A_v Z_i}{R_C} = -(-1.81)(118.37\text{k}\Omega)/2.2\text{k}\Omega$

$= \underline{97.39}$

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

$= 747.6\Omega + \left[\dfrac{(141) + 2.2\text{k}\Omega/20\text{k}\Omega}{1 + (3.4\text{k}\Omega)/20\text{k}\Omega}\right]1.2\text{k}\Omega$

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

$= 145.47\text{k}\Omega$

$Z_i = R_B \| Z_b = 390\text{k}\Omega \| 145.47\text{k}\Omega = \underline{105.95\text{k}\Omega}$

$Z_o = R_C = \underline{2.2\text{k}\Omega}$ (any level of $r_o$)

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

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

$= \dfrac{-2.117 + 0.11}{1.11} = -\underline{1.81}$

$A_i = -A_v \dfrac{Z_i}{R_C} = -(-1.81)\dfrac{(105.95\text{k}\Omega)}{2.2\text{k}\Omega} = \underline{87.17}$

9 (a) dc analysis the same

$\therefore r_e = \underline{5.34\Omega}$ (as in #7)

(b) $Z_i = R_B \| Z_b = R_B \| \beta r_e = 390\text{k}\Omega \| (140)(5.34\Omega) = \underline{746.17\Omega}$

vs. $118.37\text{k}\Omega$ in #7

$Z_o = R_C = 2.2\text{ k}\Omega$ (as in #7)

(c) $A_v = -\dfrac{R_C}{r_e} = -\dfrac{2.2\text{ k}\Omega}{5.34\,\Omega} = \underline{-411.99}$ vs $-1.81$ in #7

$A_i = \dfrac{\beta R_B}{R_B + Z_b} = \dfrac{(140)(390\text{ k}\Omega)}{390\text{ k}\Omega + 0.746\text{ k}\Omega} = \underline{139.73}$ vs. 97.39 in #7

(d) $Z_i = \underline{746.17\,\Omega}$ vs. $105.95\text{ k}\Omega$ for #7

$Z_o = R_C \| r_o = 2.2\text{ k}\Omega \| 20\text{ k}\Omega = \underline{1.98\text{ k}\Omega}$ vs. $2.2\text{ k}\Omega$ in #7

$A_v = -\dfrac{R_C \| r_o}{r_e} = -\dfrac{1.98\text{ k}\Omega}{5.34\,\Omega} = \underline{-370.79}$ vs. $-1.81$ in #7

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

$= \underline{125.76}$ vs 87.17 in #7

Significant difference in the results for $A_v$ and $A_i$.

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

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

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

$= 2.98\text{ mA}$

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

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

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

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

$= 300.66\text{ k}\Omega$

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

$= 142.25\text{ k}\Omega$

$Z_o = R_E \| r_e = 2.7\text{ k}\Omega \| 8.72\,\Omega = \underline{8.69\,\Omega}$

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

$A_i = -A_v Z_i / R_L = -(0.997)(142.25\text{ k}\Omega)/2.7\text{ k}\Omega$

$= \underline{-52.53}$

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

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

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

Use approximate approach:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$A_i = \dfrac{I_o}{I_i} = \dfrac{\alpha I_e}{I_e} = \alpha = \underline{0.9868} \cong 1$

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

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

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

$19 R_F + 3800 R_C = 200 R_F$

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

$= \underline{33.59k\Omega}$

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

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

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

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

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

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

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

$= \underline{5.28V}$

19. (a)

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

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

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

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

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

$$= 39\text{k}\Omega \| (80)(7.93\ \Omega) = 39\text{k}\Omega \| 634.4\ \Omega = \underline{0.62\text{k}\Omega}$$

$$Z_o = R_C \| R_{F_2} = 1.8\text{k}\Omega \| 22\text{k}\Omega = \underline{1.66\text{k}\Omega}$$

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

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

$$A_i = -\frac{A_v Z_i}{R_C} = -\frac{(-209.82)(0.62\text{k}\Omega)}{1.8\text{k}\Omega} = \underline{72.27}$$

21. (a) $r_e = \underline{8.31\ \Omega}$ (from problem 1)

(b) $h_{fe} = \beta = \underline{60}$

$h_{ie} = \beta r_e = (60)(8.31\ \Omega) = \underline{498.6\ \Omega}$

(c) $Z_i = R_B \| h_{ie} = 220\text{k}\Omega \| 498.6\ \Omega = \underline{497.47\ \Omega}$

$Z_o = R_C = \underline{2.2\text{k}\Omega}$

(d) $$A_v = -\frac{h_{fe} R_C}{h_{ie}} = -\frac{(60)(2.2\text{k}\Omega)}{498.6\ \Omega} = \underline{-264.74}$$

$A_i \cong h_{fe} = \underline{60}$

(e) $Z_i = 497.47\ \Omega$ (the same)

$Z_o = r_o \| R_C$, $\quad r_o = \frac{1}{25\ \mu\text{S}} = 40\text{k}\Omega$

$= 40\text{k}\Omega \| 2.2\text{k}\Omega$

$= 2.09\text{k}\Omega$

(f) $$A_v = -\frac{h_{fe}(r_o \| R_C)}{h_{ie}} = -\frac{(60)(2.085\text{k}\Omega)}{498.6\ \Omega} = \underline{-250.90}$$

$$A_i = -A_v Z_i / R_C = -(-250.90)(497.47\ \Omega)/2.2\text{k}\Omega = \underline{56.73}$$

23. a. $Z_i = R_E \| h_{ib}$

$= 1.2\text{k}\Omega \| 9.45\Omega$

$= \underline{9.38\Omega}$

$Z_o = R_C \| \frac{1}{h_{ob}} = 2.7\text{k}\Omega \| \frac{1}{1\times10^{-6}\text{A/V}} = 2.7\text{k}\Omega \| 1\text{M}\Omega \cong \underline{2.7\text{k}\Omega}$

b. $A_v = \frac{-h_{fb}(R_C \| 1/h_{ob})}{h_{ib}} = \frac{-(-0.992)(\cong 2.7\text{k}\Omega)}{9.45\Omega}$

$= \underline{283.43}$

$A_i \cong \underline{-1}$

c. $\alpha = -h_{fb} = -(-0.992) = \underline{0.992}$

$\beta = \frac{\alpha}{1-\alpha} = \frac{0.992}{1-0.992} = \underline{124}$

$r_e = h_{ib} = \underline{9.45\Omega}$

$r_o = \frac{1}{h_{ob}} = \frac{1}{1\mu\text{A/V}} = \underline{1\text{M}\Omega}$

25. a. $Z_i = h_{ie} - \frac{h_{fe}h_{re}R_L}{1+h_{oe}R_L}$

$= 0.86\text{k}\Omega - \frac{(140)(1.5\times10^{-4})(2.2\text{k}\Omega)}{1+(25\mu\text{S})(2.2\text{k}\Omega)}$

$= 0.86\text{k}\Omega - 43.79\Omega$

$= 816.21\Omega$

$Z_i' = R_B \| Z_i = 470\text{k}\Omega \| 80$

$= 470\text{k}\Omega \| 816.21\Omega$

$= \underline{814.8\Omega}$

b. $A_v = \frac{-h_{fe}R_L}{h_{ie} + (h_{ie}h_{oe} - h_{fe}h_{re})R_L}$

$= \frac{-(140)(2.2\text{k}\Omega)}{0.86\text{k}\Omega + ((0.86\text{k}\Omega)(25\mu\text{S}) - (140)(1.5\times10^{-4}))2.2\text{k}\Omega}$

$= \underline{-357.68}$

c. $A_i = \frac{I_o}{I_i} = \frac{h_{fe}}{1+h_{oe}R_L} = \frac{140}{1+(25\mu\text{S})(2.2\text{k}\Omega)}$

$= 132.70$

$A_i' = \frac{I_o}{I_i'} = \left(\frac{I_o}{I_i}\right)\left(\frac{I_i}{I_i'}\right)$ $\quad I_i = \frac{470\text{k}\Omega I_i'}{470\text{k}\Omega + 0.816\text{k}\Omega}$

$= (132.70)(0.998)$ $\quad \frac{I_i}{I_i'} = 0.998$

$= \underline{132.43}$

d. $Z_o = \frac{1}{h_{oe} - (h_{fe}h_{re}/(h_{ie}+R_s))}$

$$= \frac{1}{25\times10^{-6} - ((140)(1.5\times10^{-4})/(0.86\,k\Omega + 1\,k\Omega))}$$

$$= 72.94\,k\Omega$$

$$Z_o' = R_C \| Z_o = 2.2\,k\Omega \| 72.94\,k\Omega$$

$$= \underline{2.14\,k\Omega}$$

27. a. Test:

$$\beta R_E \geq 10R_2$$

$$70(1.5\,k\Omega) \overset{?}{\geq} 10(39\,k\Omega)$$

$$105\,k\Omega \geq 390\,k\Omega$$

no!

$$R_{Th} = 39\,k\Omega \| 150\,k\Omega = 30.95\,k\Omega$$

$$E_{Th} = \frac{39\,k\Omega(14\,V)}{39\,k\Omega + 150\,k\Omega} = 2.89\,V$$

$$I_B = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta+1)R_E} = \frac{2.89\,V - 0.7\,V}{30.95\,k\Omega + (71)(1.5\,k\Omega)}$$

$$= 15.93\,\mu A$$

$$V_B = E_{Th} - I_B R_{Th}$$

$$= 2.89\,V - (15.93\,\mu A)(30.95\,k\Omega)$$

$$= 2.397\,V \neq 6.18\,V$$

∴ No – not operating properly

$$V_E = 6.18\,V - 0.7\,V = 5.48\,V$$

$$\text{+ } I_E = \frac{V_E}{R_E} = \frac{5.48\,V}{1.5\,k\Omega} = 3.65\,mA$$

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

$$= 14\,V - 3.65\,mA(2.2\,k\Omega + 1.5\,k\Omega)$$

$$= 0.495\,V$$

Device is saturated

$$V_{CE} \cong V_{CE_{sat}}$$

$$I_C \cong I_E = 3.65\,mA$$

with $I_{C_{sat}} = \dfrac{14\,V}{2.2\,k\Omega + 1.5\,k\Omega} = 3.78\,mA$ ∴ Saturated.

(b) $R_2$ not connected at base:

$$I_B = \frac{V_{CC} - 0}{R_B + (\beta+1)R_E} = \frac{14\,V - 0.7\,V}{150\,K + (71)(1.5\,k\Omega)} = 51.85\,\mu A$$

$$V_B = V_{CC} - I_B R_B = 14\,V - (51.85\,\mu A)(150\,k\Omega)$$

$= \underline{6.22\,V}$ as noted in Fig. 8.82.

Chapter 8 (Even)

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

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

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

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

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

$= 12.15\text{ V} + 0.7\text{ V}$

$= \underline{12.85\text{ V}}$

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

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

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

Use approximate approach:

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

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

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

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

(b) $Z_i = R_1 \| R_2 \| \beta r_e$

$= 4.7\text{ k}\Omega \| 39\text{ k}\Omega \| (100)(30.56\ \Omega)$

$= \underline{1.768\text{ k}\Omega}$

$r_o \geq 10 R_C \therefore Z_o \cong R_C = \underline{3.9\text{ k}\Omega}$

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

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

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

(b) $Z_i$ (unchanged) $= \underline{1.768\text{ k}\Omega}$

$Z_o = R_C \| r_o = 3.9\text{ k}\Omega \| 25\text{ k}\Omega = \underline{3.37\text{ k}\Omega}$

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

$= \underline{-110.28}$ (vs. $-127.6$)

$A_i = -A_v \cdot Z_i / R_C = -(-110.28)(1.768\text{ k}\Omega)/3.9\text{ k}\Omega$

$\cong \underline{50}$

6. Test $\beta R_E \geq 10 R_2$

$(180)(2.2\text{ k}\Omega) \overset{?}{\geq} 10(56\text{ k}\Omega)$

$396\text{ k}\Omega < 560\text{ k}\Omega$ (not satisfied)

Use exact analysis:

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

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

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

$= 7.58\ \mu\text{A}$

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

$= 1.372\text{ mA}$

$r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{1.372\text{ mA}} = \underline{18.95\Omega}$

(b) $V_E = I_E R_E = (1.372\text{ mA})(2.2\text{ k}\Omega) = 3.02\text{ V}$

$V_B = V_E + V_{BE} = 3.02\text{ V} + 0.7\text{ V}$

$= \underline{3.72\text{ V}}$

$V_C = V_{CC} - I_C R_C$

$= 20\text{ V} - \beta I_B R_C = 20\text{ V} - (180)(7.58\ \mu\text{A})(6.8\text{ k}\Omega)$

$= \underline{10.72\text{ V}}$

(c) $Z_i = R_1 \| R_2 \| \beta r_e$

$= 56\text{ k}\Omega \| 220\text{ k}\Omega \| (180)(18.95\Omega)$

$= 44.64\text{ k}\Omega \| 3.41\text{ k}\Omega$

$= \underline{3.17\text{ k}\Omega}$

$r_o < 10R_C \therefore A_v = -\dfrac{R_C \| r_o}{r_e}$

$= -\dfrac{(6.8\text{ k}\Omega) \| (50\text{ k}\Omega)}{18.95\Omega}$

$= \underline{-315.88}$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$= 560\Omega + [81.14/1.17]\,1.2k\Omega = 560\Omega + 83.22k\Omega$$

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

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

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

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

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

$$= \underline{-4.57}$$

(c) $A_i = -A_v \dfrac{Z_i}{R_C} = -(-4.57)(66.82k\Omega)/5.6k\Omega$

$$= \underline{54.53}$$

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

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

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

$r_o < 10R_E$:

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

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

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

$= \underline{598.16\text{k}\Omega}$

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

$= \underline{236.1\text{k}\Omega}$

$Z_o \cong R_E \| r_e$

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

$= \underline{31.2\Omega}$

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

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

$= \underline{0.994}$

(c) $A_v = \frac{V_o}{V_i} = 0.994$

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

14. a. $$I_E = \frac{V_{EE}-V_{BE}}{R_E} = \frac{6\text{V}-0.7\text{V}}{6.8\text{k}\Omega} = 0.779\text{mA}$$

$$r_e = \frac{26\text{mV}}{I_E} = \frac{26\text{mV}}{0.779\text{mA}} = \underline{33.38\Omega}$$

b. $Z_i = R_E \| r_e = 6.8\text{k}\Omega \| 33.38\Omega$

$= \underline{33.22\Omega}$

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

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

$= \underline{140.52}$

$A_i = \dfrac{I_o}{I_i} = -\alpha = \underline{-0.998}$

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

$= 16.42\mu\text{A}$

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

$= 1.987\text{mA}$

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

b. $Z_i = \beta r_e \| \dfrac{R_F}{|A_v|}$

Need $A_v$!

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

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

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

$= \underline{501.98\Omega}$

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

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

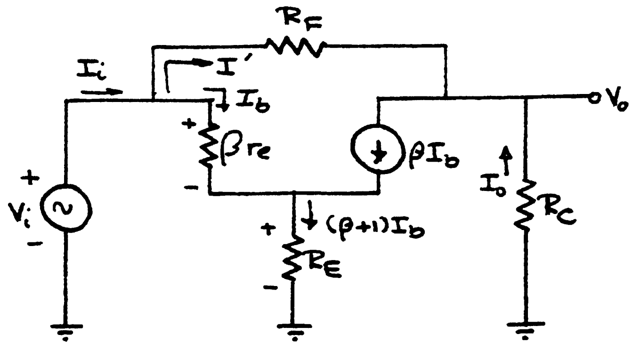
c. From above, $A_v = -298$

$A_i = -A_v Z_i / R_C$

$= -(-298)(501.98\Omega)/3.9\text{k}\Omega$

$= \underline{38.37}$

18. a.




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 $I' = I_i - I_b$

Subst: $I_o + (I_i - I_b) = \beta I_b$

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, $\dfrac{V_o}{V_i} = \dfrac{-(\beta+1)I_b R_C}{I_b\beta r_e + (\beta+1)I_b R_E}$

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

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

b. Kirchhoff's voltage law:

$V_i - V_{R_F} - V_o = 0$

$(I_b\beta r_e + (\beta+1)I_b R_E) - (I'R_F) - (-I_o R_C) = 0$

but $I'R_F = (I_i - I_b)R_F = I_i R_F - I_b R_F$

and $I_o \cong (\beta+1)I_b$ from part a

Using $\beta+1 \cong \beta$

$I_b\beta r_e + \beta I_b R_E - I_i R_F + I_b R_F + I_o R_C = 0$

Using $I_o \cong \beta I_b$

$I_o r_e + I_o R_E - I_i R_F + \dfrac{\beta I_b}{\beta} R_F + I_o R_C = 0$

and $I_o(r_e + R_E + \dfrac{R_F}{\beta} + R_C) = I_i R_F$

Assuming $r_e \ll R_E$, $R_C$ or $R_F/\beta$

$$\underline{A_i = \frac{I_o}{I_i} \cong \frac{R_F}{R_E + R_C + R_F/\beta}}$$

c. $V_i \cong \beta I_b(r_e + R_E)$

For $r_e \ll R_E$

$V_i \cong \beta I_b R_E$

Now $I_i = I' + I_b$

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

Since $V_o \gg V_i$

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

or $I_b = I_i + \dfrac{V_o}{R_F}$

and $V_i = \beta I_b R_E$

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

but $V_o = A_v V_i$

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

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

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

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

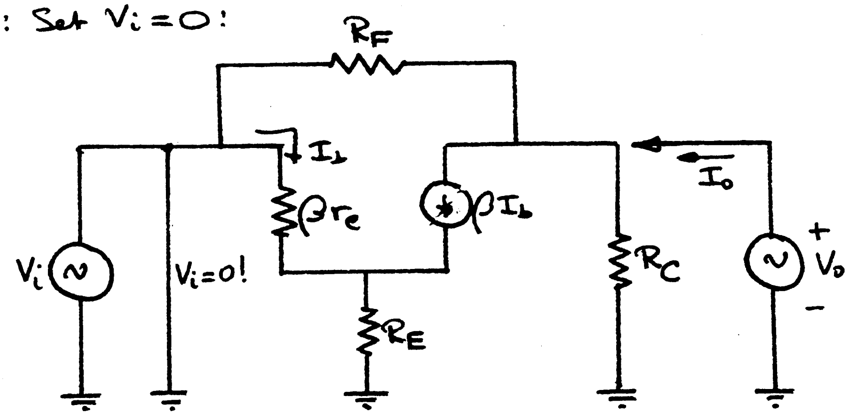
$Z_i = \dfrac{V_i}{I_i} = X \| Y$ where $X = \beta R_E$

& $Y = R_F/|A_v|$

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

$Z_i \cong \underline{\dfrac{\beta R_E R_F}{\beta R_E |A_v| + R_F}}$

$Z_o$: Set $V_i = 0$:



$V_i = I_b\beta r_e + (\beta+1)I_b R_E$

$V_i \cong \beta I_b(r_e + R_E) = 0$

since $\beta$, $r_e + R_E \neq 0$ $\quad I_b = 0 + \beta I_b = 0$

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

$+ Z_o = \dfrac{V_o}{I_o} = \dfrac{1}{\frac{1}{R_C} + \frac{1}{R_F}} = \dfrac{R_C R_F}{R_C + R_F} = \underline{R_C \| R_F}$

d. $A_v \cong -\dfrac{R_C}{R_E} = -\dfrac{2.2\text{ k}\Omega}{1.2\text{ k}\Omega} = \underline{-1.83}$

$A_i \cong \dfrac{R_F}{R_E + R_C + R_F/\beta} = \dfrac{120\text{ k}\Omega}{1.2\text{ k}\Omega + 2.2\text{ k}\Omega + 120\text{ k}\Omega/90}$

$= \underline{25.37}$

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

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

$Z_o \cong R_C \| R_F$

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

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

20. a. $h_{fe} = \beta = \underline{120}$

$h_{ie} \cong \beta r_e = (120)(4.5\ \Omega) = \underline{540\ \Omega}$

$h_{oe} = \dfrac{1}{r_o} = \dfrac{1}{40\text{ k}\Omega} = \underline{25\ \mu\text{S}}$

b. $r_e \cong \dfrac{h_{ie}}{\beta} = \dfrac{1\text{ k}\Omega}{90} = \underline{11.11\ \Omega}$

$\beta = h_{fe} = \underline{90}$

$r_o = \dfrac{1}{h_{oe}} = \dfrac{1}{20\ \mu\text{S}}$

$= \underline{50\text{ k}\Omega}$

22. a. $68\text{ k}\Omega \| 12\text{ k}\Omega = 10.2\text{ k}\Omega$

$Z_i = 10.2\text{ k}\Omega \| h_{ie} = 10.2\text{ k}\Omega \| 2.75\text{ k}\Omega$

$= \underline{2.166\text{ k}\Omega}$

$Z_o = R_C \| r_o$

$= 2.2\text{ k}\Omega \| 40\text{ k}\Omega$

$= \underline{2.085\text{ k}\Omega}$

b. $A_v = -\dfrac{h_{fe} R_C'}{h_{ie}} \qquad R_C' = R_C \| r_o = 2.085\text{ k}\Omega$

$= -\dfrac{(180)(2.085\text{ k}\Omega)}{2.75\text{ k}\Omega} = \underline{-136.5}$

$$A_i = -A_v Z_i/R_C$$
$$= -(-136.5)(2.166\text{k}\Omega)/2.2\text{k}\Omega$$
$$= \underline{134.39}$$

c. $$I_B = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta+1)R_E}$$
$$= \frac{2.7\text{V} - 0.7\text{V}}{10.2\text{ k}\Omega + (181)(1.2\text{k}\Omega)}$$
$$= \frac{2\text{V}}{10.2\text{k}\Omega + 217.2\text{k}\Omega}$$
$$= 8.795\,\mu\text{A}$$

$$E_{Th} = \frac{R_2}{R_1+R_2} V_{CC}$$
$$= \frac{12\text{k}\Omega\,(18\text{V})}{68\text{k}\Omega + 12\text{k}\Omega}$$
$$= 2.7\text{ V}$$
$$R_{Th} = R_1 \| R_2$$
$$= 68\text{k}\Omega \| 12\text{ k}\Omega$$
$$= 10.2\text{k}\Omega$$

$$I_E = (\beta+1)I_B$$
$$= (181)(8.795\,\mu\text{A})$$
$$= 1.59\text{mA}$$

$$r_e = \frac{26\text{mV}}{I_E} = \frac{26\text{mV}}{1.59\text{mA}} = 16.33\Omega$$

$$\beta r_e = (180)(16.33\Omega) = \underline{2.94\text{k}\Omega} \text{ vs. } h_{ie} = 2.75\text{k}\Omega$$

24. a. $$Z_i = h_{ie} - \frac{h_{fe}\,h_{re}\,R_L}{1 + h_{oe}R_L}$$
$$= 2.75\text{k}\Omega - \frac{(180)(2\times10^{-4})(2.2\text{k}\Omega)}{1+(25\times10^{-6})(2.2\text{k}\Omega)}$$
$$= 2.75\text{ k}\Omega - 75.07\Omega$$
$$= 2.675\text{k}\Omega$$

$$Z_i' = R_{BIAS} \| Z_i$$
$$= 10.2\text{k}\Omega \| 2.675\text{k}\Omega$$
$$= \underline{2.12\text{k}\Omega} \text{ (vs. } 2.166\text{k}\Omega \text{ \#22)}$$

$$Z_o = \frac{1}{h_{oe} - [h_{fe}h_{re}/(h_{ie}+R_s)]}$$
$$= \frac{1}{25\times10^{-6} - [(180)(2\times10^{-4})/(2.75\text{k}\Omega+0)]}$$
$$= 83.97\text{k}\Omega$$

$$Z_o' = Z_o \| R_C = 83.97\text{k}\Omega \| 2.2\text{k}\Omega$$
$$= \underline{2.14\text{k}\Omega} \text{ (vs. } 2.085\text{k}\Omega \text{ \#22)}$$

(b) $$A_v = \frac{-h_{fe}R_L}{h_{ie} + (h_{ie}h_{oe} - h_{fe}h_{re})R_L}$$
$$= \frac{-(180)(2.2\text{k}\Omega)}{2.75\text{k}\Omega + ((2.75\text{k}\Omega)(25\times10^{-6}) - (180)(2\times10^{-4}))(2.2\text{k}\Omega)}$$

$A_v = \underline{140.32}$ (vs. 136.5 #22)

$$A_i = \frac{h_{fe}}{1 + h_{oe}R_L} = \frac{180}{1 + (25\times10^{-6})(2.2\text{ k}\Omega)}$$
$$= 170.62$$

$$A_i' = \frac{I_o}{I_i} = \frac{I_o}{I_b}\cdot\frac{I_b}{I_i}$$
$$= A_i \frac{I_b}{I_i}$$

$$I_b = \frac{10.2\text{ k}\Omega\, I_i}{10.2\text{ k}\Omega + 2.75\text{ k}\Omega} = 0.788 I_i$$

$$A_i' = (170.62)(0.788)$$
$$= \underline{134.45} \text{ (vs. 134.39 \#22)}$$

26. a. $$Z_i = h_{ib} - \frac{h_{fb}h_{rb}R_L}{1 + h_{ob}R_L}$$
$$= 9.45\,\Omega - \frac{(-0.997)(1\times10^{-6})(2.2\text{ k}\Omega)}{1 + (0.5\times10^{-6})(2.2\text{ k}\Omega)}$$
$$= 9.452\,\Omega$$
$$Z_i' = Z_i \parallel R_E$$
$$= 9.452\,\Omega \parallel 1.2\text{ k}\Omega$$
$$= \underline{9.38\,\Omega}$$

b. $$A_i = \frac{h_{fb}}{1 + h_{ob}R_L}$$
$$= \frac{-0.997}{1 + (0.5\times10^{-6})(2.2\times10^{3})}$$
$$= \underline{-0.996}$$

c. $$A_v = \frac{-h_{fb}R_L}{h_{ib} + (h_{ib}h_{ob} - h_{fb}h_{rb})R_L}$$
$$= \frac{-(-0.997)(2.2\text{ k}\Omega)}{9.45\,\Omega + ((9.45\,\Omega)(0.5\times10^{-6}\text{ S}) - (-0.997)(1\times10^{-6}))(2.2\text{ k}\Omega}$$
$$= \underline{231.79}$$

d. $$Z_o = \frac{1}{h_{ob} - [h_{fb}h_{rb}/(h_{ib} + R_s)]}$$
$$= \frac{1}{0.5\times10^{-6}\text{ S} - [(-0.997)(1\times10^{-6})/(9.45\,\Omega + 0.6\text{ k}\Omega)]}$$
$$= 1.993\times10^{6}\,\Omega = \underline{1.993\text{ M}\Omega}$$

## Chapter 9 (Odd)

1. $g_{m0} = \dfrac{2I_{DSS}}{|V_p|} = \dfrac{2(15\text{mA})}{|-5\text{V}|} = \underline{6\text{mS}}$

3. $g_{m0} = \dfrac{2I_{DSS}}{|V_p|} \Rightarrow I_{DSS} = \dfrac{(g_{m0})(|V_p|)}{2} = \dfrac{5\text{mS}(3.5\text{V})}{2} = \underline{8.75\text{mA}}$

5. $g_m = \dfrac{2I_{DSS}}{|V_p|}\left(1 - \dfrac{V_{GS_Q}}{V_p}\right)$

$6\text{mS} = \dfrac{2I_{DSS}}{2.5\text{V}}\left(1 - \dfrac{-1\text{V}}{-2.5\text{V}}\right)$

$I_{DSS} = \underline{12.5\text{mA}}$

7. $g_{m0} = \dfrac{2I_{DSS}}{|V_p|} = \dfrac{2(8\text{mA})}{5\text{V}} = 3.2\text{mS}$

$g_m = g_{m0}\left(1 - \dfrac{V_{GS_Q}}{V_p}\right) = 3.2\text{mS}\left(1 - \dfrac{V_P/4}{V_p}\right) = 3.2\text{mS}(1 - 1/4) = 3.2\text{mS}\left(\dfrac{3}{4}\right)$

$= \underline{2.4\text{mS}}$

9. $g_m = y_{fs} = 4.5\text{mS}$

$r_d = \dfrac{1}{y_{os}} = \dfrac{1}{25\mu\text{S}} = 40\text{k}\Omega$

$Z_o = r_d = \underline{40\text{k}\Omega}$

$A_v(\text{FET}) = -g_m r_d = -(4.5\text{mS})(40\text{k}\Omega) = \underline{-180}$

11. a. $g_{m0} = \dfrac{2I_{DSS}}{|V_p|} = \dfrac{2(10\text{mA})}{5\text{V}} = \underline{4\text{mS}}$

b. $g_m = \dfrac{\Delta I_D}{\Delta V_{GS}} = \dfrac{6.4\text{mA} - 3.6\text{mA}}{2\text{V} - 1\text{V}} = \underline{2.8\text{mS}}$

(c) Eq. 9.6: $g_m = g_{m0}\left(1 - \dfrac{V_{GS_Q}}{V_p}\right) = 4\text{mS}\left(1 - \dfrac{-1.5\text{V}}{-5\text{V}}\right) = \underline{2.8\text{mS}}$

(d) $g_m = \dfrac{\Delta I_D}{\Delta V_{GS}} = \dfrac{3.6\text{mA} - 1.6\text{mA}}{3\text{V} - 2\text{V}} = \underline{2\text{mS}}$

(e) $g_m = g_{m0}\left(1 - \dfrac{V_{GS_Q}}{V_p}\right) = 4\text{mS}\left(1 - \dfrac{-2.5\text{V}}{-5\text{V}}\right) = \underline{2\text{mS}}$

13. From 2N4220 data:

$$g_m = y_{fs} = 750\mu S = \underline{0.75\,mS}$$

$$r_d = \frac{1}{y_{os}} = \frac{1}{10\mu S} = \underline{100k\Omega}$$

15. $g_m = y_{fs} = \underline{5.6mS}$, $r_d = \frac{1}{y_{os}} = \frac{1}{15\mu S} = \underline{66.67}\,k\Omega$

17. Graphically, $V_{GS_Q} = -1.5V$

$$g_m = \frac{2I_{DSS}}{|V_P|}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = \frac{2(10mA)}{4V}\left(1 - \frac{-1.5V}{-4V}\right) = 3.125mS$$

$$Z_i = R_G = \underline{1M\Omega}$$

$$Z_o = R_D \| r_d = 1.8k\Omega \| 40k\Omega = \underline{1.72k\Omega}$$

$$A_v = -g_m(R_D \| r_d) = -(3.125mS)(1.72k\Omega)$$

$$= \underline{-5.375}$$

19. $g_m = y_{fs} = 3000\mu S = 3mS$

$$r_d = \frac{1}{y_{os}} = \frac{1}{50\mu S} = 20k\Omega$$

$$Z_i = R_G = 10M\Omega$$

$$Z_o = r_d \| R_D = 20k\Omega \| 3.3k\Omega = \underline{2.83k\Omega}$$

$$A_v = -g_m(r_d \| R_D)$$

$$= -(3mS)(2.83k\Omega)$$

$$= -8.49$$

21. $g_m = 3mS$, $r_d = 20k\Omega$

$$Z_i = 1M\Omega$$

$$Z_o = \frac{R_D}{1 + g_m R_S + \frac{R_D + R_S}{r_d}} = \frac{3.3k\Omega}{1 + (3mS)(1.1k\Omega) + \frac{3.3k\Omega + 1.1k\Omega}{20k\Omega}}$$

$$= \frac{3.3\,k\Omega}{1 + 3.3 + 0.22} = \frac{3.3\,k\Omega}{4.52} = \underline{730\,\Omega}$$

$$A_v = \frac{-g_m R_D}{1 + g_m R_S + \frac{R_D + R_S}{r_d}} = \frac{-(3\,mS)(3.3\,k\Omega)}{1 + (3\,mS)(1.1\,k\Omega) + \frac{3.3\,k\Omega + 1.1\,k\Omega}{20\,k\Omega}}$$

$$= \frac{-9.9}{1 + 3.3 + 0.22} = -\frac{9.9}{4.52} = \underline{-2.19}$$

23. $V_{GS_Q} = -0.95\,V.$

$$g_m = \frac{2I_{DSS}}{V_P}\left(1 - \frac{V_{GS_Q}}{V_P}\right)$$

$$= \frac{2(12\,mA)}{3V}\left(1 - \frac{-0.95V}{-3V}\right)$$

$$= 5.47\,mS$$

$Z_i = 82\,M\Omega \parallel 11\,M\Omega = \underline{9.7\,M\Omega}$

$Z_o = r_d \parallel R_D = 100\,k\Omega \parallel 2\,k\Omega = \underline{1.96\,k\Omega}$

$A_v = -g_m(r_d \parallel R_D) = -(5.47\,mS)(1.96\,k\Omega) = \underline{-10.72}$

$V_o = A_v V_i = (-10.72)(20\,mV) = \underline{-214.4\,mV}$

25. $V_{GS_Q} = -0.95\,V$, $g_m$ (problem 23) $= 5.47\,mS$

$Z_i$ (the same) $= \underline{9.7\,M\Omega}$

$Z_o$ (reduced) $= r_d \parallel R_D = 20\,k\Omega \parallel 2\,k\Omega = \underline{1.82\,k\Omega}$

$A_v$ (reduced) $= -g_m(r_d \parallel R_D) = -(5.47\,mS)(1.82\,k\Omega) = \underline{-9.94}$

$V_o$ (reduced) $= A_v V_i = (-9.94)(20\,mV) = \underline{-198.8\,mV}$

27. $V_{GS_Q} = -2.85\,V$, $g_m = \frac{2I_{DSS}}{V_P}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = \frac{2(9\,mA)}{4.5V}\left(1 - \frac{-2.85V}{-4.5V}\right) = 1.47\,mS$

$Z_i = R_G = \underline{10\,M\Omega}$

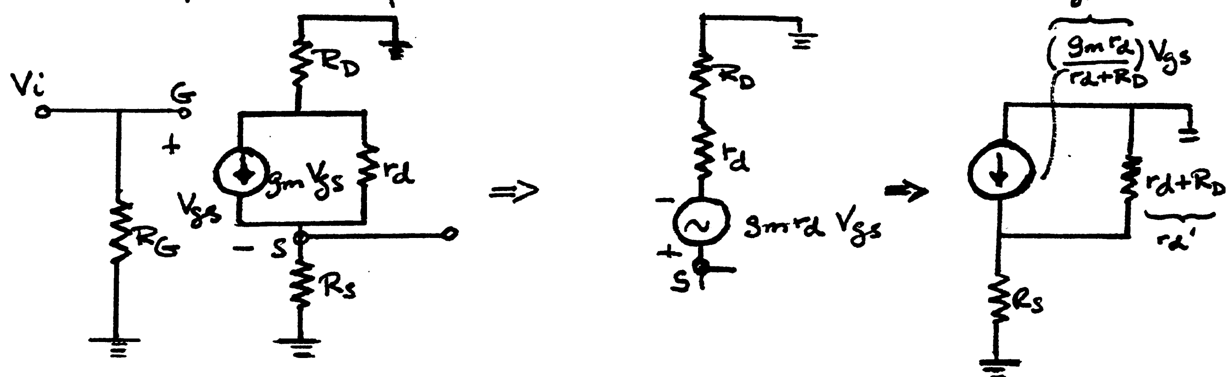
$$Z_o = r_d \| R_S \| 1/g_m = 40\text{k}\Omega \| 2.2\text{k}\Omega \| \underbrace{1/1.47\text{mS}}_{680.27\Omega} = \underline{512.9\Omega}$$

$$A_v = \frac{g_m(r_d \| R_S)}{1+g_m(r_d \| R_S)} = \frac{(1.47\text{mS})(40\text{k}\Omega \| 2.2\text{k}\Omega)}{1+(1.47\text{mS})(40\text{k}\Omega \| 2.2\text{k}\Omega)} = \frac{3.065}{1+3.065}$$

$$= \underline{0.754}$$

29. $V_{GS_Q} = -3.8\text{V}$

$$g_m = \frac{2I_{DSS}}{V_P}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = \frac{2(6\text{mA})}{6\text{V}}\left(1 - \frac{-3.8\text{V}}{-6\text{V}}\right) = 0.733\text{mS}$$




the network now has the format examined in the Text and

$Z_i = R_G = \underline{10\text{M}\Omega}$

$r_d' = r_d + R_D = 30\text{k}\Omega + 3.3\text{k}\Omega = 33.3\text{k}\Omega$

$g_m' = \frac{g_m r_d}{r_d + R_D} = \frac{(0.733\text{mS})(30\text{k}\Omega)}{30\text{k}\Omega + 3.3\text{k}\Omega} = \frac{21.99}{33.3\text{k}\Omega} = .66\text{mS}$

$Z_o = r_d' \| R_S \| 1/g_m' =$

$= 33.3\text{k}\Omega \| 3.3\text{k}\Omega \| 1/0.66\text{mS}$

$= 3\text{k}\Omega \| 1.52\text{k}\Omega$

$\cong \underline{1\text{k}\Omega}$

$$A_v = \frac{V_o}{V_i} = \frac{g_m'(r_d' \| R_S)}{1+g_m'(r_d' \| R_S)} = \frac{0.66\text{mS}(3\text{k}\Omega)}{1+0.66\text{mS}(3\text{k}\Omega)} = \frac{1.98}{1+1.98} = \frac{1.98}{2.98}$$

$$= \underline{0.66}$$

31. $V_{GS_Q} = -1.75\text{V}$, $g_m = \frac{2I_{DSS}}{V_P}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = \frac{2(8\text{mA})}{2.8\text{V}}\left(1 - \frac{-1.75\text{V}}{-2.8\text{V}}\right) = 2.14\text{mS}$

$$Z_i = R_S \| \left[\frac{r_d + R_D}{1 + g_m r_d}\right] = 1.5\,k\Omega \| \left[\frac{25\,k\Omega + 3.3\,k\Omega}{1 + (2.14\,mS)(25\,k\Omega)}\right] = 1.5\,k\Omega \| \frac{28.3\,k\Omega}{54.5}$$

$$= 1.5\,k\Omega \| 0.52\,k\Omega = \underline{386.1\,\Omega}$$

$$Z_o = R_D \| r_d = 3.3\,k\Omega \| 25\,k\Omega = \underline{2.92\,k\Omega}$$

$$A_v = \frac{g_m R_D + R_D/r_d}{1 + R_D/r_d} = \frac{(2.14\,mS)(3.3\,k\Omega) + 3.3\,k\Omega/25\,k\Omega}{1 + 3.3\,k\Omega/25\,k\Omega}$$

$$= \frac{7.062 + 0.132}{1 + 0.132} = \frac{7.194}{1.132} = 6.36$$

$$V_o = A_v V_i = (6.36)(0.1\,mV) = \underline{0.636\,mV}$$

33. $r_d = \frac{1}{y_{os}} = \frac{1}{20\,\mu S} = 50\,k\Omega$, $V_{GS_Q} = 0\,V$

$$g_m = g_{m0} = \frac{2I_{DSS}}{V_P} = \frac{2(8\,mA)}{3} = 5.33\,mS$$

$$A_v = -g_m R_D = -(5.33\,mS)(1.1\,k\Omega) = -5.863$$

$$V_o = A_v V_i = (-5.863)(2\,mV) = \underline{11.73\,mV}$$

35. $Z_i = \underline{10\,M\Omega}$

$$Z_o = r_d \| R_D = 25\,k\Omega \| 1.8\,k\Omega = \underline{1.68\,k\Omega}$$

$$A_v = -g_m (r_d \| R_D)$$

$$g_m = \frac{2I_{DSS}}{V_P}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = \frac{2(12\,mA)}{3.5\,V}\left(1 - \frac{-0.75\,V}{-3.5\,V}\right) = 5.4\,mS$$

$$A_v = -(5.4\,mS)(1.68\,k\Omega)$$

$$= \underline{-9.07}$$

37.

$$Z_i = 10\,M\Omega \| 91\,M\Omega \cong \underline{9\,M\Omega}$$

$$g_m = \frac{2I_{DSS}}{V_P}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = \frac{2(12\,mA)}{3\,V}\left(1 - \frac{-1.45\,V}{-3\,V}\right) = 4.13\,mS$$

$$Z_o = r_d \| R_S \| 1/g_m = 45\,k\Omega \| 1.1\,k\Omega \| 1/4.13\,mS$$

$$= 1.074\,k\Omega \| 242.1\,\Omega$$

$$= \underline{197.6\,\Omega}$$

$$A_v = \frac{g_m(r_d \| R_S)}{1 + g_m(r_d \| R_S)} = \frac{(4.13\,mS)(45\,k\Omega \| 1.1\,k\Omega)}{1 + (4.13\,mS)(45\,k\Omega \| 1.1\,k\Omega)}$$

$$= \frac{(4.13\,mS)(1.074\,k\Omega)}{1 + (4.13\,mS)(1.074\,k\Omega)} = \frac{4.436}{1 + 4.436}$$

$$= \underline{0.816}$$

39. $V_{GS_Q} = 6.7\,V$

$$g_m = 2k(V_{GS_Q} - V_T) = 2(0.3 \times 10^{-3})(6.7\,V - 3\,V) = 2.22\,mS$$

$$Z_i = \frac{R_F + r_d \| R_D}{1 + g_m(r_d \| R_D)} = \frac{10\,M\Omega + 100\,k\Omega \| 2.2\,k\Omega}{1 + (2.22\,mS)(100\,k\Omega \| 2.2\,k\Omega)}$$

$$= \frac{10\,M\Omega + 2.15\,k\Omega}{1 + 2.22\,mS(2.15\,k\Omega)} \cong \underline{1.73\,M\Omega}$$

$$Z_o = R_F \| r_d \| R_D = 10\,M\Omega \| 100\,k\Omega \| 2.2\,k\Omega = \underline{2.15\,k\Omega}$$

$$A_v = -g_m(R_F \| r_d \| R_D) = -2.22\,mS(2.15\,k\Omega) = \underline{-4.77}$$

41. $V_{GS_Q} = 5.7\,V$, $g_m = 2k(V_{GS_Q} - V_T) = 2(0.3 \times 10^{-3})(5.7\,V - 3.5\,V)$

$$= 1.32\,mS$$

$$r_d = \frac{1}{30\,\mu S} = 33.33\,k\Omega$$

$$A_v = -g_m(R_F \| r_d \| R_D) = -1.32\,mS(22\,M\Omega \| 33.33\,k\Omega \| 10\,k\Omega)$$

$$= -10.15$$

$$V_o = A_v V_i = (-10.15)(20\,mV) = \underline{-203\,mV}$$

43. $V_{GS_Q} = 4.8V$, $g_m = 2k(V_{GS_Q} - V_{GS(Th)}) = 2(0.4\times10^{-3})(4.8V-3V) = 1.44mS$

$$A_v = -g_m\,(r_d \| R_D) = -(1.44mS)(40k\Omega \| 3.3k\Omega) = -4.39$$

$$V_o = A_v V_i = (-4.39)(0.8mV) = \underline{-3.51mV}$$

45. $V_{GS_Q} = \frac{1}{3}V_P = \frac{1}{3}(-3V) = -1V$

$$I_{D_Q} = I_{DSS}\left(1 - \frac{V_{GS_Q}}{V_P}\right)^2 = 12mA\left(1 - \frac{-1V}{-3V}\right)^2 = 5.33mA$$

$$R_S = \frac{V_S}{I_{D_Q}} = \frac{1V}{5.33mA} = 187.62\Omega \;\therefore\; \text{use } R_S = \underline{180\Omega}$$

$$g_m = \frac{2I_{DSS}}{V_P}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = \frac{2(12mA)}{3V}\left(1 - \frac{-1V}{-3V}\right) = 5.33mS$$

$$A_v = -g_m(R_D \| r_d) = -10$$

or $R_D \| 40k\Omega = \dfrac{-10}{5.33mS} = 1.876k\Omega$

$$\frac{R_D \cdot 40k\Omega}{R_D + 40k\Omega} = 1.876k\Omega$$

$$40k\Omega R_D = 1.876k\Omega R_D + 75.04k\Omega^2$$

$$38.124 R_D = 75.04k\Omega$$

$$R_D = 1.97k\Omega \Rightarrow R_D = \underline{2k\Omega}$$

Chapter 9 (Even)

2. $g_{mo} = \dfrac{2I_{DSS}}{|V_P|} \Rightarrow |V_P| = \dfrac{2I_{DSS}}{g_{mo}} = \dfrac{2(12\text{mA})}{10\text{mS}} = 2.4\text{V}$

$V_P = \underline{-2.4\text{V}}$

4. $g_m = g_{mo}\left(1 - \dfrac{V_{GS_Q}}{V_P}\right) = \dfrac{2(12\text{mA})}{|-3\text{V}|}\left(1 - \dfrac{-1\text{V}}{-3\text{V}}\right) = \underline{5.3\text{mS}}$

6. $g_m = g_{mo}\sqrt{\dfrac{I_D}{I_{DSS}}} = \dfrac{2I_{DSS}}{|V_P|}\sqrt{\dfrac{I_{DSS}/4}{4}} = \dfrac{2(10\text{mA})}{5\text{V}}\sqrt{\dfrac{1}{4}}$

$= \dfrac{20\text{mA}}{5\text{V}}\left(\dfrac{1}{2}\right) = \underline{2\text{mS}}$

8. (a) $g_m = y_{fs} = \underline{4.5\text{mS}}$

(b) $r_d = \dfrac{1}{y_{os}} = \dfrac{1}{25\mu\text{S}} = \underline{40\text{k}\Omega}$

10. $A_v = -g_m r_d \Rightarrow g_m = -\dfrac{A_v}{r_d} = -\dfrac{(-200)}{(100\text{k}\Omega)} = \underline{2\text{mS}}$

12. (a) $r_d = \left.\dfrac{\Delta V_{DS}}{\Delta I_D}\right|_{V_{GS}=\text{constant}} = \dfrac{(15\text{V}-5\text{V})}{(9.1\text{mA}-8.8\text{mA})} = \dfrac{10\text{V}}{0.3\text{mA}} = \underline{33.33\text{k}\Omega}$

(b) At $V_{DS} = 10\text{V}$, $I_D = 9\text{mA}$ on $V_{GS} = 0\text{V}$ curve

$\therefore g_{mo} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(9\text{mA})}{4\text{V}} = \underline{4.5\text{mS}}$

14. (a) $g_m(@V_{GS} = -6\text{V}) = \underline{0}$, $g_m(@V_{GS} = 0\text{V}) = g_{mo} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(8\text{mA})}{6\text{V}} = \underline{2.67\text{mS}}$

(b) $g_m(@I_D = 0\text{mA}) = \underline{0}$, $g_m(@I_D = I_{DSS} = 8\text{mA}) = g_{mo} = \underline{2.67\text{mS}}$

16. $g_m = \dfrac{2I_{DSS}}{|V_P|}\left(1 - \dfrac{V_{GS_Q}}{V_P}\right) = \dfrac{2(10\text{mA})}{4\text{V}}\left(1 - \dfrac{-2\text{V}}{-4\text{V}}\right) = \underline{2.5\text{mS}}$

$r_d = \dfrac{1}{y_{os}} = \dfrac{1}{25\mu\text{S}} = \underline{40\text{k}\Omega}$

18. $V_{GS_Q} = -1.5V$

$$g_m = \frac{2I_{DSS}}{|V_P|}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = \frac{2(12mA)}{6V}\left(1 - \frac{-1.5V}{-6V}\right) = 3mS$$

$Z_i = R_G = \underline{1M\Omega}$

$Z_o = R_D \| r_d$, $r_d = \frac{1}{y_{os}} = \frac{1}{40\mu S} = 25k\Omega$

$= 1.8k\Omega \| 25k\Omega$

$= \underline{1.68k\Omega}$

$A_v = -g_m(R_D \| r_d) = -(3mS)(1.68k\Omega) = \underline{-5.04}$

20. $V_{GS_Q} = 0V$, $g_m = g_{m0} = \frac{2I_{DSS}}{|V_P|} = \frac{2(6mA)}{6V} = 2mS$, $r_d = \frac{1}{y_{os}} = \frac{1}{40\mu S} = 25k\Omega$

$Z_i = \underline{1M\Omega}$

$Z_o = r_d \| R_D = 25k\Omega \| 2k\Omega = \underline{1.852k\Omega}$

$A_v = -g_m(r_d \| R_D) = -(2mS)(1.852k\Omega) \cong \underline{-3.7}$

22. $g_m = y_{fs} = 3000\mu S = 3mS$

$r_d = \frac{1}{y_{os}} = \frac{1}{10\mu S} = 100k\Omega$

$Z_i = R_G = \underline{10M\Omega}$ (the same)

$Z_o = r_d \| R_D = 100k\Omega \| 3.3k\Omega = \underline{3.195k\Omega}$ (higher)

$A_v = -g_m(r_d \| R_D)$

$= -(3mS)(3.195k\Omega)$

$= \underline{-9.59}$ (higher)

24. $V_{GS_Q} = -0.95V$ (as before), $g_m = 5.47mS$ (as before)

$Z_i = \underline{9.7M\Omega}$ as before

$$Z_o = \frac{R_D}{1+g_m R_S + \frac{R_D+R_S}{r_d}}$$

but $r_d \geq 10(R_D+R_S)$

$$\therefore Z_o = \frac{R_D}{1+g_m R_S} = \frac{2\,k\Omega}{1+(5.47\,mS)(0.61\,k\Omega)} = \frac{2\,k\Omega}{1+3.337} = \frac{2\,k\Omega}{4.337}$$

$$= \underline{461.1\,\Omega}$$

$$A_v = -\frac{g_m R_D}{1+g_m R_S} \quad \text{since } r_d \geq 10(R_D+R_S)$$

$$= -\frac{(5.47\,mS)(2\,k\Omega)}{4.337 \text{(from above)}} = -\frac{10.94}{4.337} = \underline{-2.52} \text{ (a big reduction)}$$

$V_o = A_v V_i = (-2.52)(20\,mV) = \underline{-50.40\,mV}$ (compared to $-214.4\,mV$ earlier)

26. $V_{GS_Q} = -0.95\,V$ (as before), $g_m = 5.47\,mS$ (as before)

$Z_i = \underline{9.7\,M\Omega}$ as before

$$Z_o = \frac{R_D}{1+g_m R_S + \frac{R_D+R_S}{r_d}} \quad \text{since } r_d < 10(R_D+R_S)$$

$$= \frac{2\,k\Omega}{1+(5.47\,mS)(0.61\,k\Omega) + \frac{2\,k\Omega+0.61\,k\Omega}{20\,k\Omega}}$$

$$= \frac{2\,k\Omega}{1+3.33+0.13} = \frac{2\,k\Omega}{4.46}$$

$= \underline{448.4\,\Omega}$ (slightly less than $461.1\,\Omega$ obtained in problem 24)

$$A_v = -\frac{g_m R_D}{1+g_m R_S + \frac{R_D+R_S}{r_d}}$$

$$= -\frac{(5.47\,mS)(2\,k\Omega)}{1+(5.47\,mS)(0.61\,k\Omega) + \frac{2\,k\Omega+0.61\,k\Omega}{20\,k\Omega}}$$

$$= -\frac{10.94}{1+3.33+0.13} = -\frac{10.94}{4.46} = \underline{-2.45}$$ (slightly less than $-2.52$ obtained in problem 24)

28. $V_{GS_Q} = -2.85\text{V},\ g_m = 1.47\text{mS}$

$Z_i = \underline{10\text{M}\Omega}$ (as in problem 27)

$Z_o = \hat{r_d} \| R_S \| 1/g_m = \underbrace{20\text{k}\Omega \| 2.2\text{k}\Omega}_{1.982\text{k}\Omega} \| 680.27\Omega = \underline{506.4\Omega} < 512.9\Omega\ (\#27)$

$$A_v = \frac{g_m(r_d \| R_S)}{1 + g_m(r_d \| R_S)} = \frac{1.47\text{mS}(20\text{k}\Omega \| 2.2\text{k}\Omega)}{1 + 1.47\text{mS}(20\text{k}\Omega \| 2.2\text{k}\Omega)} = \frac{2.914}{1+2.914}$$

$= \underline{0.745} < 0.754\ (\#27)$

30. $V_{GS_Q} = -1.75\text{V},\ g_m = 2.14\text{mS}$

$r_d \geq 10R_D, \therefore Z_i \cong R_S \| 1/g_m = 1.5\text{k}\Omega \| 1/2.14\text{mS}$

$= 1.5\text{k}\Omega \| 467.29\Omega$

$= \underline{356.3\Omega}$

$r_d \geq 10R_D, \therefore Z_o \cong R_D = \underline{3.3\text{k}\Omega}$

$r_d \geq 10R_D, \therefore A_v \cong g_m R_D = (2.14\text{mS})(3.3\text{k}\Omega) = \underline{7.06}$

$V_o = A_v V_i = (7.06)(0.1\text{mV}) = \underline{0.706\text{mV}}$

32. $V_{GS_Q} \cong -1.2\text{V},\ g_m = 2.63\text{mS}$

$r_d \geq 10R_D, \therefore Z_i \cong R_S \| 1/g_m = 1\text{k}\Omega \| 1/2.63\text{mS} = 1\text{k}\Omega \| 380.2\Omega = \underline{275.5\Omega}$

$Z_o \cong R_D = \underline{2.2\text{k}\Omega}$

$A_v \cong g_m R_D = (2.63\text{mS})(2.2\text{k}\Omega) = \underline{5.79}$

34. $V_{GS_Q} = -0.75\text{V},\ g_m = 5.4\text{mS}$

$Z_i = \underline{10\text{M}\Omega}$

$r_o \geq 10R_D, \therefore Z_o \cong R_D = \underline{1.8\text{k}\Omega}$

$r_o \geq 10R_D, \therefore A_v \cong -g_m R_D = -(5.4\text{mS})(1.8\text{k}\Omega)$

$= \underline{-9.72}$

36. $g_m = y_{fs} = 6000\,\mu S = 6\,mS$

$r_d = \frac{1}{y_{os}} = \frac{1}{35\,\mu S} = 28.57\,k\Omega$

$r_d \leq 10R_D, \therefore\ A_v = -g_m(r_d \| R_D)$

$= -(6\,mS)(\underbrace{28.57\,k\Omega \| 6.8\,k\Omega}_{5.49\,k\Omega})$

$= -32.94$

$V_o = A_v V_i = (-32.94)(4\,mV)$

$= \underline{-131.76\,mV}$

38. $g_m = 2k(V_{GS_Q} - V_{GS(Th)})$

$= 2(0.3\times10^{-3})(8V - 3V)$

$= 3\,mS$

40. $g_m = 2k(V_{GS_Q} - V_T) = 2(0.2\times10^{-3})(6.7V - 3V)$

$= 1.48\,mS$

$$Z_i = \frac{R_F + r_d \| R_D}{1 + g_m(r_d \| R_D)} = \frac{10\,M\Omega + 100\,k\Omega \| 2.2\,k\Omega}{1 + (1.48\,mS)(100\,k\Omega \| 2.2\,k\Omega)}$$

$$= \frac{10\,M\Omega + 2.15\,k\Omega}{1 + (1.48\,mS)(2.15\,k\Omega)} = \underline{2.39\,M\Omega} > 1.73\,M\Omega\ (\#39)$$

$Z_o = R_F \| r_d \| R_D = \underline{2.15\,k\Omega} = 2.15\,k\Omega\ (\#39)$

$A_v = -g_m(R_F \| r_d \| R_D) = -(1.48\,mS)(2.15\,k\Omega)$

$= \underline{-3.182} < -4.77\ (\#39)$

42. $I_D = k(V_{GS} - V_T)^2$

$$\therefore\ k = \frac{I_{D(on)}}{(V_{GS(on)} - V_T)^2} = \frac{4\,mA}{(7V - 4V)^2} = 0.444\times10^{-3}$$

$g_m = 2k(V_{GS_Q} - V_{GS(Th)}) = 2(0.444\times10^{-3})(7V - 4V)$

$= 2.66\,mS$

$$A_v = -g_m(R_F \| r_d \| R_D) = -(2.66\text{mS})(\underbrace{22\text{M}\Omega \| \underbrace{50\text{k}\Omega \| 10\text{k}\Omega}_{8.33\text{k}\Omega}}_{\cong 8.33\text{k}\Omega})$$

$$= -22.16$$

$$V_o = A_v V_i = (-22.16)(4\text{mV}) = \underline{-88.64\text{mV}}$$

44. $r_d = \dfrac{1}{y_{os}} = \dfrac{1}{25\mu\text{S}} = 40\text{k}\Omega$

$V_{GS_Q} = 0\text{V}, \therefore g_m = g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(8\text{mA})}{2.5\text{V}} = 6.4\text{mS}$

$|A_v| = g_m(r_d \| R_D)$

$8 = (6.4\text{mS})(40\text{k}\Omega \| R_D)$

$\dfrac{8}{6.4\text{mS}} = 1.25\text{k}\Omega = \dfrac{40\text{k}\Omega \cdot R_D}{40\text{k}\Omega + R_D}$

and $R_D = 1.29\text{k}\Omega$

use $R_D = \underline{1.3\text{k}\Omega}$

Chapter 10 (Odd)

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

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

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

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

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

$Z_o = R_C = \underline{3.3\text{k}\Omega}$

b. –

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

d. $A_i = -A_v\dfrac{Z_i}{R_L} = -(-191.65)\dfrac{(1.01\text{k}\Omega)}{4.7\text{k}\Omega}$
$= \underline{41.18}$

e. $A_v = \dfrac{V_o}{V_i} = \dfrac{-\beta \cancel{I_b}(R_C\|R_L)}{\cancel{I_b}(\beta r_e)} = -\dfrac{\cancel{100}(1.939\text{k}\Omega)}{\cancel{100}(10.116\,\Omega)}$
$= \underline{-191.98}$

$Z_i = R_B \| \beta r_e = \underline{1.01\text{k}\Omega}$

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

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

$A_i = \dfrac{I_o}{I_i} = \dfrac{I_L}{I_i} = \dfrac{I_L}{I_b}\cdot\dfrac{I_b}{I_i} = (41.25)(0.9985)$
$= \underline{41.19}$

$Z_o = R_C = \underline{3.3\text{k}\Omega}$

3\. a. $A_{v_{NL}} = -326.22$

$A_v = \dfrac{R_L}{R_L+R_o}A_{v_{NL}}$

$R_L = 4.7\text{k}\Omega$: $A_v = \dfrac{4.7\text{k}\Omega}{4.7\text{k}\Omega+3.3\text{k}\Omega}(-326.22) = \underline{-191.65}$

$R_L = 2.2\,k\Omega$: $\quad A_v = \dfrac{2.2\,k\Omega}{2.2\,k\Omega + 3.3\,k\Omega}(-326.22) = \underline{-130.49}$

$R_L = 0.5\,k\Omega$: $\quad A_v = \dfrac{0.5\,k\Omega}{0.5\,k\Omega + 3.3\,k\Omega}(-326.22) = -\underline{42.92}$

As $R_L \downarrow$, $A_v \downarrow$

b. No change for $Z_i$, $Z_o$ & $A_{v_{NL}}$!

5. a. $I_B = \dfrac{V_{CC} - V_{BE}}{R_B} = \dfrac{24\,V - 0.7\,V}{500\,k\Omega} = 41.61\,\mu A$

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

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

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

$Z_i = R_B \| \beta r_e = 560\,k\Omega \| (80)(7.715\,\Omega)$

$= 560\,k\Omega \| 617.2\,\Omega$

$= \underline{616.52\,\Omega}$

$Z_o = R_C = 4.3\,k\Omega$

b. –

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

$= \underline{-214.98}$

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

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

$A_{v_s} = (-214.98)(0.381)$

$= -\underline{81.91}$

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

$= \underline{49.04}$

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

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

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

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

f. $A_v$ the same $= -214.98$

$\dfrac{V_i}{V_s} = \dfrac{Z_i}{Z_i + R_s} = \dfrac{616.52\,\Omega}{616.52\,\Omega + 0.5\,k\Omega} = 0.552$

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

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

(g) no change!

7. a. DC: $V_{CE} = V_{CC} - I_C(R_C + R_E) = 16\text{V} - I_C(2.2\text{k}\Omega + 0.75\text{k}\Omega)$

$V_{CE} = 16\text{V} - I_C(2.95\text{k}\Omega)$

Load line:

$V_{CE} = 0\text{V},\ I_C = \dfrac{16\text{V}}{2.95\text{k}\Omega} = \underline{5.42\text{mA}}$

$I_C = 0\text{mA},\ V_{CE} = \underline{16\text{V}}$

Analysis: Test $\beta R_E \geq 10R_2$

$(100)(0.75\text{k}\Omega) \geq 10(16\text{k}\Omega)$

$75\text{k}\Omega \not\geq 160\text{k}\Omega$ No!

Exact Approach:

$R_{Th} = 68\text{k}\Omega \| 16\text{k}\Omega = 12.95\text{k}\Omega$

$E_{Th} = \dfrac{16\text{k}\Omega(16\text{V})}{16\text{k}\Omega + 68\text{k}\Omega} = 3.048\text{V}$

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

$= 26.47\mu\text{A}$

From graph: $V_{CE_Q} \cong 8.2\text{V},\ I_{C_Q} \cong 2.6\text{mA}$

AC: Vertical intersection:

AC Load line

$R_L' = 2.2\text{k}\Omega \| 5.6\text{k}\Omega = 1.58\text{k}\Omega$

$I_{C_Q} + \dfrac{V_{CE_Q}}{R_L'} = 2.6\text{mA} + \dfrac{8.2\text{V}}{1.58\text{k}\Omega} = \underline{7.79\text{mA}}$

Horizontal intersection:

$V_{CE_Q} + I_{C_Q}R_L' = 8.2\text{V} + (2.6\text{mA})(1.58\text{k}\Omega)$

$= 12.31\text{V}$

b. From problem 6

$\beta r_e = 972.6\Omega$

For $V_i$ = positive peak of 10mV

$I_b = \dfrac{10\text{mV}}{972.6\Omega}$

$= 10.28\mu\text{A}$

and $I_b$ will rise to $26.47\mu\text{A} + 10.28\mu\text{A} = 36.75\mu\text{A}$

For the negative peak of $-10\text{mV}$

$26.47\mu\text{A} - 10.28\mu\text{A} = 16.19\mu\text{A}$

On the ac load line at $I_b = 36.75\mu\text{A}$, $V_{ce} \cong 6.7\text{V}$

" at $I_b = 16.19\mu\text{A}$, $V_{ce} \cong 9.9\text{V}$

$\Delta V_o = \Delta V_{ce} = 9.9\text{V} - 6.7\text{V} = 3.2\text{V}$

$|A_v| = \dfrac{\Delta V_o}{\Delta V_i} = \dfrac{3.2\text{V}}{20\text{mV}} = \underline{160}$

comparing very well with the $-162.4$ of problem 6

9. a. $I_B = \dfrac{V_{CC} - V_{BE}}{R_B + (\beta+1)R_E} = \dfrac{18\text{V} - 0.7\text{V}}{680\text{k}\Omega + (111)(0.82\text{k}\Omega)}$

$= 22.44\,\mu\text{A}$

$I_E = (\beta+1)I_B = (110+1)(22.44\,\mu\text{A})$

$= 2.49\text{mA}$

$r_e = \dfrac{26\text{mV}}{I_E} = \dfrac{26\text{mV}}{2.49\text{mA}} = 10.44\Omega$

$A_{v_{NL}} = -\dfrac{R_C}{r_e + R_E} = -\dfrac{3\text{k}\Omega}{10.44\Omega + 0.82\text{k}\Omega}$

$= \underline{-3.61}$

$Z_i = R_B \| Z_b = 680\text{k}\Omega \| (\beta r_e + (\beta+1)R_E$

$= 680\text{k}\Omega \| (110)(10.44\Omega) + (110+1)(0.82\text{k}\Omega)$

$= 680\text{k}\Omega \| 92.17\text{k}\Omega$

$= \underline{81.17\text{k}\Omega}$

$Z_o \cong R_C = \underline{3\text{k}\Omega}$

b. —

c. $A_v = \dfrac{V_o}{V_i} = \dfrac{R_L}{R_L + R_o} A_{v_{NL}} = \dfrac{4.7\text{k}\Omega}{4.7\text{k}\Omega + 3\text{k}\Omega}(-3.61)$

$= \underline{-2.2}$

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

$V_i = \dfrac{Z_i V_s}{Z_i + R_s} = \dfrac{81.17\text{k}\Omega\, V_s}{81.17\text{k}\Omega + 0.6\text{k}\Omega} = 0.992 V_s$

$A_{v_s} = (-2.2)(0.992)$

$= \underline{-2.18}$

d. none!

e. $A_v$ – none!

$\dfrac{V_i}{V_s} = \dfrac{Z_i}{Z_i + R_s} = \dfrac{81.17\text{k}\Omega}{81.17\text{k}\Omega + 1\text{k}\Omega} = 0.988$

$A_{v_s} = (-2.2)(0.988)$

$= \underline{-2.17}$

$R_s\uparrow$, $A_{v_s}\downarrow$ (but only slightly for moderate change in $R_s$ since $Z_i$ is typically much larger than $R_s$)

11. a. $I_E = \dfrac{V_{EE} - V_{BE}}{R_E} = \dfrac{6\text{V} - 0.7\text{V}}{2.2\text{k}\Omega} = 2.41\text{mA}$

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

$A_{v_{NL}} = \dfrac{R_C}{r_e} = \dfrac{4.7\text{k}\Omega}{10.79\Omega} = \underline{435.59}$

$Z_i = R_E \| r_e = 2.2\text{k}\Omega \| 10.79\Omega = \underline{10.74\Omega}$

$Z_o = R_C = \underline{4.7\,k\Omega}$

b. —

c. $A_v = \dfrac{R_L}{R_L+R_o} A_{v_{NL}} = \dfrac{5.6\,k\Omega(435.59)}{5.6\,k\Omega + 4.7\,k\Omega} = \underline{236.83}$

$V_i = \dfrac{Z_i}{Z_i+R_s} V_s = \dfrac{10.74\,\Omega}{10.74\,\Omega + 100\,\Omega} = 0.097$

$A_{v_s} = \dfrac{V_o}{V_i} \cdot \dfrac{V_i}{V_s} = (236.83)(0.097)$

$= \underline{22.97}$

d. $V_i = I_e \cdot r_e$

$V_o = -I_o R_L$

$I_o = \dfrac{-4.7\,k\Omega(I_e)}{4.7\,k\Omega + 5.6\,k\Omega} = -0.4563 I_e$

$A_v = \dfrac{V_o}{V_i} = \dfrac{+(0.4563 \cancel{I_e})R_L}{\cancel{I_e} \cdot r_e} = \dfrac{0.4563(5.6\,k\Omega)}{10.79\,\Omega}$

$= \underline{236.82}$ (vs. 236.83 for part c)

$A_{v_s}$: $2.2\,k\Omega \| 10.79\,\Omega = 10.74\,\Omega$

$V_i = \dfrac{Z_i}{Z_i+R_s} V_s = \dfrac{10.74\,\Omega\, V_s}{10.74\,\Omega + 100\,\Omega} = 0.097\, V_s$

$A_{v_s} = \dfrac{V_o}{V_i} \cdot \dfrac{V_i}{V_s} = (236.82)(0.097)$

$= \underline{22.97}$ (same results)

e. $A_v = \dfrac{R_L}{R_L+R_o} A_{v_{NL}} = \dfrac{2.2\,k\Omega}{2.2\,k\Omega + 4.7\,k\Omega}(435.59)$

$= \underline{138.88}$

$A_{v_s} = \dfrac{V_o}{V_i} \cdot \dfrac{V_i}{V_s}$, $\dfrac{V_i}{V_s} = \dfrac{Z_i}{Z_i+R_s} = \dfrac{10.74\,\Omega}{10.74\,\Omega + 500\,\Omega} = 0.021$

$A_{v_s} = (138.88)(0.021) = \underline{2.92}$

$A_{v_s}$ very sensitive to increase in $R_s$ due to relatively small $Z_i$; $R_s\uparrow$, $A_{v_s}\downarrow$

$A_v$ sensitive to $R_L$; $R_L\downarrow$, $A_v\downarrow$

f. $Z_o = R_C = 4.7\,k\Omega$ unaffected by value of $R_s$!

g. $Z_i = R_E \| r_e = 10.74\,\Omega$ unaffected by value of $R_L$!

13. a. DC: $V_{GS} = -I_D R_S = -I_D 3.3\,k\Omega$

From intersection of Shockley's eq. + above plot

$V_{GS_Q} = -3.45\,V$, $I_{D_Q} = 1.05\,mA$

$$g_{m0} = \frac{2I_{DSS}}{|V_P|} = \frac{2(6\text{mA})}{6\text{V}} = 2\text{mS}$$

$$g_m = g_{m0}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = 2\text{mS}\left(1 - \frac{(-3.45\text{V})}{(-6\text{V})}\right) = 0.85\text{mS}$$

$$A_{v_{NL}} = \frac{g_m R_S}{1+g_m R_S} = \frac{(0.85\text{mS})(3.3\text{k}\Omega)}{1+(0.85\text{mS})(3.3\text{k}\Omega)}$$

$$= \underline{0.737}$$

$$Z_i = R_G = \underline{2\text{M}\Omega}$$

$$Z_o = 3.3\text{k}\Omega \parallel \frac{1}{g_m} = 3.3\text{k}\Omega \parallel \frac{1}{0.85\text{mS}} = 3.3\text{k}\Omega \parallel 1176.47\Omega$$

$$= \underline{0.867\text{k}\Omega}$$

b. –

c. $$A_v = \frac{R_L A_{v_{NL}}}{R_L + R_o} = \frac{2.2\text{k}\Omega(0.737)}{2.2\text{k}\Omega + 0.867\text{k}\Omega}$$

$$= \underline{0.529}$$

$A_{v_s}$:

$$V_i = \frac{2\text{M}\Omega(V_s)}{2\text{M}\Omega + 0.5\text{k}\Omega} \cong 1$$

$$A_{v_s} = \frac{V_o}{V_i} \cdot \frac{V_i}{V_s} = (0.529)(1)$$

$$= \underline{0.529}$$

d. $$A_{v_s} \cong A_v = \frac{R_L A_{v_{NL}}}{R_L + R_o} = \frac{4.7\text{k}\Omega(0.737)}{4.7\text{k}\Omega + 0.867\text{k}\Omega}$$

$$= \underline{0.622}$$

$R_L \uparrow$, $A_{v_s} \cong A_v \uparrow$

e. Little effect since $R_i \gg R_{sig}$.

f. No effect on $Z_i$ or $Z_o$!

15. a. $$A_{v_1} = \frac{R_L A_{v_{NL}}}{R_L + R_o} = \frac{1\text{k}\Omega(-420)}{1\text{k}\Omega + 3.3\text{k}\Omega} = \underline{-97.67}$$

$$A_{v_2} = \frac{R_L A_{v_{NL}}}{R_L + R_o} = \frac{2.7\text{k}\Omega(-420)}{2.7\text{k}\Omega + 3.3\text{k}\Omega} = \underline{-189}$$

b. $$A_v = A_{v_1} \cdot A_{v_2} = (-97.67)(-189) = \underline{18.46 \times 10^3}$$

$$A_{v_s} = \frac{V_o}{V_s} = \frac{V_o}{V_{i_2}} \cdot \frac{V_{o_1}}{V_{i_1}} \cdot \frac{V_{i_1}}{V_s}$$

$$= A_{v_2} \cdot A_{v_1} \cdot \frac{V_i}{V_s}$$

$$V_i = \frac{Z_i V_s}{Z_i + R_s} = \frac{1\text{k}\Omega(V_s)}{1\text{k}\Omega + 0.6\text{k}\Omega} = 0.625$$

$$A_{v_S} = (-189)(-97.67)(0.625)$$
$$= \underline{11.54 \times 10^3}$$

c. $A_{i_1} = -\dfrac{A_v Z_i}{R_L} = -\dfrac{(-97.67)(1\,k\Omega)}{1\,k\Omega} = \underline{97.67}$

$A_{i_2} = -\dfrac{A_v Z_i}{R_L} = -\dfrac{(-189)(1\,k\Omega)}{2.7\,k\Omega} = \underline{70}$

d. $A_{i_T} = A_{i_1} \cdot A_{i_2} = (97.67)(70) = \underline{6.84 \times 10^3}$

e. no effect!

f. no effect!

g. in phase.

# Chapter 10 (Even)

2. a. DC load line

$V_{CE} = V_{CC} - I_C R_C$

$V_{CE} = 0V$: $I_C = \frac{V_{CC}}{R_C} = \frac{18V}{3.3k\Omega} = \underline{5.45mA}$ (intersection on vertical $I_C$ axis)

$I_C = 0mA$: $V_{CE} = V_{CC} = \underline{18V}$ (intersection on horizontal $V_{CE}$ axis)

From problem 1, $I_B = 25.44\mu A$

Resulting Q pt.: $I_{C_Q} \cong 2.54mA$, $V_{CE_Q} \cong 9.6V$

AC Load line

Intersection on vertical $I_C$ axis:

$I_{C_Q} + \frac{V_{CE_Q}}{R_L'}$ $\quad R_L' = R_C \| R_L = 3.3k\Omega \| 4.7k\Omega = 1.94k\Omega$

$2.54mA + \frac{9.6V}{1.94k\Omega}$

$= \underline{7.49mA}$

Intersection on horizontal $V_{CE}$ axis:

$V_{CE_Q} + I_{C_Q} R_L' = 9.6V + (2.54mA)(1.94k\Omega)$

$= \underline{14.53V}$

b. From problem 1, $Z_i = 1.01k\Omega$

When $V_i$ = positive peak value of 10mV

$I_b = \frac{10mV}{1.01k\Omega} = 9.9\mu A$

and $I_b = 25.44\mu A + 9.9\mu A = 35.34\mu A$

For negative peak of $V_i$:

$I_b = 25.44\mu A - 9.9\mu A = 15.54\mu A$

On graph at $I_b = 35.34\mu A$ on the ac load line:

$V_{ce} \cong 8V$

at $I_b = 15.54\mu A$:

$V_{ce} \cong 11.8V$

$|A_v| = \frac{\Delta V_o}{\Delta V_i} = \frac{11.8V - 8V}{20mV} = \underline{190}$

which compares very nicely with the $|A_v| = 191.65$ of Prob. 1

4. a. $I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{12V - 0.7V}{1M\Omega} = 11.3\mu A$

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

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

$A_{v_{NL}} = -\frac{R_C}{r_e} = -\frac{3k\Omega}{12.71\Omega} = \underline{-236}$

$Z_i = R_B \| \beta r_e = 1M\Omega \| (180)(12.71\Omega) = 1M\Omega \| 2.288k\Omega$

$= \underline{2.283k\Omega}$

$Z_o = R_C = \underline{3k\Omega}$

b. –

c. no-load: $A_v = A_{v_{NL}} = \underline{-236}$

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

$= \underline{-186.9}$

e. $V_o = -I_o R_C = -\beta I_b R_C$

$V_i = I_b \beta r_e$

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

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

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

$A_{v_s} = (-236)(0.792)$

$= \underline{-186.9}$ (same results)

f. no change!

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

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

h. no change!

6. a. Exact Analysis:

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

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

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

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

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

$= 2.673\text{ mA}$

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

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

$Z_i = 68\text{ k}\Omega \| 16\text{ k}\Omega \| \beta r_e$

$= 12.95\text{ k}\Omega \| (100)(9.726\ \Omega)$

$= 12.95\text{ k}\Omega \| 972.6\ \Omega$

$= \underline{904.66\ \Omega}$

$Z_o = R_C = \underline{2.2\text{ k}\Omega}$

b. —

c. $A_v = \dfrac{R_L}{R_L + Z_o}(A_{v_{NL}}) = \dfrac{5.6\text{ k}\Omega}{5.6\text{ k}\Omega + 2.2\text{ k}\Omega}(-226.2) = \underline{-162.4}$

d. $A_i = -A_v \frac{Z_i}{R_L}$

$= -(-162.4)\frac{(904.66\Omega)}{5.6k\Omega}$

$= \underline{26.24}$

e. $A_v = -\frac{R_C \| R_L}{r_e} = -\frac{2.2k\Omega \| 5.6k\Omega}{9.726\Omega}$

$= \underline{-162.4}$

$Z_i = 68k\Omega \| 16k\Omega \| \underbrace{972.6\Omega}_{\beta r_e}$

$= \underline{904.66\Omega}$

$Z_o = R_C = \underline{2.2k\Omega}$

same results!

8. a. $A_v = \frac{R_L}{R_L + Z_o} A_{v_{NL}}$

$R_L = 4.7k\Omega$: $A_v = \frac{4.7k\Omega}{4.7k\Omega + 2.2k\Omega}(-226.4) = \underline{-154.2}$

$R_L = 2.2k\Omega$: $A_v = \frac{2.2k\Omega}{2.2k\Omega + 2.2k\Omega}(-226.4) = \underline{-113.2}$

$R_L = 0.5k\Omega$: $A_v = \frac{0.5k\Omega}{0.5k\Omega + 2.2k\Omega}(-226.4) = \underline{-41.93}$

$R_L \downarrow, A_v \downarrow$

b. unaffected!

10. Using the exact approach:

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

$= \frac{2.33V - 0.7V}{10.6k\Omega + (121)(1.2k\Omega)}$

$= 10.46\mu A$

$E_{Th} = \frac{R_2}{R_1 + R_2} V_{CC}$

$= \frac{12k\Omega}{91k\Omega + 12k\Omega}(20V) = 2.33V$

$R_{Th} = R_1 \| R_2 = 91k\Omega \| 12k\Omega = 10.6k\Omega$

$I_E = (\beta+1) I_B = (121)(10.46\mu A)$

$= 1.266mA$

$r_e = \frac{26mV}{I_E} = \frac{26mV}{1.266mA} = 20.54\Omega$

a. $A_{v_{NL}} \cong \frac{R_E}{r_e + R_E} = \frac{1.2k\Omega}{20.54\Omega + 1.2k\Omega} = \underline{0.983}$

$Z_i = R_1 \| R_2 \| (\beta r_e + (\beta+1) R_E)$

$= 91k\Omega \| 12k\Omega \| ((120)(20.54\Omega) + (120+1)(1.2k\Omega))$

$= 10.6k\Omega \| (2.46k\Omega + 145.2k\Omega)$

$= 10.6k\Omega \| 147.66k\Omega$

$= \underline{9.89k\Omega}$

$Z_o = R_E \| r_e = 1.2k\Omega \| 20.54\Omega$

$= \underline{20.19\Omega}$

b.—

c. $A_v = \dfrac{R_L}{R_L+Z_o} A_{v_{NL}} = \dfrac{2.7\text{k}\Omega}{2.7\text{k}\Omega+20.19\Omega}(0.983)$

$= \underline{0.976}$

$A_{v_s} = \dfrac{Z_i}{Z_i+R_s} A_v = \dfrac{9.89\text{k}\Omega(0.976)}{9.89\text{k}\Omega+0.6\text{k}\Omega}$

$= \underline{0.92}$

d. $A_v = 0.976$ (unaffected by change in $R_s$)

$A_{v_s} = \dfrac{Z_i}{Z_i+R_s} A_v = \dfrac{9.89\text{k}\Omega(0.976)}{9.89\text{k}\Omega+1\text{k}\Omega}$

$= \underline{0.886}$ (vs. 0.92 with $R_s = 0.6\text{k}\Omega$)

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

e. Changing $R_s$ will have no affect on $A_{v_{NL}}$, $Z_i$ or $Z_o$.

f. $A_v = \dfrac{R_L}{R_L+Z_o}(A_{v_{NL}}) = \dfrac{5.6\text{k}\Omega(0.983)}{5.6\text{k}\Omega+20.19\Omega}$

$= \underline{0.979}$ (vs 0.976 with $R_L = 2.7\text{k}\Omega$)

$A_{v_s} = \dfrac{Z_i}{Z_i+R_s}(A_v) = \dfrac{9.89\text{k}\Omega}{9.89\text{k}\Omega+0.6\text{k}\Omega}(0.979)$

$= \underline{0.923}$ (vs. 0.92 with $R_L = 2.7\text{k}\Omega$)

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

12. a. $V_{GS_Q} = -2.13\text{V}$

$I_{D_Q} = 4.17\text{mA}$

$g_{m0} = \dfrac{2I_{DSS}}{|V_p|} = \dfrac{2(10\text{mA})}{6\text{V}} = 3.333\text{mS}$

$g_m = g_{m0}\left(1 - \dfrac{V_{GS}}{V_P}\right) = 3.333\text{mS}\left(1 - \dfrac{(-2.13\text{V})}{(-6\text{V})}\right)$

$= 2.15\text{mS}$

$A_{v_{NL}} = -g_m R_D = -(2.15\text{mS})(1.2\text{k}\Omega)$

$= \underline{-2.58}$

$Z_i = \underline{1\text{M}\Omega}$

$Z_o = R_D = \underline{1.2\text{k}\Omega}$

b.—

c. $A_v = \dfrac{R_L}{R_L+Z_o} A_{v_{NL}} = \dfrac{4.7\text{k}\Omega}{4.7\text{k}\Omega+1.2\text{k}\Omega}(-2.58)$

$= \underline{-2.055}$

$A_{v_s} = \dfrac{Z_i}{Z_i+R_{sig}} A_v = \dfrac{1\text{M}\Omega}{1\text{M}\Omega+0.6\text{k}\Omega}(-2.055)$

$= \underline{-2.054}$

d. $A_v = \frac{6.8\text{ k}\Omega}{6.8\text{ k}\Omega + 1.2\text{ k}\Omega}(-2.58)$

$= \underline{-2.193}$

$R_L \uparrow,\ A_v \uparrow$

$A_{v_s} = \frac{1\text{ M}\Omega}{1\text{ M}\Omega + 1\text{ k}\Omega}(-2.193)$

$= \underline{-2.191}$

$R_{sig} \uparrow,\ A_{v_s} \downarrow$

e. $Z_i + Z_o$ unaffected by $R_L$ or $R_{sig}$

14\. a. $V_{GS_Q} \cong -1.8\text{ V},\ I_{D_Q} \cong 1.5\text{ mA}$

$g_{m0} = \frac{2I_{DSS}}{|V_P|} = \frac{2(5\text{ mA})}{4\text{ V}} = 2.5\text{ mS}$

$g_m = g_{m0}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = 2.5\text{ mS}\left(1 - \frac{(-1.8\text{ V})}{(-4\text{ V})}\right)$

$= 1.375\text{ mS}$

$A_v = g_m R_D$

$= (1.375\text{ mS})(3.3\text{ k}\Omega)$

$= \underline{4.54}$

$Z_i = R_S \| \frac{1}{g_m} = 1.2\text{ k}\Omega \| \frac{1}{1.375\text{ mS}} = 1.2\text{ k}\Omega \| 727.27\Omega$

$= \underline{452.83\Omega}$

$Z_o = R_D = 3.3\text{ k}\Omega$

b. —

c. $A_v = \frac{R_L}{R_L + Z_o} A_{v_{NL}} = \frac{4.7\text{ k}\Omega}{4.7\text{ k}\Omega + 3.3\text{ k}\Omega}(4.54)$

$= \underline{2.67}$

$A_{v_s} = \frac{Z_i}{Z_i + R_{sig}} A_v = \frac{452.83\Omega}{452.83\Omega + 1\text{ k}\Omega}(2.67)$

$= 0.832$

d. $A_v = \frac{R_L}{R_L + Z_o} A_{v_{NL}} = \frac{2.2\text{ k}\Omega}{2.2\text{ k}\Omega + 3.3\text{ k}\Omega}(4.54)$

$= \underline{1.88}$

$A_{v_s} = \frac{Z_i}{Z_i + R_{sig}} A_v = \frac{452.83\Omega}{452.83\Omega + 1\text{ k}\Omega}(1.88)$

$= \underline{0.586}$

$R_L \downarrow,\ A_v \downarrow,\ A_{v_s} \downarrow$

e. $A_{v_s} = \frac{Z_i}{Z_i + R_{sig}} A_v = \frac{452.83\Omega}{452.83\Omega + 0.5\text{ k}\Omega}(2.67)$

$= \underline{1.27}$ $\quad R_{sig} \downarrow,\ A_v$ (the same), $A_{v_s} \uparrow$

f. $Z_i + Z_o$ unaffected by value of $R_L + R_{sig}$

16. a. $A_{v_1} = \dfrac{Z_{i_2}}{Z_{i_2} + Z_{o_1}} A_{v_{1NL}} = \dfrac{1.2\text{ k}\Omega}{1.2\text{ k}\Omega + 20\Omega}(1)$

$= \underline{0.984}$

$A_{v_2} = \dfrac{R_L}{R_L + Z_{o_2}} A_{v_{2NL}} = \dfrac{2.2\text{ k}\Omega}{2.2\text{ k}\Omega + 4.6\text{ k}\Omega}(-640)$

$= \underline{-207.06}$

b. $A_{v_T} = A_{v_1} \cdot A_{v_2} = (0.984)(-207.06)$

$= \underline{-203.74}$

$A_{v_s} = \dfrac{Z_i}{Z_i + R_s} A_{v_T}$

$= \dfrac{50\text{ k}\Omega}{50\text{ k}\Omega + 1\text{ k}\Omega}(-203.74)$

$= \underline{-199.75}$

c. $A_{i_1} = -A_{v_1} \dfrac{Z_{i_1}}{Z_{i_2}}$

$= -(0.984)\left(\dfrac{50\text{ k}\Omega}{1.2\text{ k}\Omega}\right)$

$= \underline{-41}$

$A_{i_2} = -A_{v_2} \dfrac{Z_{i_2}}{R_L}$

$= -(-207.06)\left(\dfrac{1.2\text{ k}\Omega}{2.2\text{ k}\Omega}\right)$

$= \underline{112.94}$

d. $A_{i_T} = -A_{v_T} \dfrac{Z_{i_1}}{R_L}$

$= -(-203.74)\left(\dfrac{50\text{ k}\Omega}{2.2\text{ k}\Omega}\right)$

$= \underline{4.63 \times 10^3}$

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.

Chapter 11 (Odd)

1. a. $\underline{3}, \underline{1.699}, \underline{-0.151}$

   b. $\underline{6.908}, \underline{3.912}, \underline{-0.347}$

   c. results differ by magnitude of 2.3

3. a. same $\underline{13.98}$

   b. same $\underline{-13.01}$

   c. same $\underline{0.699}$

5. $$G_{dBm} = 10\log_{10}\frac{P_2}{1\,mW}\bigg|_{600\Omega} = 10\log_{10}\frac{25\,W}{1\,mW}\bigg|_{600\Omega}$$
$$= \underline{43.98\text{ dBm}}$$

7. $$G_{dB} = 20\log_{10}\frac{V_2}{V_1} = 20\log_{10}\frac{25\,V}{10\,mV} = 20\log_{10}2500$$
$$= 20(3.398) = \underline{67.96\,dB}$$

9. (a) $$G_{dB} = 10\log_{10}\frac{P_2}{P_1} = 10\log_{10}\frac{48\,W}{5\,\mu W} = \underline{69.83\,dB}$$

(b) $$G_v = 20\log_{10}\frac{V_o}{V_i} = 20\log_{10}\frac{\sqrt{P_oR_o}}{V_i} = 20\log_{10}\frac{\sqrt{(48\,W)(40\,k\Omega)}}{100\,mV}$$
$$= \underline{82.83\,dB}$$

(c) $$R_i = \frac{V_i^2}{P} = \frac{(100\,mV)^2}{5\,\mu W} = \underline{2\,k\Omega}$$

(d) $$P_o = \frac{V_o^2}{R_o} \Rightarrow V_o = \sqrt{P_oR_o} = \sqrt{(48\,W)(40\,k\Omega)} = \underline{1385.64\,V}$$

11. a. $$|A_v| = \left|\frac{V_o}{V_i}\right| = \frac{1}{\sqrt{1+(f_1/f)^2}} \qquad f_1 = \frac{1}{2\pi RC} = \frac{1}{2\pi(1.2\,k\Omega)(0.068\,\mu F)}$$
$$= 1950.43\,Hz$$

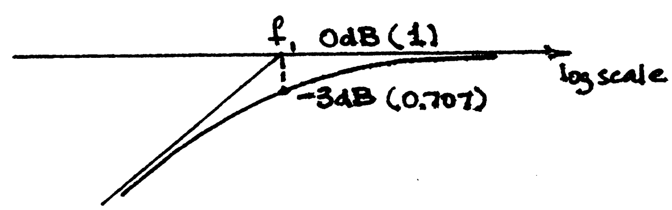
$$|A_v| = \frac{1}{\sqrt{1+\left(\frac{1950.43\,Hz}{f}\right)^2}}$$

b.

| | | $A_{v_{dB}}$ |
|---|---|---|
| 100 Hz: | $|A_v| = 0.051$ | $-25.8$ |
| 1 kHz: | $|A_v| = 0.456$ | $-6.81$ |
| 2 kHz: | $|A_v| = 0.716$ | $-2.90$ |
| 5 kHz: | $|A_v| = 0.932$ | $-0.615$ |
| 10 kHz: | $|A_v| = 0.982$ | $-0.162$ |

c. $f_1 \cong \underline{1950\,Hz}$

d. e.



13. a. $\underline{10\text{ kHz}}$

b. $\underline{1\text{ kHz}}$

c. $20\text{ kHz} \to 10\text{ kHz} \to \underline{5\text{ kHz}}$

d. $1\text{ kHz} \to 10\text{ kHz} \to \underline{100\text{ kHz}}$

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!)

$$V_B = \frac{10\text{ k}\Omega(14\text{ V})}{10\text{ k}\Omega + 68\text{ k}\Omega} = 1.795\text{ V}$$

$$V_E = V_B - V_{BE} = 1.795\text{ V} - 0.7\text{ V}$$
$$= 1.095\text{ V}$$

$$I_E = \frac{V_E}{R_E} = \frac{1.095\text{ V}}{1.2\text{ k}\Omega} = 0.913\text{ mA}$$

$$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{0.913\text{ mA}} = \underline{28.48\ \Omega}$$

b. $$A_{v_{mid}} = -\frac{(R_L \| R_C)}{r_e} = -\frac{(3.3\text{ k}\Omega \| 5.6\text{ k}\Omega)}{28.48\ \Omega}$$
$$= \underline{-72.91}$$

c. $$Z_i = R_1 \| R_2 \| \beta r_e$$
$$= 68\text{ k}\Omega \| 10\text{ k}\Omega \| \underbrace{(120)(28.48\ \Omega)}_{3.418\text{ k}\Omega}$$
$$= \underline{2.455\text{ k}\Omega}$$

d. $$A_{v_s} = \frac{V_o}{V_s} = \frac{V_o}{V_i} \cdot \frac{V_i}{V_s}$$

$$\frac{V_i}{V_s} = \frac{Z_i}{Z_i + R_s} = \frac{2.455\text{ k}\Omega}{2.455\text{ k}\Omega + 0.82\text{ k}\Omega}$$
$$= 0.75$$

$$A_{v_s} = (-72.91)(0.75)$$
$$= \underline{-54.68}$$

e. $$f_{L_S} = \frac{1}{2\pi(R_s + R_i)C_s} = \frac{1}{2\pi(0.82\text{ k}\Omega + 2.455\text{ k}\Omega)(0.47\ \mu\text{F})}$$
$$= \underline{103.4\text{ Hz}}$$

$$f_{L_C} = \frac{1}{2\pi(R_o + R_L)C_C} = \frac{1}{2\pi(5.6\text{ k}\Omega + 3.3\text{ k}\Omega)(0.47\ \mu\text{F})}$$
$$= \underline{38.05\text{ Hz}}$$

$$f_{L_E} = \frac{1}{2\pi R_e C_E} : \quad R_e = R_E \| \left(\frac{R_s'}{\beta} + r_e\right)$$

$$R_s' = R_s \| R_1 \| R_2 = 0.82\text{ k}\Omega \| 68\text{ k}\Omega \| 10\text{ k}\Omega$$
$$= 749.51\ \Omega$$

$R_e = 1.2\,k\Omega \parallel \left(\frac{749.51\Omega}{120} + 28.48\Omega\right)$

$= 1.2\,k\Omega \parallel 34.73\Omega$

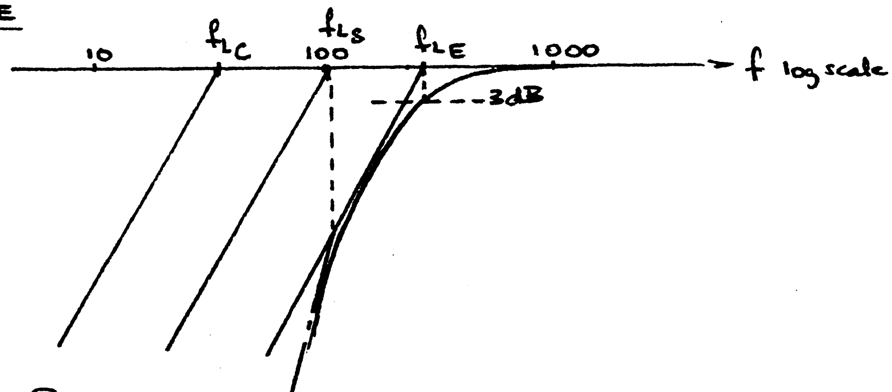
$= 33.75\Omega$

$f_{L_E} = \frac{1}{2\pi R_e C_E} = \frac{1}{2\pi(33.75\Omega)(20\,\mu F)}$

$= \underline{235.79\,Hz}$

f. $f_1 \cong \underline{f_{L_E}}$

g.h.




17. a. $\beta R_E \ge 10R_2$

$(100)(2.2\,k\Omega) \ge 10(30\,k\Omega)$

$220\,k\Omega \not\geq 300\,k\Omega$ (No!)

$R_{Th} = R_1 \parallel R_2 = 120\,k\Omega \parallel 30\,k\Omega = 24\,k\Omega$

$E_{Th} = \frac{30\,k\Omega(14V)}{30\,k\Omega + 120\,k\Omega} = 2.8V$

$I_B = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta+1)R_E} = \frac{2.8V - 0.7V}{24\,k\Omega + 222.2\,k\Omega}$

$= 8.53\,\mu A$

$I_E = (\beta+1)I_B = (101)(8.53\,\mu A)$

$= 0.86\,mA$

$r_e = \frac{26\,mV}{I_E} = \frac{26\,mV}{0.86\,mA} = \underline{30.23\Omega}$

b. $A_{v_{mid}} = \frac{R_E \parallel R_L}{r_e + R_E \parallel R_L}$

$= \frac{2.2\,k\Omega \parallel 8.2\,k\Omega}{30.23\Omega + 2.2\,k\Omega \parallel 8.2\,k\Omega}$

$= \underline{0.983}$

c. $Z_i = R_1 \parallel R_2 \parallel \beta(r_e + R_E')$ $\qquad R_E' = R_E \parallel R_L = 2.2\,k\Omega \parallel 8.2\,k\Omega = 1.735\,k\Omega$

$= 120\,k\Omega \parallel 30\,k\Omega \parallel (100)(30.23\Omega + 1.735\,k\Omega)$

$= \underline{21.13\,k\Omega}$

d. $A_{v_s} = \frac{V_o}{V_s} = \frac{V_o}{V_i} \cdot \frac{V_i}{V_s}$ $\qquad \frac{V_i}{V_s} = \frac{Z_i}{Z_i + R_s} = \frac{21.13\,k\Omega}{21.13\,k\Omega + 1\,k\Omega} = 0.955$

e. $f_{L_s} = \dfrac{1}{2\pi(R_s+R_i)C_s}$

$= \dfrac{1}{2\pi\,(1\text{k}\Omega + 21.13\text{k}\Omega)(0.1\mu F)}$

$= \underline{71.92\text{ Hz}}$

$f_{L_C} = \dfrac{1}{2\pi\,(R_o+R_L)C_C}$

$R_o = R_E \| \left(\dfrac{R_s'}{\beta} + r_e\right)$

$= (2.2\text{k}\Omega) \| \left(\dfrac{0.96\text{k}\Omega}{100} + 30.23\Omega\right)$

$= 39.12\Omega$

$R_s' = R_s \| R_1 \| R_2$

$= 1\text{k}\Omega \| 120\text{k}\Omega \| 30\text{k}\Omega$

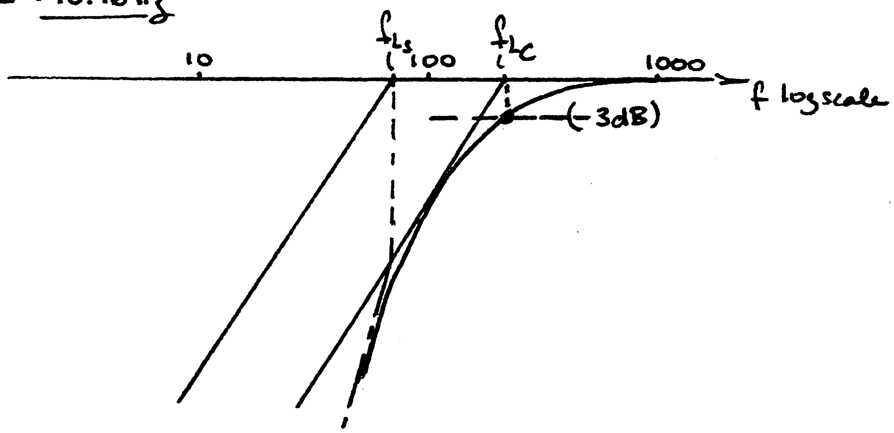
$= 0.96\text{k}\Omega$

$f_{L_C} = \dfrac{1}{2\pi(39.12\Omega + 8.2\text{k}\Omega)(0.1\mu F)}$

$= \underline{193.16\text{ Hz}}$

f. $f_{1_{low}} \cong \underline{193.16\text{ Hz}}$

g.h.




19. a. $V_{GS} = -I_D R_S$
$I_D = I_{DSS}\left(1 - \dfrac{V_{GS}}{V_P}\right)^2$ $\Big\}$ $V_{GS_Q} \cong -2.45\text{V}$, $I_{D_Q} \cong 2.1\text{mA}$

b. $g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(6\text{mA})}{6\text{V}} = 2\text{mS}$

$g_m = g_{m0}\left(1 - \dfrac{V_{GS_Q}}{V_P}\right) = 2\text{mS}\left(1 - \dfrac{(-2.45\text{V})}{(-6\text{V})}\right)$

$= 1.18\text{mS}$

c. $A_{v_{mid}} = -g_m(R_D \| R_L)$

$= -1.18\text{mS}(3\text{k}\Omega \| 3.9\text{k}\Omega) = -1.18\text{mS}(1.6956\text{k}\Omega)$

$= \underline{-2}$

d. $Z_i = R_G = \underline{1\text{M}\Omega}$

e. $A_{v_s} \cong A_v = \underline{-2}$

f. $f_{L_G} = \dfrac{1}{2\pi(R_{sig}+R_i)C_G} = \dfrac{1}{2\pi\,(1\text{k}\Omega + 1\text{M}\Omega)(0.1\mu F)}$

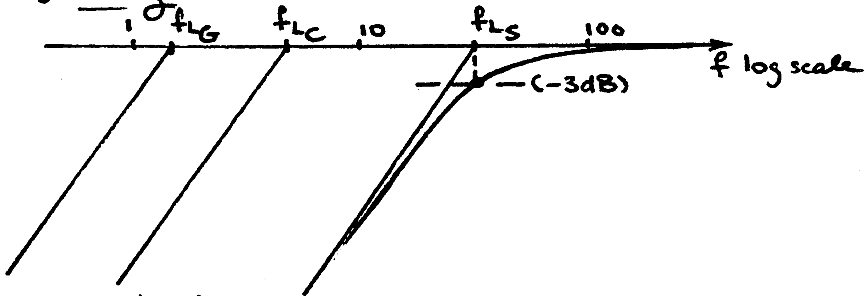
$= \underline{1.59\text{ Hz}}$

$$f_{LC} = \frac{1}{2\pi(R_o+R_L)C_C}$$
$$= \frac{1}{2\pi(3k\Omega + 3.9k\Omega)(4.7\mu F)}$$
$$= \underline{4.91 Hz}$$

$$f_{LS} = \frac{1}{2\pi R_{eq} C_S} \qquad R_{eq} = R_S \| \frac{1}{g_m} = 1.2k\Omega \| \frac{1}{1.18mS} = 1.2k\Omega \| 847.46\Omega$$
$$= \frac{1}{2\pi(496.69\Omega)(10\mu F)} \qquad = 496.69\Omega$$
$$= \underline{32.04 Hz}$$

g. $f_1 \cong f_{LS} \cong \underline{32 Hz}$

h, i.




21. a. $V_G = \frac{68k\Omega(20V)}{68k\Omega + 220k\Omega} = 4.72V$

$V_{GS} = V_G - I_D R_S$

$\left.\begin{array}{l} V_{GS} = 4.72V - I_D(2.2k\Omega) \\ I_D = I_{DSS}(1 - V_{GS}/V_P)^2 \end{array}\right\} \quad \begin{array}{l} V_{GS_Q} \cong \underline{-2.55V} \\ I_{D_Q} \cong \underline{3.3mA} \end{array}$

b. $g_{mo} = \frac{2I_{DSS}}{|V_P|} = \frac{2(10mA)}{6V} = \underline{3.33mS}$

$g_m = g_{mo}\left(1 - \frac{V_{GS}}{V_P}\right) = 3.33mS\left(1 - \frac{(-2.55V)}{(-6V)}\right)$

$= \underline{1.91mS}$

c. $A_{v_{mid}} = -g_m(R_D \| R_L)$

$= -(1.91mS)(3.9k\Omega \| 5.6k\Omega)$

$= \underline{-4.39}$

d. $Z_i = 68k\Omega \| 220k\Omega = \underline{51.94k\Omega}$

e. $A_{v_s\,mid} = \frac{V_o}{V_i} \cdot \frac{V_i}{V_s}$

$\frac{V_i}{V_s} = \frac{Z_i}{Z_i + R_s} = \frac{51.94k\Omega}{51.94k\Omega + 1.5k\Omega} = 0.972$

$A_{v_s\,mid} = (-4.39)(0.972) = \underline{-4.27}$

f. $f_{LG} = \frac{1}{2\pi(R_{sig}+R_i)C_G} = \frac{1}{2\pi(1.5k\Omega + 51.94k\Omega)(1\mu F)}$

$= \underline{2.98 Hz}$

$f_{LC} = \frac{1}{2\pi(R_o+R_L)C_C} = \frac{1}{2\pi(3.9k\Omega + 5.6k\Omega)(6.8\mu F)}$

$= \underline{2.46 Hz}$

$$f_{L_S} = \frac{1}{2\pi R_{eq} C_S} \qquad R_{eq} = R_s \| \frac{1}{g_m} = 1.5\,k\Omega \| \frac{1}{1.91\,mS}$$

$$= 1.5\,k\Omega \| 523.56\,\Omega$$

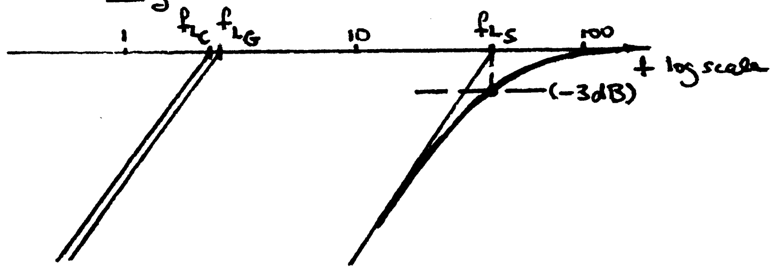
$$= 388.1\,\Omega$$

$$= \frac{1}{2\pi(388.1\,\Omega)(10\,\mu F)}$$

$$= \underline{41\,Hz}$$

g. $f_1 \cong f_{L_S} = \underline{41\,Hz}$

h, i.




23. a. $f_{H_i} = \dfrac{1}{2\pi R_{Th_1} C_i}$

$R_{Th_1} = R_s \| R_B \| R_i$

$R_i$: $I_B = \dfrac{V_{CC} - V_{BE}}{R_B + (\beta+1)R_E} = \dfrac{20\,V - 0.7\,V}{470\,k\Omega + (111)(0.91\,k\Omega)}$

$= 33.8\,\mu A$

$I_E = (\beta+1)I_B = (110+1)(33.8\,\mu A)$

$= 3.75\,mA$

$r_e = \dfrac{26\,mV}{I_E} = \dfrac{26\,mV}{3.75\,mA} = 6.93\,\Omega$

$R_i = \beta r_e = (110)(6.93\,\Omega)$

$= 762.3\,\Omega$

$R_{Th_1} = R_s \| R_B \| R_i = 0.6\,k\Omega \| 470\,k\Omega \| 762.3\,\Omega$

$= 335.50\,\Omega$

$f_{H_i} = \dfrac{1}{2\pi(335.50\,\Omega)(C_i)}$

$C_i$: $C_i = C_{W_i} + C_{be} + (1 - A_v)C_{bc}$

$A_v$: $A_{v_{mid}} = \dfrac{-(R_L \| R_C)}{r_e} = \dfrac{-(4.7\,k\Omega \| 3\,k\Omega)}{6.93\,\Omega}$

$= -264.2$

$C_i = 7\,pF + 20\,pF + (1-(-264.2))6\,pF$

$= 1.62\,nF$

$f_{H_i} = \dfrac{1}{2\pi(335.50\,\Omega)(1.62\,nF)}$

$\cong \underline{293\,kHz}$

$f_{H_o} = \dfrac{1}{2\pi R_{Th_2} C_o}$

$R_{Th_2} = R_C \| R_L \| r_o = 3\,k\Omega \| 4.7\,k\Omega = 1.831\,k\Omega$

$$C_o = C_{W_o} + C_{ce} + \underbrace{C_{M_o}}_{\cong C_f = C_{bc}}$$

$$= 11\,pF + 10\,pF + 6\,pF$$

$$= 27\,pF$$

$$f_{H_o} = \frac{1}{2\pi(1.831\,k\Omega)(27\,pF)}$$

$$= \underline{3.22\,MHz}$$

b. $$f_\beta = \frac{1}{2\pi \beta_{mid}\, r_e\, (C_{be} + C_{bc})}$$

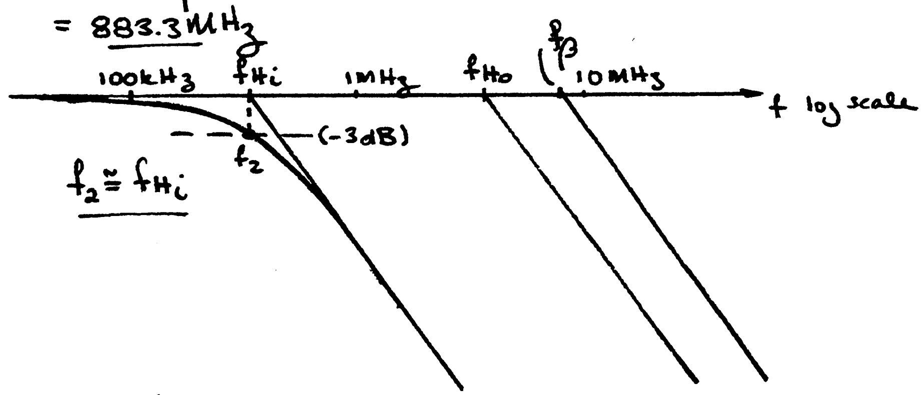
$$= \frac{1}{2\pi(110)(6.93\,\Omega)(20\,pF + 6\,pF)}$$

$$= \underline{8.03\,MHz}$$

$$f_T = \beta_{mid} f_\beta = (110)(8.03\,MHz)$$

$$= \underline{883.3\,MHz}$$

c.




$\underline{f_2 \cong f_{H_i}}$

25. a. $$f_{H_i} = \frac{1}{2\pi R_{Th_1} C_i}$$

$$R_{Th_1} = R_s \| R_E \| R_i$$

$R_i$: $$I_E = \frac{V_{EE} - V_{BE}}{R_E} = \frac{4V - 0.7V}{1.2\,k\Omega} = 2.75\,mA$$

$$r_e = \frac{26\,mV}{I_E} = \frac{26\,mV}{2.75\,mA} = 9.45\,\Omega$$

$$R_i = R_E \| r_e = 1.2\,k\Omega \| 9.45\,\Omega$$

$$= 9.38\,\Omega$$

$C_i$: $$C_i = C_{W_i} + C_{be}$$ (no Miller cap – non-inverting!)

$$= 8\,pF + 24\,pF$$

$$= 32\,pF$$

$$R_i = .1\,k\Omega \| 1.2\,k\Omega \| 9.38\,\Omega = 8.52\,\Omega$$

$$f_{H_i} = \frac{1}{2\pi(8.52\,\Omega)(32\,pF)} \cong \underline{584\,MHz}$$

$$f_{H_o} = \frac{1}{2\pi R_{Th_2} C_o} \qquad R_{Th_2} = R_C \| R_L = 3.3\,k\Omega \| 4.7\,k\Omega$$

$$= 1.94\,k\Omega$$

$C_o = C_{W_o} + C_{bc} +$ (no Miller)

$$= 10\,pF + 18\,pF$$

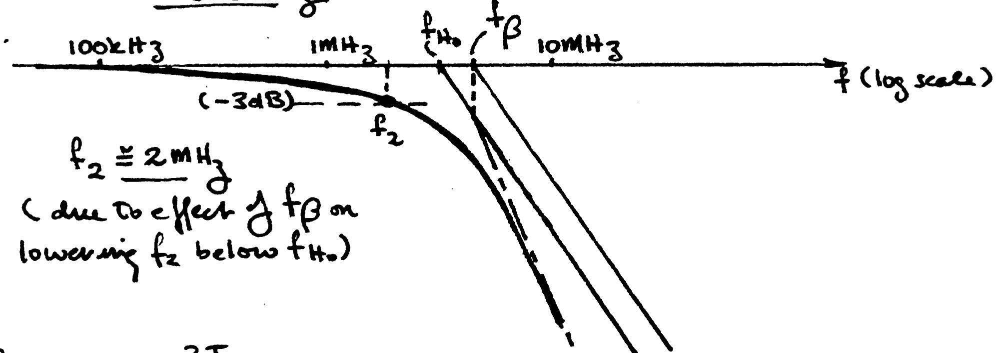
$$= 28\,pF$$

$$f_{H_o} = \frac{1}{2\pi(1.94\,k\Omega)(28\,pF)}$$
$$= \underline{2.93\,MHz}$$

b. $$f_\beta = \frac{1}{2\pi\beta_{mid}\, r_e (C_{be} + C_{bc})}$$
$$= \frac{1}{2\pi(80)(9.45\,\Omega)(24\,pF + 18\,pF)}$$
$$= \underline{5.01\,MHz}$$

$$f_T = \beta_{mid} f_\beta = (80)(5.01\,MHz)$$
$$= \underline{400.8\,MHz}$$

c.




$f_2 \cong \underline{2\,MHz}$
(due to effect of $f_\beta$ on lowering $f_2$ below $f_{H_o}$)

27. a. $$g_{m0} = \frac{2I_{DSS}}{|V_P|} = \frac{2(10\,mA)}{6\,V} = \underline{3.33\,mS}$$

From problem #21 $V_{GS_Q} \cong -2.55\,V$, $I_{D_Q} \cong 3.3\,mA$

$$g_m = g_{m0}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = 3.33\,mS\left(1 - \frac{(-2.55\,V)}{(-6\,V)}\right) = \underline{1.91\,mS}$$

b. $$A_{v_{mid}} = -g_m(R_D \| R_L)$$
$$= -(1.91\,mS)(3.9\,k\Omega \| 5.6\,k\Omega)$$
$$= \underline{-4.39}$$

$$Z_i = 68\,k\Omega \| 220\,k\Omega = 51.94\,k\Omega$$
$$\frac{V_i}{V_s} = \frac{Z_i}{Z_i + R_{sig}} = \frac{51.94\,k\Omega}{51.94\,k\Omega + 1.5\,k\Omega} = 0.972$$
$$A_{v_{s\,mid}} = (-4.39)(0.972)$$
$$= \underline{-4.27}$$

c. $$f_{H_i} = \frac{1}{2\pi R_{Th_1} C_i} \qquad R_{Th_1} = R_{sig} \| R_1 \| R_2$$
$$= 1.5\,k\Omega \| 51.94\,k\Omega$$
$$= 1.46\,k\Omega$$

$$C_i = C_{W_i} + C_{gs} + (1 - A_v)C_{gd}$$
$$= 4\,pF + 12\,pF + (1 - (-4.39))8\,pF$$
$$= 59.12\,pF$$

$$f_{H_i} = \frac{1}{2\pi(1.46\,k\Omega)(59.12\,pF)}$$
$$= \underline{1.84\,MHz}$$

$$f_{H_o} = \frac{1}{2\pi R_{Th_2} C_o} \qquad R_{Th_2} = R_D \| R_L = 3.9\,k\Omega \| 5.6\,k\Omega = 2.3\,k\Omega$$

$$C_o = C_{W_o} + C_{ds} + \left(1 - \frac{1}{A_v}\right) C_{gd}$$

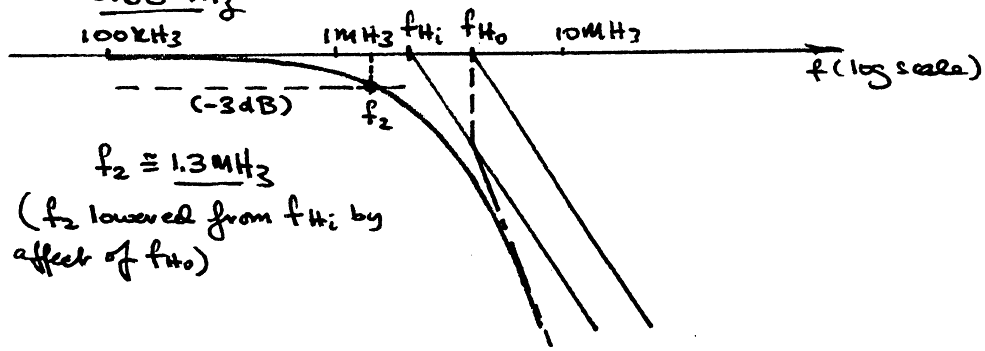
$$= 6\,pF + 3\,pF + \left(1 - \frac{1}{(-4.39)}\right) 8\,pF$$

$$= 18.82\,pF$$

$$f_{H_o} = \frac{1}{2\pi(2.3\,k\Omega)(18.82\,pF)}$$

$$= \underline{3.68\,MHz}$$

d.




$f_2 \cong \underline{1.3\,MHz}$

($f_2$ lowered from $f_{H_i}$ by affect of $f_{H_o}$)

29.

$$f_2' = \left(\sqrt{2^{1/n} - 1}\right) f_2$$

$$= \left(\sqrt{\underbrace{2^{1/4}}_{1.18} - 1}\right)(2.5\,MHz)$$

$$= 0.435(2.5\,MHz)$$

$$= \underline{1.09\,MHz}$$

31. a. $$v = \frac{4}{\pi} V_m \Big(\sin 2\pi f_s t + \frac{1}{3}\sin 2\pi(3f_s)t + \frac{1}{5}\sin 2\pi(5f_s)t + \frac{1}{7}\sin 2\pi(7f_s)t + \frac{1}{9}\sin 2\pi(9f_s)t + \cdots\Big]$$

$$= 12.73\times10^{-3}\Big(\sin 2\pi(100\times10^3)t + \frac{1}{3}\sin 2\pi(300\times10^3)t + \frac{1}{5}\sin 2\pi(500\times10^3)t + \frac{1}{7}\sin 2\pi(700\times10^3)t + \frac{1}{9}\sin 2\pi(900\times10^3)t\Big]$$

b. $$BW \cong \frac{0.35}{t_r} \cong \frac{0.35}{0.7\,\mu s} \cong \underline{500\,kHz}$$

At 90% or 81mV, $t \cong 0.75\,\mu s$

At 10% or 9mV, $t \cong 0.05\,\mu s$

$t_r \cong 0.75\,\mu s - 0.05\,\mu s = 0.7\,\mu s$

c. $$P = \frac{V - V'}{V} = \frac{90\,mV - 80\,mV}{90\,mV} = 0.111$$

$$f_{L_o} = \frac{P}{\pi} f_s = \frac{(0.111)(100\,kHz)}{\pi} \cong \underline{3.53\,kHz}$$

## Chapter 11 (Even)

2. a. $\log_{10} 2.2\times10^3 = \underline{3.3424}$

b. $\log_e (2.2\times10^3) = 2.3\log_{10}(2.2\times10^3) = \underline{7.6962}$

c. $\log_e (2.2\times10^3) = \underline{7.6962}$

4. a. $dB = 10\log_{10}\frac{P_o}{P_i} = 10\log_{10}\frac{100\,W}{5\,W} = 10\log_{10}20 = 10(1.301)$

$= \underline{13.01\,dB}$

b. $dB = 10\log_{10}\frac{100\,mW}{5\,mW} = 10\log_{10}20 = 10(1.301)$

$= \underline{13.01\,dB}$

c. $dB = 10\log_{10}\frac{100\,\mu W}{20\,\mu W} = 10\log_{10}5 = 10(0.6987)$

$= \underline{6.9897\,dB}$

6. $G_{dB} = 20\log_{10}\frac{V_2}{V_1} = 20\log_{10}\frac{100\,V}{25\,V} = 20\log_{10}4 = 20(0.6021)$

$= \underline{12.04\,dB}$

8. a. Gain of stage 1 = A dB

" " 2 = 2A dB

" " 3 = 2.7A dB

$A + 2A + 2.7A = 120$

$A = 21.05\,dB$

b. Stage 1: $A_{v_1} = 21.05\,dB = 20\log_{10}\frac{V_{o_1}}{V_{i_1}}$

$\frac{21.05}{20} = 1.0526 = \log_{10}\frac{V_{o_1}}{V_{i_1}}$

$10^{1.0526} = \frac{V_{o_1}}{V_{i_1}}$

and $\frac{V_{o_1}}{V_{i_1}} = \underline{11.288}$

Stage 2: $A_{v_2} = 42.1\,dB = 20\log_{10}\frac{V_{o_2}}{V_{i_2}}$

$2.105 = \log_{10}\frac{V_{o_2}}{V_{i_2}}$

$10^{2.105} = \frac{V_{o_2}}{V_{i_2}}$

and $\frac{V_{o_2}}{V_{i_2}} = \underline{127.35}$

Stage 3: $A_{v_3} = 56.835\,dB = 20\log_{10}\frac{V_{o_3}}{V_{i_3}}$

$2.8418 = \log_{10}\frac{V_{o_3}}{V_{i_3}}$

$10^{2.8418} = \frac{V_{o_3}}{V_{i_3}}$

and $\frac{V_{o_3}}{V_{i_3}} = \underline{694.624}$

$A_{v_T} = A_{v_1}\cdot A_{v_2}\cdot A_{v_3} = (11.288)(127.35)(694.624) = 998541.1$

$A_T = 120\,dB \overset{?}{=} 20\log_{10} 998541.1$

$120\,dB \cong 119.99\,dB$ (difference due to level of accuracy carried through calculations)

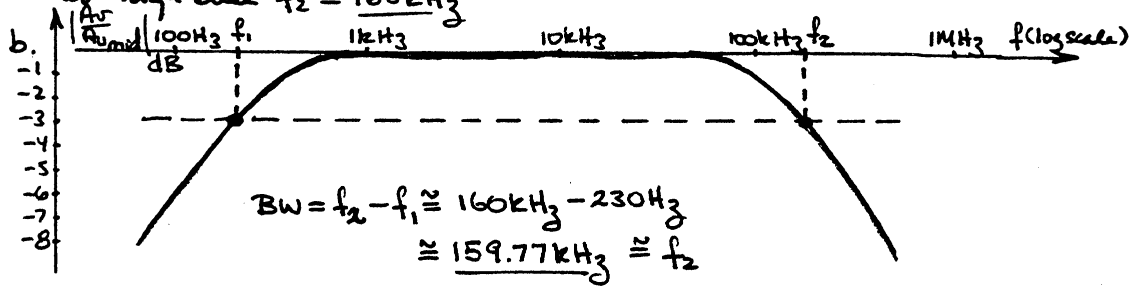
10. a. Same shape except $A_v = 190$ is now level of 1. In fact, all levels of $A_v$ are divided by 190 to obtain normalized plot.

$0.707(190) = \underline{134.33}$ defining cutoff frequencies

at low end $f_1 \cong \underline{230\text{ Hz}}$ (remember this is a log scale)

at high end $f_2 \cong \underline{160\text{ kHz}}$

b.




$BW = f_2 - f_1 \cong 160\text{ kHz} - 230\text{ Hz}$

$\cong \underline{159.77\text{ kHz}} \cong f_2$

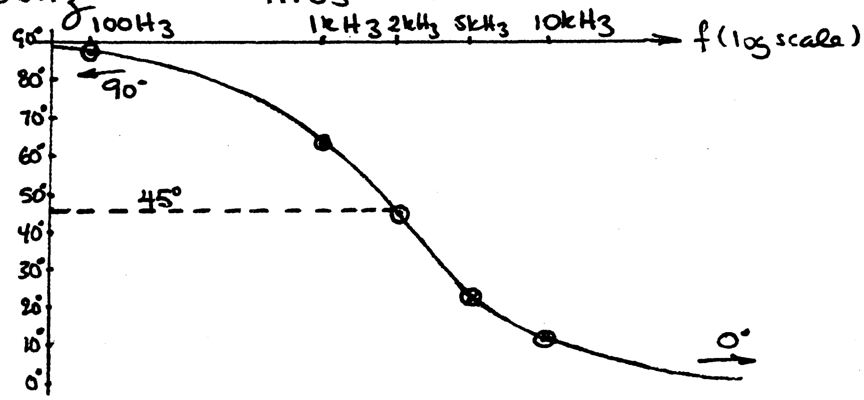
12. a. $f_1 = \frac{1}{2\pi RC} = 1.95\text{ kHz}$

$\theta = \tan^{-1}\frac{f_1}{f} = \underline{\tan^{-1}\frac{1.95\text{ kHz}}{f}}$

b.

| $f$ | $\theta = \tan^{-1}\frac{1.95\text{ kHz}}{f}$ |
|---|---|
| 100 Hz | 87.06° |
| 1 kHz | 62.85° |
| 2 kHz | 44.27° |
| 5 kHz | 21.3° |
| 10 kHz | 11.03° |

Curve from data points!




c. $f_1 = \frac{1}{2\pi RC} = 1.95\text{ kHz}$

d. First find $\theta = 45°$ at $f_1 = 1.95\text{ kHz}$. 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 $\theta$ occurs near $f_1$. the resulting curve should be quite close to that plotted above.

14. From example 11.9 $r_e = 15.76\,\Omega$

$A_v = -\frac{R_C \| R_L \| r_o}{r_e} = -\frac{4\text{ k}\Omega \| 2.2\text{ k}\Omega \| 40\text{ k}\Omega}{15.76\,\Omega}$

$= -86.97$ (vs. $-90$ for Ex. 11.9)

$f_{L_S}$: $r_o$ does not affect $R_i$ ∴ $f_{L_S} = \frac{1}{2\pi(R_s + R_i)C_s}$ the same $\cong \underline{6.86\text{ Hz}}$

$$f_{L_C} = \frac{1}{2\pi(R_o+R_L)C_C} = \frac{1}{2\pi(R_C\|r_o+R_L)C_C}$$

$R_C\|r_o = 4\text{k}\Omega\|40\text{k}\Omega = 5.636\text{k}\Omega$

$$f_{L_C} = \frac{1}{2\pi(5.636\text{k}\Omega+2\text{k}\Omega)(1\mu\text{F})}$$

$= \underline{28.23\text{ Hz}}$ (vs. 25.68 Hz for Ex. 11.9)

$f_{L_E}$: $R_e$ not affected by $r_o$, therefore $f_{L_E} = \frac{1}{2\pi R_e C_E} \cong \underline{327\text{ Hz}}$ is the same.

In total, the effect of $r_o$ on the frequency response was to slightly reduce the mid-band gain.

16\. a. $$I_B = \frac{V_{CC}-V_{BE}}{R_B+(\beta+1)R_E} = \frac{20\text{V}-0.7\text{V}}{470\text{k}\Omega+(111)(0.91\text{k}\Omega)} = \frac{19.3\text{V}}{470\text{k}\Omega+101.01\text{k}\Omega}$$

$= 33.8\mu\text{A}$

$I_E = (\beta+1)I_B = (111)(33.8\mu\text{A})$

$= 3.752\text{mA}$

$$r_e = \frac{26\text{mV}}{3.752\text{mA}} = \underline{6.93\Omega}$$

b. $$A_{v_{mid}} = \frac{V_o}{V_i} = -\frac{(R_C\|R_L)}{r_e} = -\frac{(3\text{k}\Omega\|4.7\text{k}\Omega)}{6.93\Omega} = -\frac{1.831\text{k}\Omega}{6.93\Omega}$$

$= \underline{-264.24}$

c. $Z_i = R_B\|\beta r_e = 470\text{k}\Omega\|(110)(6.93\Omega) = 470\text{k}\Omega\|762.3\Omega$

$= \underline{761.07\Omega}$

d. $$A_{v_{s\,mid}} = \frac{Z_i}{Z_i+R_s}A_{v_{mid}} = \frac{761.07\Omega}{761.07\Omega+0.6\text{k}\Omega}(-264.24)$$

$= \underline{-147.76}$

e. $$f_{L_S} = \frac{1}{2\pi(R_s+Z_i)C_s} = \frac{1}{2\pi(600\Omega+761.07\Omega)(1\mu\text{F})}$$

$= \underline{116.93\text{ Hz}}$

$$f_{L_C} = \frac{1}{2\pi(R_o+R_L)C_C} = \frac{1}{2\pi(3\text{k}\Omega+4.7\text{k}\Omega)(1\mu\text{F})}$$

$= \underline{20.67\text{ Hz}}$

$$f_{L_E} = \frac{1}{2\pi R_e C_E}$$

$$= \frac{1}{2\pi(12.21\Omega)(6.8\mu\text{F})}$$

$= \underline{1.917\text{ kHz}}$

$$R_e = R_E\|\left(\frac{R_s'}{\beta}+r_e\right)$$

$$= .91\text{k}\Omega\|\left(\frac{R_s\|R_B}{\beta}+r_e\right)$$

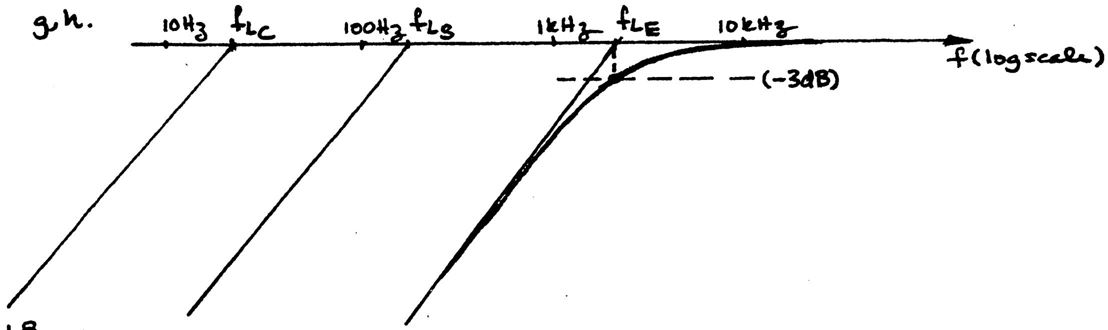
$$= 0.91\text{k}\Omega\|\left(\frac{0.6\text{k}\Omega\|470\text{k}\Omega}{110}+6.93\Omega\right)$$

$= 910\Omega\|12.38\Omega$

$= 12.21\Omega$

f. $f_1 \cong f_{L_E} = \underline{1.917\text{ kHz}}$

g, h.




18. a. $I_E = \dfrac{V_{EE} - V_{EB}}{R_E} = \dfrac{4\text{V} - 0.7\text{V}}{1.2\text{k}\Omega} = 2.75\text{mA}$

$r_e = \dfrac{26\text{mV}}{I_E} = \dfrac{26\text{mV}}{2.75\text{mA}} = 9.45\Omega$

b. $A_{v_{mid}} = \dfrac{R_C \| R_L}{r_e} = \dfrac{3.3\text{k}\Omega \| 4.7\text{k}\Omega}{9.45\Omega}$

$= \underline{205.1}$

c. $Z_i = R_E \| r_e = 1.2\text{k}\Omega \| 9.45\Omega$

$= \underline{9.38\Omega}$

d. $A_{v_{s\,mid}} = \dfrac{Z_i}{Z_i + R_s} A_{v_{mid}} = \dfrac{9.38\Omega}{9.38\Omega + 100\Omega}(205.1)$

$= \underline{17.59}$

e. $f_{L_S} = \dfrac{1}{2\pi(R_s + Z_i)C_s} = \dfrac{1}{2\pi(100\Omega + 9.38\Omega)(10\mu\text{F})}$

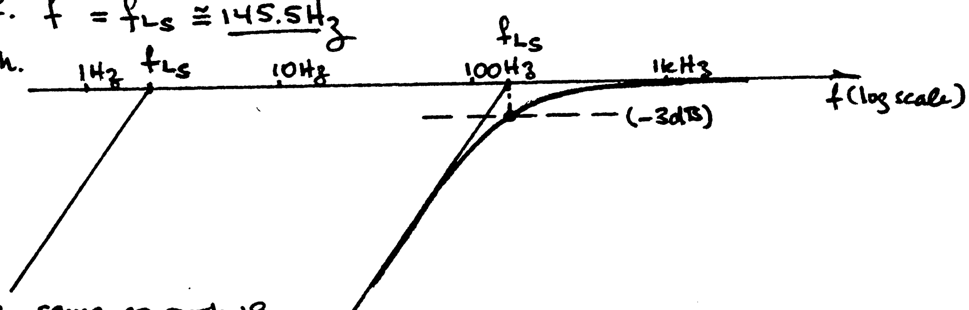
$= \underline{145.5\text{Hz}}$

$f_{L_C} = \dfrac{1}{2\pi(R_o + R_L)C_E} = \dfrac{1}{2\pi(3.3\text{k}\Omega + 4.7\text{k}\Omega)(10\mu\text{F})}$

$= \underline{1.989\text{Hz}}$

f. $f = f_{L_S} \cong \underline{145.5\text{Hz}}$

g, h.




20. a. same as prob. 19

$V_{GS_Q} \cong \underline{-2.45\text{V}}$, $I_{D_Q} \cong \underline{2.1\text{mA}}$

b. $g_{m0} = \underline{2\text{mS}}$, $g_m = \underline{1.18\text{mS}}$ ($r_d$ has no effect!)

c. $A_{v_{mid}} = -g_m(R_D \| R_L \| r_d)$

$= -1.18\text{mS}(3\text{k}\Omega \| 3.9\text{k}\Omega \| 100\text{k}\Omega)$

$= -1.18\text{mS}(1.67\text{k}\Omega)$

$= \underline{-1.971}$ (vs. −2 for problem 19)

d. $Z_i = R_G = 1\text{M}\Omega$ (the same)

e. $A_{v_{s\,mid}} = \dfrac{Z_i}{Z_i + R_{sig}}(A_{v_{mid}}) = \dfrac{1\text{M}\Omega}{1\text{M}\Omega + 1\text{k}\Omega}(-1.971)$

$= \underline{-1.969}$ vs $-2$ for problem 19

f. $f_{L_G} = \underline{1.59\text{ Hz}}$ (no effect)

$f_{L_C}$: $R_o = R_D \| r_d = 3\text{k}\Omega \| 100\text{k}\Omega = 2.91\text{k}\Omega$

$f_{L_C} = \dfrac{1}{2\pi(R_o + R_L)C_C} = \dfrac{1}{2\pi(2.91\text{k}\Omega + 3.9\text{k}\Omega)(4.7\mu\text{F})}$

$= \underline{4.97\text{ Hz}}$ vs. $4.91\text{ Hz}$ for problem 19

$f_{L_S}$: $R_{eq} = \dfrac{R_S}{1 + R_S(1 + g_m r_d)/(r_d + R_D \| R_L)}$

$= \dfrac{1.2\text{k}\Omega}{1 + (1.2\text{k}\Omega)(1 + (1.18\text{mS})(100\text{k}\Omega))/(100\text{k}\Omega + 3\text{k}\Omega \| 3.9\text{k}\Omega)}$

$= \dfrac{1.2\text{k}\Omega}{1 + 1.404}$

$\cong 499.2\Omega$

$f_{L_S} = \dfrac{1}{2\pi R_{eq} C_S} = \dfrac{1}{2\pi(499.2\Omega)(10\mu\text{F})}$

$= \underline{31.88\text{ Hz}}$ vs. $32.04$ for problem 19

Effect of $r_d = 100\text{k}\Omega$ insignificant!

22. a. $f_{H_i} = \dfrac{1}{2\pi R_{Th_1} C_i}$

$= \dfrac{1}{2\pi(614.56\Omega)(931.92\text{pF})}$

$= \underline{277.89\text{ kHz}}$

$R_{Th_1} = R_s \| R_1 \| R_2 \| R_i$

$= 0.82\text{k}\Omega \| 68\text{k}\Omega \| 10\text{k}\Omega \| 3.418\text{k}\Omega$

$= 0.81\text{k}\Omega \| 2.547\text{k}\Omega$

$= 614.56\Omega$

$C_i = C_{W_i} + C_{be} + C_{bc}(1 - A_v)$

$= 5\text{pF} + 40\text{pF} + 12\text{pF}(1 - (-72.91))$ ← prob 15

$= 931.92\text{pF}$

$f_{H_o} = \dfrac{1}{2\pi R_{Th_2} C_o}$

$= \dfrac{1}{2\pi(2.08\text{k}\Omega)(28\text{pF})}$

$= \underline{2.73\text{ MHz}}$

$R_{Th_2} = R_C \| R_L = 5.6\text{k}\Omega \| 3.3\text{k}\Omega$

$= 2.08\text{k}\Omega$

$C_o = C_{W_o} + C_{ce} + C_{M_o}$

$= 8\text{pF} + 8\text{pF} + 12\text{pF}$

$= 28\text{pF}$

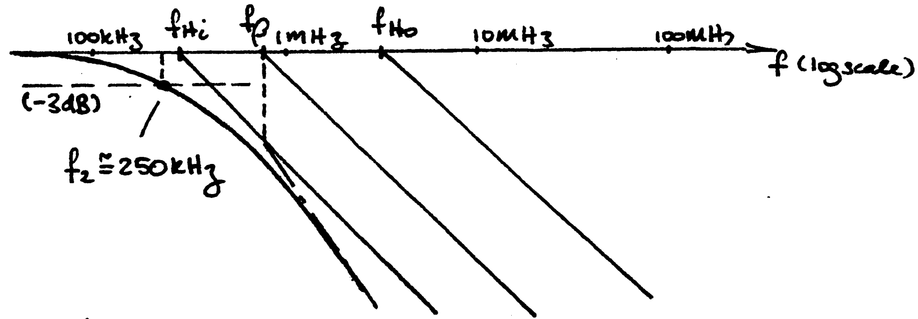
b. $f_\beta \cong \dfrac{1}{2\pi \beta_{mid} r_e (C_{be} + C_{bc})} = \dfrac{1}{2\pi(120)(28.48\Omega)(40\text{pF} + 12\text{pF})}$ ← prob 15

$= \underline{895.56\text{ kHz}}$

$f_T = \beta f_\beta = (120)(895.56\text{ kHz})$

$= \underline{107.47\text{ MHz}}$

c.




24. a. $f_{H_i} = \dfrac{1}{2\pi R_{Th_1} C_i}$

$= \dfrac{1}{2\pi(955\Omega)(58pF)}$

$= \underline{2.87\text{MHz}}$

$R_{Th_1} = R_s \| R_1 \| R_2 \| Z_b$

$Z_b = \beta r_e + (\beta+1)(R_E \| R_L)$

$= (100)(30.23\Omega) + (101)(2.2k\Omega \| 8.2k\Omega)$

$= 3.023k\Omega + 175.2k\Omega$

$= 178.2k\Omega$

$R_{Th_1} = 1k\Omega \| 120k\Omega \| 30k\Omega \| 178.2k\Omega$

$= 955\Omega$

$C_i = C_{W_i} + C_{be} + C_{bc}$ (No Miller effect)

$= 8pF + 30pF + 20pF$

$= 58pF$

$f_{H_o} = \dfrac{1}{2\pi R_{Th_2} C_o}$

$= \dfrac{1}{2\pi(38.94\Omega)(32pF)}$

$= \underline{127.72\text{MHz}}$

$R_{Th_2} = R_E \| R_L \| \left(r_e + \dfrac{\overbrace{R_1 \| R_2 \| R_s}^{24k\Omega}}{\beta}\right)$

$= 2.2k\Omega \| 8.2k\Omega \| \left(30.23\Omega + \dfrac{24k\Omega \| 1k\Omega}{100}\right)$

$= 1.735k\Omega \| (30.23\Omega + 9.6\Omega)$

$= 1.735k\Omega \| 39.83\Omega$

$= 38.94\Omega$

$C_o = C_{W_o} + C_{ce}$

$= 10pF + 12pF$

$= 32pF$

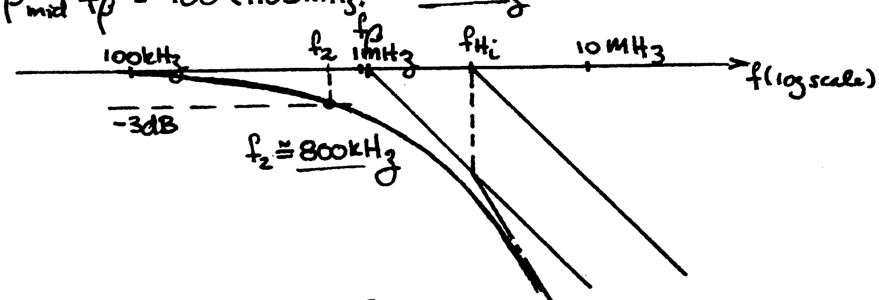
b. $f_\beta = \dfrac{1}{2\pi \beta_{mid} r_e (C_{be} + C_{bc})}$

$= \dfrac{1}{2\pi(100)(30.23\Omega)(30pF + 20pF)}$

$= \underline{1.05\text{MHz}}$

$f_T = \beta_{mid} f_\beta = 100(1.05\text{MHz}) = \underline{105\text{MHz}}$

c.




26. a. From problem 19 $g_{m0} = \underline{2mS}$, $g_m = \underline{1.18mS}$

b. " " " $A_{v_{mid}} \cong A_{v_{3\,mid}} = \underline{-2}$

c. $f_{H_i} = \dfrac{1}{2\pi R_{Th_1} C_i}$

$R_{Th_1} = R_{sig} \| R_G$

$= 1k\Omega \| 1M\Omega$

$= 999\Omega$

$$f_{H_i} = \frac{1}{2\pi(999\,\Omega)(21\,pF)} = \underline{7.59\,MHz}$$

$$C_i = C_{W_i} + C_{gs} + C_{M_i}$$

$$C_{M_i} = (1 - A_v)C_{gd} = (1-(-2))4\,pF = 12\,pF$$

$$C_i = 3\,pF + 6\,pF + 12\,pF = 21\,pF$$

$$f_{H_o} = \frac{1}{2\pi R_{Th_2}C_o} = \frac{1}{2\pi(1.696\,k\Omega)(12\,pF)} = \underline{7.82\,MHz}$$

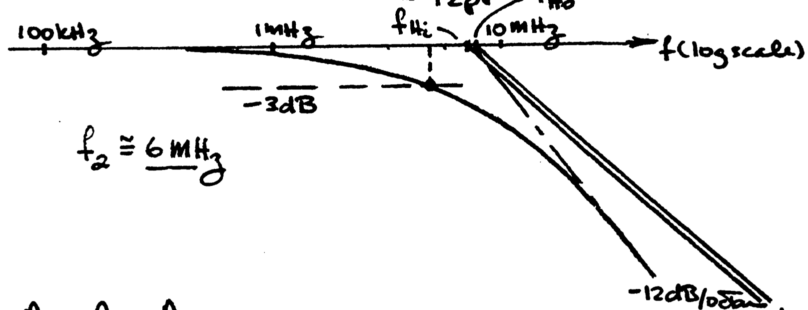
$$R_{Th_2} = R_D \| R_L = 3\,k\Omega \| 3.9\,k\Omega = 1.696\,k\Omega$$

$$C_o = C_{W_o} + C_{ds} + C_{M_o}$$

$$C_{M_o} = \left(1 - \frac{1}{-2}\right)4\,pF = (1.5)(4\,pF) = 6\,pF$$

$$C_o = 5\,pF + 1\,pF + 6\,pF = 12\,pF$$

d.




$f_2 \cong \underline{6\,MHz}$

28. $$A_{v_T} = A_{v_1} \cdot A_{v_2} \cdot A_{v_3} \cdot A_{v_4} = A_v^{\,4} = (20)^4 = \underline{160{,}000}$$

30. $$f_1' = \frac{f_1}{\sqrt{2^{1/n} - 1}} = \frac{40\,Hz}{\sqrt{2^{1/4} - 1}} = \frac{40\,Hz}{0.435} = \underline{91.96\,Hz}$$

# Chapter 12. Compound Configurations

§12.2

1. For both stages:

dc bias point

$V_{GS_Q} = -1.4V$

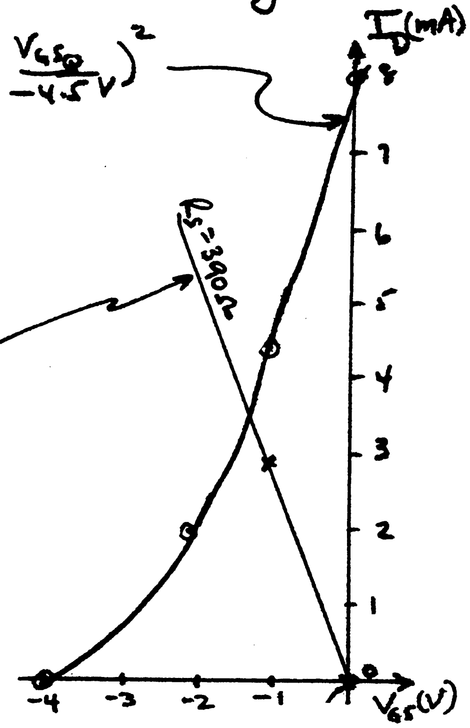
$I_{D_Q} = 3.7mA$

$I_D = 8mA\left(1 - \frac{V_{GS_Q}}{-4.5V}\right)^2$

| $V_{GS}$ | $I_D$ |
|---|---|
| 0 | 8 |
| −1.1 | 4.5 |
| −2.2 | 2 |
| −4.5 | 0 |

$V_{GS} = -I_D(390)$

| $I_D$ | $V_{GS}$ |
|---|---|
| 0 | 0 |
| 3 | −1.2 |




$V_G = \underline{0V}$

$V_S = \underline{+1.4V}$

$V_D = V_{DD} - I_D R_D = 18V - (3.7mA)(2.2k\Omega)$

$= \underline{9.86V}$

3.

dc bias point:

$V_{GS} = -1.4V$

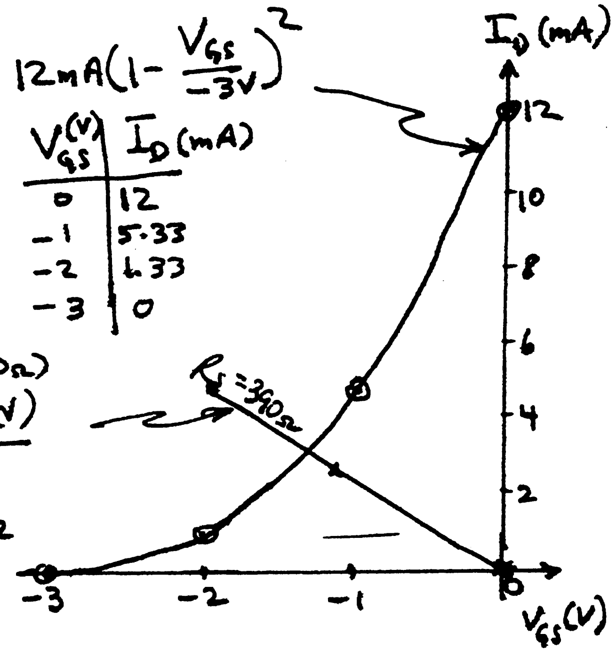
$I_D = 3.5mA$

$I_D = 12mA\left(1 - \frac{V_{GS}}{-3V}\right)^2$

| $V_{GS}$(V) | $I_D$(mA) |
|---|---|
| 0 | 12 |
| −1 | 5.33 |
| −2 | 1.33 |
| −3 | 0 |

$V_{GS} = -I_D(390\Omega)$

| $I_D$(mA) | $V_{GS}$(V) |
|---|---|
| 0 | 0 |
| 3 | −1.2 |




$V_G = \underline{0V}$

$V_S = \underline{+1.4V}$

$V_D = V_{DD} - I_D R_D$

$= 18V - (3.5mA)(2.2k\Omega)$

$= \underline{10.3V}$

5. $Z_i = R_{G_1} = \underline{10\,M\Omega}$

$$Z_o = R_{D_2} \| \frac{1}{y_{os_2}} = 2.2\,k\Omega \| \frac{1}{25\,\mu S} = \underline{2.1\,k\Omega}$$

7. $$r_e = \frac{26\ mV}{I_E\ mA} = \frac{26}{1.59} = 16.35\,\Omega$$

$$R_{i_2} = R_1 \| R_2 \| \beta r_e = 6.2\,k\Omega \| 24\,k\Omega \| (150)(16.35\,\Omega)$$
$$= 1.64\ k\Omega$$

$$A_{v_1} = -\frac{R_C \| R_{i_2}}{r_e} = -\frac{5.1\,k\Omega \| 1.64\,k}{16.35\,\Omega} = \underline{-75.8}$$

$$A_{v_2} = -\frac{R_C}{r_e} = \frac{-5.1\,k\Omega}{16.35\,\Omega} = \underline{-311.9}$$

$$A_v = A_{v_1} A_{v_2} = (-75.8)(-311.9) = \underline{23{,}642}$$

9. STAGE 1 - FET

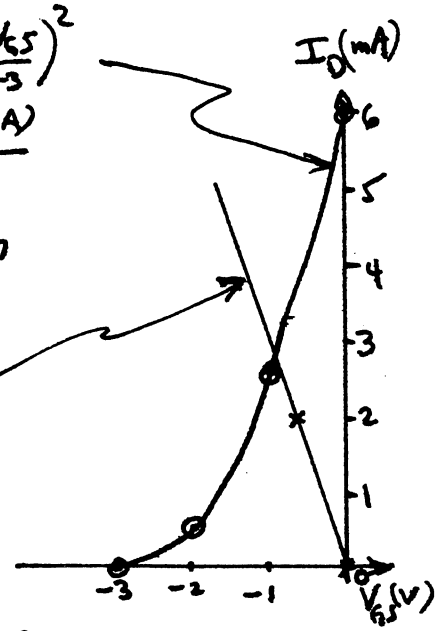
$$I_D = 6\,mA\left(1 - \frac{V_{GS}}{-3}\right)^2$$

| $V_{GS}$ (V) | $I_D$ (mA) |
|---|---|
| 0 | 6 |
| −1 | 2.67 |
| −2 | 0.667 |
| −3 | 0 |

$R_S = 330\,\Omega$

$V_{GS} = -I_D(330)$

| $I_D$ | $V_{GS}$ |
|---|---|
| 0 | 0 |
| 2 | 0.66 |




$V_{GS_Q} = \underline{-0.9\ V}$

$I_{D_Q} = \underline{2.8\ mA}$

STAGE 2 - BJT

$$V_B = \frac{R_2}{R_1 + R_2} V_{CC} = \frac{8.2\,k}{24\,k + 8.2\,k}(10\,V)$$
$$= 2.55\ V$$

$$V_E = V_B - 0.7\,V = 2.55\,V - 0.7\,V$$
$$= 1.85\,V$$

$$I_C \cong I_E = \frac{V_E}{R_E} = \frac{1.85\,V}{2.2\,k\Omega} = \underline{0.841\ mA}$$

$$V_C = V_{CC} - I_C R_C$$
$$= 10\,V - (0.841\,mA)(2.7\,k\Omega)$$
$$= \underline{7.73\ V}$$

11. $Z_i = R_G = \underline{10\,M\Omega}$

$Z_o = R_D = \underline{2.7\,k\Omega}$

§12.3

13. $r_e = \dfrac{26}{I_E} = \dfrac{26}{3.7} = 7\,\Omega$

$A_{v_1} = -\dfrac{r_e}{r_e} = -1$

$A_{v_2} = \dfrac{R_C}{r_e} = \dfrac{1.5\,k\Omega}{7\,\Omega} \cong 214$

$A_{v_T} = A_{v_1} A_{v_2} = (-1)(214) = -214$

$V_o = A_{v_T} V_i = (-214)(10\,mV) = \underline{-2.14\,V}$

§12.4

15. $I_B = \dfrac{V_{CC} - V_{BE}}{\beta_D R_E + R_B} = \dfrac{(16\,V - 1.6\,V)}{(6000)(510\,\Omega) + 2.4\,M\Omega}$

$= \dfrac{14.4\,V}{5.46\,M\Omega} = 2.64\,\mu A$

$I_C \cong I_E = \beta_D I_B = 6000\,(2.64\,\mu A) = \underline{15.8\,mA}$

$V_E = I_E R_E = (15.8\,mA)(510\,\Omega) = \underline{8.06\,V}$

§12.5

17. $$I_B = \frac{V_{CC} - V_{EB1}}{R_B + \beta_1\beta_2 R_E} = \frac{16\text{V} - 0.7\text{V}}{1.5\text{M}\Omega + (160)(200)(100)}$$

$$= 3.255\,\mu\text{A}$$

$$I_C \cong \beta_1\beta_2 I_B = (160)(200)(3.255\,\mu\text{A}) \cong \underline{104.2\text{ mA}}$$

$$V_{C2} = V_{CC} - I_C R_C = 16\text{V} - (104.2\text{ mA})(100\Omega) = \underline{5.58\text{ V}}$$

$$V_{B1} = I_B R_B = (3.255\,\mu\text{A})(1.5\text{M}\Omega) = \underline{4.48\text{ V}}$$

§12.6

19. (a) $V_1 = 0\text{ V}$: $Q_1$ on, $Q_4$ off; $V_2 = 0\text{V}$: $Q_2$ on, $Q_3$ off } output = +5 V

(b) $V_1 = +5\text{ V}$: $Q_1$ off, $Q_4$ on; $V_2 = +5\text{ V}$: $Q_2$ off, $Q_3$ on } Output = 0 V

(c) $V_1 = 0\text{V}$: $Q_1$ on, $Q_4$ off; $V_2 = +5\text{V}$: $Q_2$ off, $Q_3$ on } output = 0 V

§12.7

21. $I_{D_Q} = I_{DSS} = \underline{6\text{ mA}}$

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

§12.8

25. For current mirror:

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

§12.9

27. $I_{C_1} = I_{C_2} = \dfrac{I_E}{2} = \dfrac{2\text{ mA}}{2} = \underline{1\text{ mA}}$

$V_C = V_{CC} - I_C R_C = 18\text{ V} - (1\text{ mA})(18\text{ k}\Omega) = \underline{0\text{ V}}$

29. $V_{B3} = \dfrac{1.5\text{ k}\Omega}{1.5\text{ k}\Omega + 1.5\text{ k}\Omega}(-12\text{ V}) = -6\text{ V}$

$V_{E3} = -6\text{ V} - 0.7\text{ V} = -6.7\text{ V}$

$I_E = \dfrac{V_{RE}}{R_E} = \dfrac{12\text{ V} - 6.7\text{ V}}{4.3\text{ k}\Omega} = 1.2\text{ mA}$

$I_{C_1} = I_{C_2} = \dfrac{I_E}{2} = \dfrac{1.2\text{ mA}}{2} = 0.6\text{ mA}$

$r_e = \dfrac{26}{I_E} = \dfrac{26}{0.6} = 43.3\,\Omega$

$A_v = \dfrac{R_C}{r_e} = \dfrac{8.2\text{ k}\Omega}{43.3\,\Omega} = 189.4$

$V_o = A_v V_i = 189.4(10\text{ mV}) = \underline{1.89\text{ V}}$

§12.2

2. $$g_{mo} = \frac{2I_{DSS}}{|V_p|} = \frac{2(8\text{ mA})}{|-4.5\text{V}|} = 3.556\text{ mS}$$

dc bias (from problem 1): $V_{GS_Q} = -1.44\text{V}$

$$g_m = g_{mo}\left(1 - \frac{V_{GSQ}}{V_p}\right) = 3.556\text{ mS}\left(1 - \frac{-1.44\text{V}}{-4.5\text{V}}\right)$$
$$= 2.418\text{ mS}$$

$$A_{v_1} = A_{v_2} = -g_m R_D = -(2.418\text{ mS})(2.2\text{ k}\Omega)$$
$$= -5.32$$

$$A_v = A_{v_1} \cdot A_{v_2} = (-5.32)(-5.32) = 28.3$$
$$V_o = A_v V_i = (28.3)(20\text{ mV}) = \underline{566\text{ mV}}$$

4. $$g_{mo} = \frac{2I_{DSS}}{|V_p|} = \frac{2(12\text{ mA})}{|-3\text{V}|} = 8\text{ mS}$$
$$r_d = \frac{1}{y_{os}} = \frac{1}{25\,\mu\text{S}} = 40\text{ k}\Omega$$

at dc bias ($V_{GS_Q} = -1.37$):
$$g_m = g_{mo}\left(1 - \frac{V_{GSQ}}{V_p}\right) = 8\text{ mS}\left(1 - \frac{-1.37\text{V}}{-3\text{V}}\right)$$
$$= 4.35\text{ mS}$$

$$A_v(\text{1 stage}) = -g_m(R_D \| r_d) = -4.35\text{ mS}(2.2\text{ k}\Omega \| 40\text{ k}\Omega)$$
$$= -9.07$$

$$A_v = (-9.07)(-9.07) = 82.265$$
$$V_o = A_v V_i = (82.265)(20\text{ mV}) = \underline{1.645\text{ V}}$$

6. For each stage:

$$V_B = \frac{6.2\text{ k}\Omega}{24\text{ k}\Omega + 6.2\text{ k}\Omega}(15\text{ V}) = 3.08\text{ V}$$

$$V_E = V_B - 0.7\text{ V} = 3.08\text{ V} - 0.7\text{ V} = 2.38\text{ V}$$

$$I_E \cong I_C = \frac{V_E}{R_E} = \frac{2.38\text{ V}}{1.5\text{ k}\Omega} = 1.59\text{ mA}$$

$$V_C = V_{CC} - I_C R_C = 15\text{ V} - (1.59\text{ mA})(5.1\text{ k}\Omega)$$
$$= \underline{6.89\text{ V}}$$

8. $$Z_i = R_1 \| R_2 \| \beta_1 r_{e_1} = 24\text{ k}\Omega \| 6.2\text{ k}\Omega \| 150(16.35\,\Omega)$$
$$= \underline{1.64\text{ k}\Omega}$$

$$Z_o = R_{C_2} = \underline{5.1\text{ k}\Omega}$$

10. FET stage

$$g_{m0} = \frac{2I_{DSS}}{|V_P|} = \frac{2(6\text{ mA})}{|-3\text{ V}|} = 4\text{ mS}$$

at dc bias: $V_{GS_Q} = -0.9\text{ V}$

$$g_m = g_{m0}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = 4\text{ mS}\left(1 - \frac{-0.9\text{ V}}{-3\text{ V}}\right) = 2.8\text{ mS}$$

$$A_{v_1} = -g_m(R_D \| R_{i_2}) = -2.8\text{ mS}(\underbrace{1.8\text{ k}\Omega \| 2.64\text{ k}\Omega}_{1.07\text{ k}\Omega})$$
$$\cong \underline{-3}$$

where, [from problem 9: $I_{E_Q} = 0.84\text{ mA}$]

$$r_e = \frac{26\text{ mV}}{I_E(\text{mA})} = \frac{26}{0.84} = 30.95\,\Omega$$

$$R_{i_2} = R_3 \| R_4 \| \beta r_{e_2}$$
$$= 8.2\text{ k}\Omega \| 24\text{ k}\Omega \| (150)(30.95\,\Omega)$$
$$= 2.64\text{ k}\Omega$$

BJT Stage

since, $r_e = 30.9\,\Omega$

$$A_{v_2} = -\frac{R_C}{r_e} = -\frac{2.7\,k\Omega}{30.9\,\Omega} = \underline{-87.24}$$

$$A_v = A_{v_1} \cdot A_{v_2} = (-3)(-87.24) = \underline{261.7}$$

§12.3

12. $$V_{B_1} = \frac{3.9\,k\Omega}{3.9\,k\Omega + 6.2\,k\Omega + 7.5\,k\Omega}(20\,V) = \underline{4.4\,V}$$

$$V_{B_2} = \frac{6.2\,k\Omega + 3.9\,k\Omega}{3.9\,k\Omega + 6.2\,k\Omega + 7.5\,k\Omega}(20\,V) = \underline{11.48\,V}$$

$$V_{E_1} = V_{B_1} - 0.7\,V = 4.4\,V - 0.7\,V = 3.7\,V$$

$$I_{C_1} \cong I_{E_1} = \frac{V_{E_1}}{R_E} = \frac{3.7\,V}{1\,k\Omega} = 3.7\,mA \cong I_{E_2} \cong I_{C_2}$$

$$V_{C_2} = V_{CC} - I_C R_C = 20\,V - (3.7\,mA)(1.5\,k\Omega)$$
$$= \underline{14.45\,V}$$

14. $R_o = R_D = 1.5\,k\Omega$ $\{V_o$ [from problem 13] $= -2.14\,V\}$

$$V_o\,(\text{load}) = \frac{R_L}{R_o + R_L}(V_o) = \frac{10\,k\Omega}{10\,k\Omega + 1.5\,k\Omega}(-2.14\,V)$$
$$= \underline{-1.86\,V}$$

16. From problem 15, $I_E = 15.8\text{ mA}$

$$r_e = \frac{26}{I_E} = \frac{26}{15.8} = 1.65\,\Omega$$

$$A_v = \frac{R_E}{r_e + R_E} = \frac{510\,\Omega}{1.65\,\Omega + 510\,\Omega} = \underline{0.997} \approx 1$$

§12.5

18. From problem 17: $I_{E_1} = 0.521\text{ mA}$

$$r_{e_1} = \frac{26\text{ mV}}{I_E\text{ (mA)}} = \frac{26}{0.521} = 49.9\,\Omega$$

$$R_{i_1} = \beta r_{e_1} = 160(49.9\,\Omega) = 7.98\text{ k}\Omega$$

$$A_v = \frac{\beta_1\beta_2 R_C}{\beta_1\beta_2 R_C + R_{i_1}} = \frac{(160)(200)(100\,\Omega)}{(160)(200)(100\,\Omega) + 7.98\text{ k}\Omega}$$

$$= 0.9975$$

$$V_o = A_v V_i = 0.9975(120\text{ mV})$$

$$= \underline{119.7\text{ mV}}$$

§12.6

20.

| $V_1$ | $V_2$ | $V_o$ |
|---|---|---|
| 0 V | 0V | +5V |
| 0V | +5V | 0V |
| +5V | 0 V | 0V |
| +5V | +5V | 0V |

§12.7

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

$V_E = -9\,V - 0.7\,V = -9.7\,V$

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

§12.8

24. $I\,(2k) = \dfrac{18\,V - 0.7\,V}{2\,k\Omega} = \underline{8.65\,mA} \cong I$

§12.9

26. $V_E = -0.7\,V$

$V_{R_E} = |-15\,V - (-0.7\,V)| = 14.3\,V$

$I_{R_E} = \dfrac{V_{R_E}}{R_E} = \dfrac{14.3\,V}{4.7\,k\Omega} = 3\,mA$

$I_{C_1} = I_{C_2} = \dfrac{I_E}{2} = \dfrac{3\,mA}{2} = 1.5\,mA$

$V_C = V_{CC} - I_C R_C = 15\,V - 1.5\,mA(4.7\,k\Omega)$

$= \underline{7.95\,V}$

28. $I_E = \dfrac{V_{R_E}}{R_E} = \dfrac{12\,V - 0.7\,V}{33\,k\Omega} = 342\,\mu A$

$I_{E_1} = I_{E_2} = \dfrac{I_E}{2} = \dfrac{342\,\mu A}{2} = 171\,\mu A = 0.171\,mA$

$r_e = \dfrac{26}{I_E} = \dfrac{26}{0.171} = 152\,\Omega$

$A_v = \dfrac{R_C}{2r_e} = \dfrac{36\,k\Omega}{2(152)} = 118.4$

$V_o = A_v V_i = 118.4(2\,mV) = \underline{236.8\,mV}$

# Chapter 14 OPAMPS

§14.2

1. $A_d = \frac{V_o}{V_d} = \frac{120\text{ mV}}{1\text{ mV}} = 120$

$A_c = \frac{V_o}{V_c} = \frac{20\,\mu\text{V}}{1\text{ mV}} = 20\times10^{-3}$

$\text{Gain (dB)} = 20\log\frac{A_d}{A_c} = 20\log\frac{120}{20\times10^{-3}}$

$= 20\log(6\times10^{3}) = \underline{75.56\text{ dB}}$

§14.4

3. $V_o = -\frac{R_f}{R_1}V_1 = -\frac{250\text{ k}\Omega}{20\text{ k}\Omega}(1.5\text{ V}) = \underline{-18.75\text{ V}}$

5. $V_o = -\frac{R_f}{R_1}V_1 = -\left(\frac{1\text{M}\Omega}{20\text{ k}\Omega}\right)V_1 = 2\text{V}$

$V_1 = \frac{2\text{ V}}{-50} = \underline{-40\text{ mV}}$

7. $V_o = \left(1+\frac{R_f}{R_1}\right)V_1 = \left(1+\frac{360\text{ k}\Omega}{12\text{ k}\Omega}\right)(-0.3\text{V})$

$= 31(-0.3\text{V}) = \underline{-9.3\text{V}}$

9. $V_o = \left(1+\frac{R_f}{R_1}\right)V_1$

<u>For $R_1 = 10\text{ k}\Omega$</u>

$V_o = \left(1+\frac{200\text{k}\Omega}{10\text{k}\Omega}\right)(0.5\text{ V}) = 21(0.5\text{V}) = 10.5\text{ V}$

<u>For $R_1 = 20\text{ k}\Omega$</u>

$V_o = \left(1+\frac{200\text{k}\Omega}{20\text{k}\Omega}\right)(0.5\text{V}) = 11(0.5\text{V}) = 5.5\text{ V}$

<u>$V_o$ ranges from 5.5 V to 10.5 V</u>

11. $$V_0 = -\left[\frac{R_F}{R_1}V_1 + \frac{R_F}{R_2}V_2 + \frac{R_F}{R_3}V_3\right]$$

$$= -\left[\frac{68\,k\Omega}{33\,k\Omega}(0.2V) + \frac{68\,k\Omega}{22\,k\Omega}(-0.5V) + \frac{68\,k\Omega}{12\,k\Omega}(+0.8V)\right]$$

$$= -[0.41V - 1.55V + 4.53V]$$

$$= \underline{-\ 3.39V}$$

13. $$V_o = V_1 = +0.5V$$

15. $$V_2 = -\left[\frac{200\,k\Omega}{20\,k\Omega}\right](0.2V) = \underline{-2V}$$

$$V_3 = \left[1 + \frac{200\,k\Omega}{10\,k\Omega}\right](0.2V) = \underline{+4.2V}$$

17. $$V_o = -\left[\frac{600\,k\Omega}{15\,k\Omega}(25mV) + \frac{600\,k\Omega}{30\,k\Omega}(-20mV)\right]\left(-\frac{300\,k\Omega}{30\,k\Omega}\right) + \left[-\left(\frac{300\,k\Omega}{15\,k\Omega}\right)(-20mV)\right]$$

$$= -[40(25mV) + (20)(-20mV)](-10) + (-20)(-20mV)$$

$$= -[1V - 0.4V](-10) + 0.4V$$

$$= 6V + 0.4V = \underline{6.4V}$$

§14.5

19. $I_{IB}^{+} = I_{IB^+} + \frac{I_{IO}}{2} = 20\,nA + \frac{4\,nA}{2} = \underline{22\,nA}$

$I_{IB}^{-} = I_{IB^-} - \frac{I_{IO}}{2} = 20\,nA - \frac{4\,nA}{2} = \underline{18\,nA}$

21. $A_{CL} = \frac{SR}{\Delta V_i/\Delta t} = \frac{2.4\ V/\mu s}{0.3V/10\mu s} = \underline{80}$

23. $V_{IO} = 1\,mV$, typical

$I_{IO} = 20\,nA$, typical

$V_o\,(\text{offset}) = \left(1 + \frac{R_f}{R_1}\right) V_{IO} + I_{IO} R_f$

$= \left(1 + \frac{200k\Omega}{20k\Omega}\right)(1\,mV) + (200\,k\Omega)(20\,nA)$

$= 101\,(1mV) + 4000 \times 10^{-6}$

$= 101\,mV + 4\,mV = \underline{105\,mV}$

2. $V_d = V_{i_1} - V_{i_2} = 200\,\mu V - 140\,\mu V = 60\,\mu V$

$$V_c = \frac{V_{i_1} + V_{i_2}}{2} = \frac{(200\,\mu V + 140\,\mu V)}{2} = 170\,\mu V$$

(a) $\text{CMRR} = \dfrac{A_d}{A_c} = 200$

$$A_c = \frac{A_d}{200} = \frac{6000}{200} = \underline{30}$$

(b) $\text{CMRR} = \dfrac{A_d}{A_c} = 10^5$

$$A_c = \frac{A_d}{10^5} = \frac{6000}{10^5} = 0.06 = \underline{60 \times 10^{-3}}$$

Using $V_o = A_d V_d \left[1 + \dfrac{1}{\text{CMRR}} \dfrac{V_c}{V_d}\right]$

(a)

$$V_o = 6000(60\,\mu V)\left[1 + \frac{1}{200}\,\frac{170\,\mu V}{60\,\mu V}\right] = \underline{365.1\text{ mV}}$$

(b)

$$V_o = 6000(60\,\mu V)\left[1 + \frac{1}{10^5}\,\frac{170\,\mu V}{60\,\mu V}\right] = \underline{360.01\text{ mV}}$$

§14.4

4. $A_v = \dfrac{V_o}{V_i} = -\dfrac{R_F}{R_1}$

For $R_1 = 10\text{ k}\Omega$:

$$A_v = -\frac{500\text{ k}\Omega}{10\text{ k}\Omega} = \underline{-50}$$

For $R_1 = 20\text{ k}\Omega$:

$$A_v = -\frac{500\text{ k}\Omega}{20\text{ k}\Omega} = \underline{-25}$$

6. $V_o = -\frac{R_F}{R_1} V_1 = -\frac{200\,k\Omega}{20\,k\Omega} V_1 = -10 V_1$

For $V_1 = 0.1\,V$:

$$V_o = -10(0.1\,V) = \underline{-1\,V}$$

For $V_1 = 0.5\,V$:

$$V_o = -10(0.5\,V) = \underline{-5\,V}$$

$V_o$ ranges from $\underline{-1\,V \text{ to } -5\,V}$

8. $V_o = \left(1 + \frac{R_F}{R_1}\right) V_1 = \left(1 + \frac{360\,k\Omega}{12\,k\Omega}\right) V_1 = 2.4\,V$

$$V_1 = \frac{2.4\,V}{31} = \underline{77.42\,mV}$$

10. $V_o = -\left[\frac{R_f}{R_1} V_1 + \frac{R_f}{R_2} V_2 + \frac{R_f}{R_3} V_3\right]$

$$= -\left[\frac{330k}{33k}(0.2V) + \frac{330k}{22k}(-0.5V) + \frac{330k}{12k}(0.8V)\right]$$

$$= -\left[10(0.2V) + 15(-0.5V) + 27.5(0.8V)\right]$$

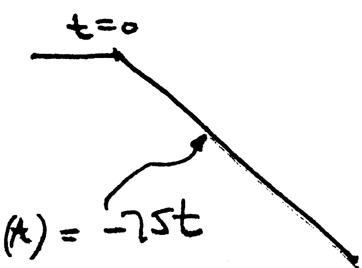
$$= -\left[2V + (-7.5V) + 22V\right]$$

$$= -\left[24V - 7.5V\right] = \underline{-16.5\,V}$$

12. $v_o(t) = -\frac{1}{RC}\int v_i(t)\,dt$

$$= -\frac{1}{(200\,k\Omega)(0.1\,\mu F)}\int 1.5\,dt$$

$$= -50(1.5t) = \underline{-75t}$$



14. $V_o = -\frac{R_f}{R_1}V_1 = -\frac{100\,k\Omega}{20\,k\Omega}(1.5\,V)$

$= -5(1.5V) = \underline{-7.5V}$

16. $V_o = \left(1 + \frac{400k}{20k}\right)(0.1V) \cdot \left(-\frac{100k}{20k}\right) + \left(-\frac{100k}{10k}\right)(0.1V)$

$= (2.1V)(-5) + (-10)(0.1V)$

$= -10.5V - 1V = \underline{-11.5V}$

§14.5

18. $V_o = \left(1 + \frac{R_f}{R_1}\right)V_{IO} + I_{IO}R_F$

$= \left(1 + \frac{200k}{2k}\right)(6\,mV) + (120\,nA)(200\,k)$

$= 101(6\,mV) + 24\,mV$

$= 606\,mV + 24\,mV = \underline{630\,mV}$

§14.6

20. $f_1 = B_1 = 800\,kHz$

$f_c = \frac{f_1}{A_{v_2}} = \frac{800\,kHz}{150\times10^3} = \underline{5.3\,Hz}$

22. $A_{CL} = \frac{R_f}{R_1} = \frac{200k}{2k} = 100$

$K = A_{CL} V_i = 100(50\,mV) = 5V$

$\omega_s \leq \frac{SR}{K} = \frac{0.4\ V/\mu s}{5V} = \underline{80 \times 10^3\ rad/s}$

$f_s = \frac{\omega s}{2\pi} = \frac{80 \times 10^3}{2\pi} = \underline{12.73\,kHz}$

24. Typical characteristics for 741

$R_o = 25\Omega,\ A = 200K$

(a) $A_{CL} = -\frac{R_f}{R_1} = -\frac{200k}{2k} = -100$

(b) $Z_i = R_1 = 2k\Omega$

(c) $Z_o = \frac{R_o}{1+\beta \cdot A} = \frac{25\Omega}{1 + \frac{1}{100}(200{,}000)}$

$= \frac{25\Omega}{2001} = 0.0125\ \Omega$

# Chapter 15. OPAMP APPLICATIONS

§15.1

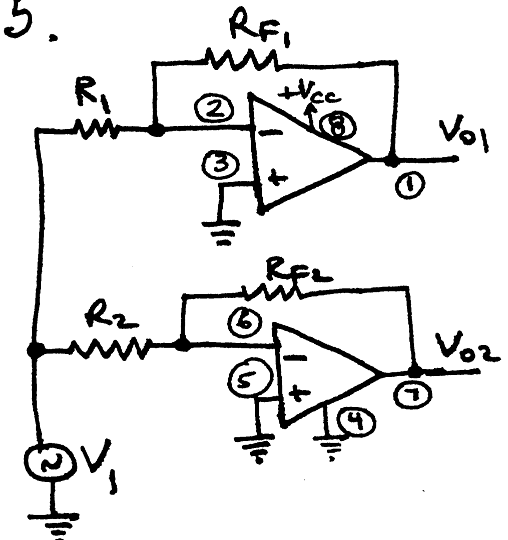
1. $V_o = -\frac{R_F}{R_1}V_1 = -\frac{180\,k\Omega}{3.6\,k\Omega}(3.5\,mV) = \underline{-175\,mV}$

3. $V_o = \left(1+\frac{510\,k\Omega}{18\,k\Omega}\right)(20\,\mu V)\left[-\frac{680\,k\Omega}{22\,k\Omega}\right]\left[-\frac{750\,k\Omega}{33\,k\Omega}\right]$

$= (29.33)(-30.91)(-22.73)(20\,\mu V)$

$= \underline{412\,mV}$

5.




$V_{o1} = -\frac{R_{F1}}{R_1}V_1 = -\frac{150\,k\Omega}{R_1}V_1$

$\frac{V_{o1}}{V_1} = A_{V_1} = -15 = -\frac{150\,k\Omega}{R_1}$

$R_1 = \frac{150\,k\Omega}{15} = \underline{10\,k\Omega}$

$V_{o2} = -\frac{R_{F2}}{R_2}V_1 = -\frac{150\,k\Omega}{R_2}V_1$

$\frac{V_{o2}}{V_1} = A_{V_2} = -30 = \frac{-150\,k\Omega}{R_2}$

$R_2 = \frac{150\,k\Omega}{30} = \underline{5\,k\Omega}$

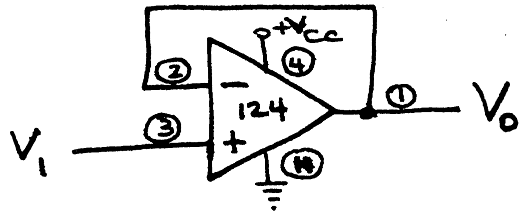
§15.2

7. $V_o = \left(\frac{10\,k\Omega}{10\,k\Omega + 10\,k\Omega}\right)\left(\frac{150\,k\Omega + 300\,k\Omega}{150\,k\Omega}\right)V_1 - \frac{300\,k\Omega}{150\,k\Omega}V_2$

$= 0.5(3)(1V) - 2(2V) = 1.5V - 4V = \underline{-2.5V}$

§15.3

9.




§15.4

11. $I_L = \frac{V_1}{R_1} = \frac{12V}{2k\Omega} = \underline{6\,mA}$

§15.5

13. $\frac{I_o}{V_1} = \frac{R_F}{R_1}\left(\frac{1}{R_S}\right)$

$I_o = \frac{100\,k\Omega}{200\,k\Omega}\left(\frac{1}{10\Omega}\right)(10\,mV) = \underline{0.5\,mA}$

§15.6

15. $f_{OH} = \frac{1}{2\pi R_1 C_1} = \frac{1}{2\pi(2.2\,k\Omega)(0.05\,\mu F)}$

$= \underline{1.45\,kHz}$

17. $f_{OL} = \frac{1}{2\pi R_1 C_1} = \frac{1}{2\pi(10\,k\Omega)(0.05\,\mu F)} = \underline{318.3\,Hz}$

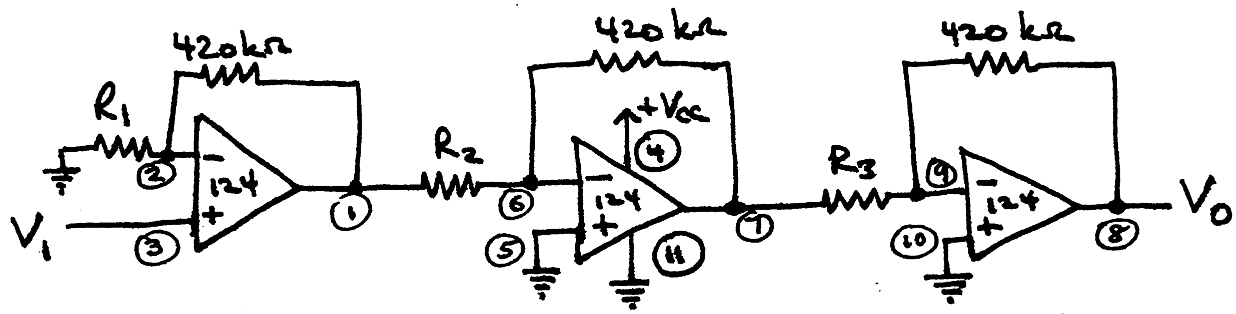
$f_{OH} = \frac{1}{2\pi R_2 C_2} = \frac{1}{2\pi(20\,k\Omega)(0.02\,\mu F)}$

$= \underline{397.9\,Hz}$

2. $V_o = \left(1 + \frac{R_F}{R_1}\right)V_1 = \left(1 + \frac{750\text{ k}\Omega}{36\text{ k}\Omega}\right)(150\text{ mV, rms})$

$= \underline{3.275\text{ V, rms}} \angle 0^\circ$

4.




$\left(1 + \frac{420k}{R_1}\right) = +15$ $\qquad -\frac{420k}{R_2} = -22$ $\qquad -\frac{420k}{R_3} = -30$

$R_1 = \frac{420k}{14}$ $\qquad R_2 = \frac{420k}{22}$ $\qquad R_3 = \frac{420k}{30}$

$\underline{R_1 = 71.4\text{k}\Omega}$ $\qquad \underline{R_2 = 19.1\text{k}\Omega}$ $\qquad \underline{R_3 = 14\text{k}\Omega}$

$V_o = (+15)(-22)(-30)V_1 = 9900(80\mu\text{V}) = \underline{792\text{ mV}}$

$= \underline{0.792\text{V}}$

§ 15.2

6. $V_o = -\left[\frac{R_F}{R_1}V_1 + \frac{R_F}{R_2}V_2\right] = -\left[\frac{470\text{k}\Omega}{47\text{k}\Omega}(40\text{mV}) + \frac{470\text{k}\Omega}{12\text{k}\Omega}(20\text{mV})\right]$

$= -[400\text{ mV} + 783.3\text{ mV}] = \underline{-1.18\text{V}}$

8.

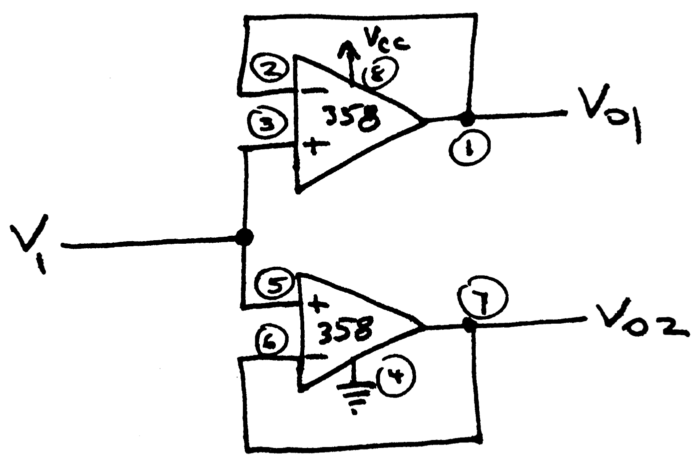
$$V_o = -\left\{\left[\frac{330\,k\Omega}{33\,k\Omega}(12\,mV)\right]\left(\frac{470\,k\Omega}{47\,k\Omega}\right) + \frac{470\,k\Omega}{47\,k\Omega}(18\,mV)\right\}$$

$$= -\left[(-120\,mV)(10) + 180\,mV\right] = -\left[-1.2\,V + 0.18\,V\right]$$

$$= \underline{+1.02\,V}$$

§15.3

10.




§15.4

12. $V_o = -I_1 R_1 = -(2.5\,mA)(10\,k\Omega) = \underline{-25\,V}$

§15.5

14. $V_o = \left(1 + \frac{2R}{R_P}\right)\left[V_2 - V_1\right]$

$$= \left(1 + \frac{2(5000)}{1000}\right)\left[1\,V - 3\,V\right] = \underline{-22\,V}$$

§15.6

16. $f_{oL} = \dfrac{1}{2\pi R_1 C_1} = \dfrac{1}{2\pi(20\text{ k}\Omega)(0.02\,\mu\text{F})}$

$= \underline{397.9\text{ Hz}}$

# Chapter 16. Power Amplifiers

§16.2

1. $I_{B_Q} = \dfrac{V_{CC} - V_{BE}}{R_B} = \dfrac{18V - 0.7V}{1.2k\Omega} = 14.42mA$

$I_{C_Q} = \beta I_{B_Q} = 40(14.42mA) = 576.67\ mA$

$P_i = V_{CC} I_{dc} \cong V_{CC} I_{C_Q} = (18V)(576.67mA)$

$\cong \underline{10.4\ W}$

$I_C(rms) = \beta I_B(rms)$

$= 40(5mA) = 200\ mA$

$P_o = I_C^2(rms) R_C = (200\ mA)^2 (16\Omega) = \underline{640mW}$

3. From problem 16.2: $I_{C_Q} = 460mA$, $P_i = 8.3W$.

For maximum efficiency of 25%:

$\%\eta = 100\% \times \dfrac{P_o}{P_i} = \dfrac{P_o}{8.3W} \times 100\% = 25\%$

$P_o = 0.25(8.3W) = \underline{2.1W}$

[If dc bias condition also considered:

$V_C = V_{CC} - I_{C_Q} R_C = 18V - (460mA)(16\Omega) = 10.64V$

collector may vary $\pm$ 7.36V about Q-point, resulting in maximum output power

$P_o = \dfrac{V_{CE}^2(P)}{2R_C} = \dfrac{(7.36V)^2}{2(16)} = 1.69W$ ]

§16.3

5. $R_p = \left(\frac{N_1}{N_2}\right)^2 R_s = \left(\frac{25}{1}\right)^2 (4\,\Omega) = \underline{2.5\text{ k}\Omega}$

7. $R_2 = a^2 R_1$

$8\text{ k}\Omega = a^2 (4\,\Omega)$

$a^2 = \frac{8\text{ k}\Omega}{4\,\Omega} = 2000$

$a = \sqrt{2000} = \underline{44.7}$

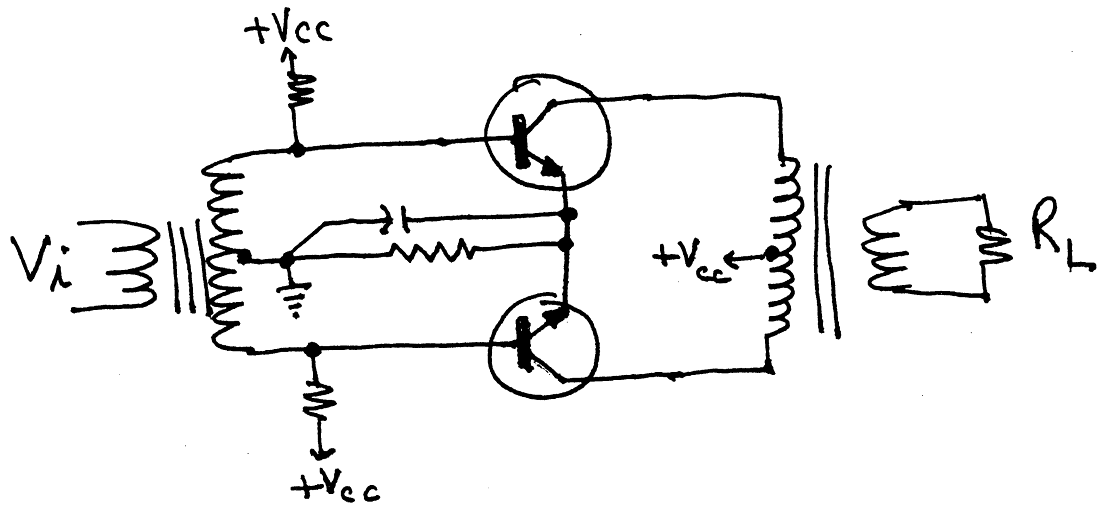
9. $I_{dc} = I_{C_Q} = 150\text{ mA}$

$P_i = V_{CC} I_{C_Q} = (36\text{V})(150\text{mA}) = 5.4\text{W}$

$\%\eta = \frac{P_o}{P_i} \times 100\% = \frac{2\text{ W}}{5.4\text{W}} \times 100\% = \underline{37\%}$

§16.4

11.



13. (a) $\max P_i = V_{CC} I_{dc}$

$$= V_{CC} \cdot \left(\frac{2}{\pi} \cdot \frac{V_{CC}}{R_L}\right) = (25\text{V})\left[\frac{2}{\pi} \cdot \frac{25\text{V}}{8\Omega}\right]$$

$$= \underline{49.74\text{W}}$$

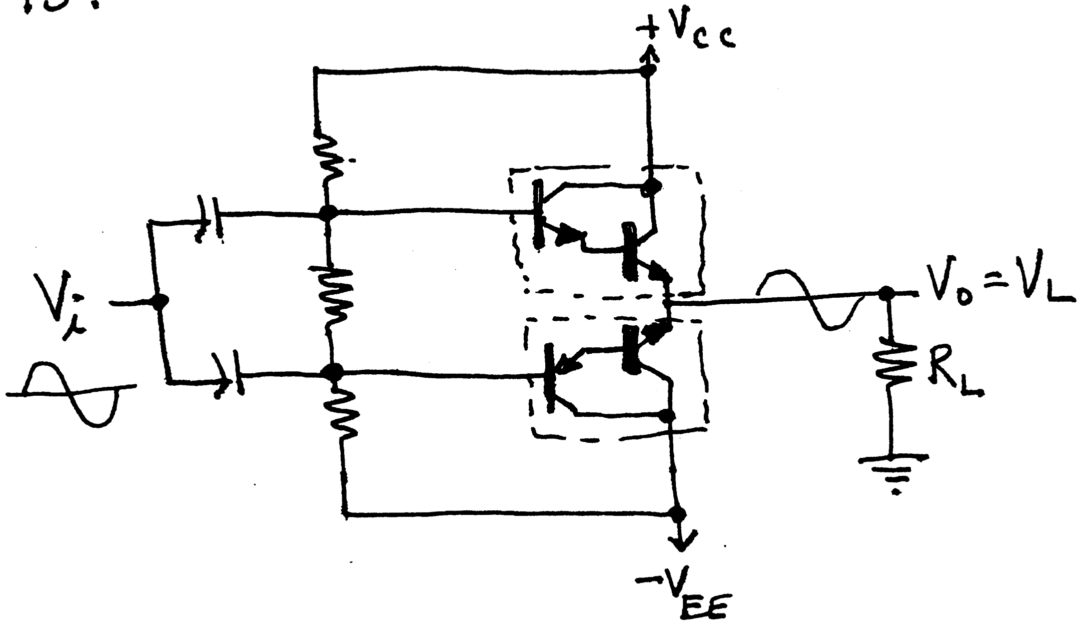
(b) $$\max P_o = \frac{V_{CC}^2}{2R_L} = \frac{(25\text{V})^2}{2(8\Omega)} = 39.06\text{W}$$

(c) $$\max \% \eta = \frac{\max P_o}{\max P_i} \times 100\% = \frac{39.06\text{W}}{49.74\text{W}} \times 100\%$$

$$= \underline{78.5\%}$$

§16.5

15.



17. (a) $P_i(dc) = V_{CC} I_{dc} = V_{CC} \cdot \frac{2}{\pi}\left(\frac{V_o(p)}{R_L}\right)$

$$= 30V \cdot \frac{2}{\pi}\left[\frac{\sqrt{2}\,8}{8}\right] = \underline{27\,W}$$

(b) $P_o(ac) = \dfrac{V_L^2(rms)}{R_L} = \dfrac{(8V)^2}{8\Omega} = \underline{8\,W}$

(c) $\%\eta = \dfrac{P_o}{P_i} \times 100\% = \dfrac{8W}{27W} \times 100\% = \underline{29.6\%}$

(d) $P_{2Q} = P_i - P_o = 27W - 8W = \underline{19\,W}$

§16.6

19. $\% D_2 = \left|\dfrac{A_2}{A_1}\right| \times 100\% = \left|\dfrac{0.3V}{2.1V}\right| \times 100\% = \underline{14.3\%}$

$\% D_3 = \left|\dfrac{A_3}{A_1}\right| \times 100\% = \dfrac{0.1V}{2.1V} \times 100\% \cong \underline{4.8\%}$

$\% D_4 = \left|\dfrac{A_4}{A_1}\right| \times 100\% = \dfrac{0.05V}{2.1V} \times 100\% \cong \underline{2.4\%}$

21. $D_2 = \left|\dfrac{\frac{1}{2}(V_{CE_{max}} + V_{CE_{min}})}{V_{CE_{max}} - V_{CE_{min}}}\right| \times 100\%$

$$= \left|\frac{\frac{1}{2}(20V + 2.4V) - 10V}{20V - 2.4V}\right| \times 100\%$$

$$= \frac{1.2V}{17.6V} \times 100\% = \underline{6.8\%}$$

§16.7

23. $P_D(150°C) = P_D(25°C) - (T_{150} - T_{25})(\text{Derating Factor})$

$$= 100\,W - (150°C - 25°C)(0.6\,W/°C)$$

$$= 100\,W - 125(0.6) = 100 - 75$$

$$= \underline{25\,W}$$

25. $$P_D = \frac{T_J - T_A}{\theta_{JA}}$$

$$= \frac{200°C - 80°C}{(40\,°C/W)} = \frac{120\,°C}{40\,\frac{°C}{W}}$$

$$= \underline{3\,W}$$

§16.2

2. $I_{BQ} = \dfrac{V_{CC} - V_{BE}}{R_B} = \dfrac{18V - 0.7V}{1.5k\Omega} = 11.5mA$

$I_{CQ} = \beta I_{BQ} = 40(11.5mA) = 460mA$

$P_i(dc) = V_{CC} I_{dc} = V_{CC}(I_{CQ} + I_{BQ})$

$= 18V(460mA + 11.5mA)$

$= \underline{8.5W}$

$[P_i \approx V_{CC} I_{CQ} = 18V(460mA) = 8.3W]$

4. Assuming maximum efficiency of 25%
with $P_o(max) = 1.5W$

$\%\eta = \dfrac{P_o}{P_i} \times 100\%$

$P_i = \dfrac{1.5W}{0.25} = \underline{6W}$

---

Assuming dc bias at mid-point, $V_C = 9V$

$I_{CQ} = \dfrac{V_{CC} - V_C}{R_C} = \dfrac{18V - 9V}{16\Omega} = 0.5625A$

$P_i(dc) = V_{CC} I_{CQ} = (18V)(0.5625A)$

$= \underline{10.38W}$

at this input: $\%\eta = \dfrac{P_o}{P_i} \times 100\% = \dfrac{1.5W}{10.38W} \times 100\% = 14.45\%$

§16.3

6. $R_2 = a^2 R_1$

$$a^2 = \frac{R_2}{R_1} = \frac{8\,k\Omega}{8\,\Omega} = 1000$$

$$a = \sqrt{1000} = \underline{31.6}$$

8. (a) $P_{pri} = P_L = \underline{2\,W}$

(b) $P_L = \frac{V_L^2}{R_L}$

$$V_L = \sqrt{P_L R_L} = \sqrt{(2\,W)(16\,\Omega)}$$

$$= \sqrt{32} = \underline{5.66\,V}$$

(c) $R_2 = a^2 R_1 = (3.87)^2 (16\,\Omega) = 239.6\,\Omega$

$$P_{pri} = \frac{V_{pri}^2}{R_{pri}} = 2\,W$$

$$V_{pri}^2 = (2\,W)(239.6\,\Omega)$$

$$V_{pri} = \sqrt{479.2} = \underline{21.89\,V}$$

[or, $V_{pri} = a V_L = (3.87)(5.66\,V) = 21.9\,V$]

(d) $P_L = I_L^2 R_L$

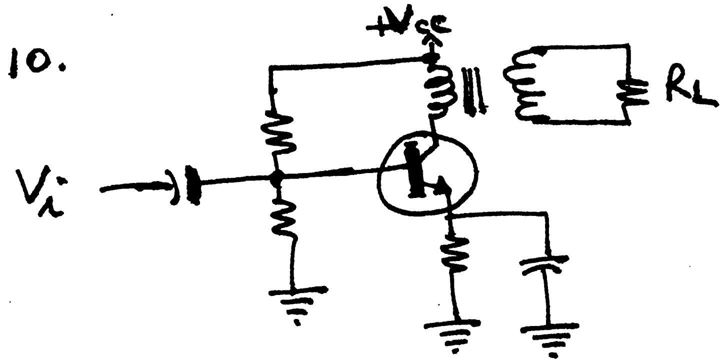
$$I_L = \sqrt{\frac{P_L}{R_L}} = \sqrt{\frac{2\,W}{16\,\Omega}} = \underline{353.55\,mA}$$

$$P_{pri} = 2\,W = I_{pri}^2 R_{pri} = (239.6\,\Omega) I_{pri}^2$$

$$I_{pri} = \sqrt{\frac{2\,W}{239.6\,\Omega}} = \underline{91.36\,mA}$$

[or, $I_{pri} = \frac{I_L}{a} = \frac{353.55\,mA}{3.87} = 91.36\,mA$]

10.




§16.4

12. (a) $P_i = V_{CC} I_{dc} = (25\,V)(1.75\,A) = \underline{43.77\,W}$

where, $I_{dc} = \frac{2}{\pi} I_p = \frac{2}{\pi} \frac{V_p}{R_L} = \frac{2}{\pi} \cdot \frac{22\,V}{8\,\Omega} = 1.75\,A$

(b) $P_o = \frac{V_p^2}{2R_L} = \frac{(22\,V)^2}{2(8\,\Omega)} = \underline{30.25\,W}$

(c) $\%\eta = \frac{P_o}{P_i} \times 100\% = \frac{30.75\,W}{43.77\,W} \times 100\% = \underline{69\%}$

14. (a) $V_L(p) = 20\,V$

$P_i = V_{CC} I_{dc} = V_{CC}\left[\frac{2}{\pi} \cdot \frac{V_L(p)}{R_L}\right]$

$= (22\,V)\left[\frac{2}{\pi} \cdot \frac{20\,V}{4\,\Omega}\right] = 70\,W$

$P_o = \frac{V_L^2(p)}{2\,R_L} = \frac{(20\,V)^2}{2(4\,\Omega)} = 50\,W$

$\%\eta = \frac{P_o}{P_i} \times 100\% = \frac{50\,W}{70\,W} \times 100\% = \underline{71.4\%}$

(b) $P_i = (22\,V)\left[\frac{2}{\pi} \cdot \frac{4\,V}{4\,\Omega}\right] = 14\,W$

$P_o = \frac{(4)^2}{2(4)} = 2\,W$

$\%\eta = \frac{P_o}{P_i} \times 100\% = \frac{2\,W}{14\,W} \times 100\% = \underline{14.3\%}$

§16.5

16. (a) max $P_o$ (ac) for $V_L(p) = 30\text{V}$:

$$\max P_o(\text{ac}) = \frac{V_L^2(p)}{2R_L} = \frac{(30\text{V})^2}{2(8\Omega)} = \underline{56.25\text{W}}$$

(b)

$$\max P_i(\text{dc}) = V_{CC}I_{dc} = V_{CC}\left[\frac{2}{\pi}\cdot\frac{V_o(p)}{R_L}\right]$$

$$= (30\text{V})\left[\frac{2}{\pi}\cdot\frac{30\text{V}}{8\Omega}\right] = \underline{71.62\text{W}}$$

(c)

$$\max \%\eta = \frac{\max P_o}{\max P_i}\times 100\% = \frac{56.25\text{W}}{71.62\text{W}}\times 100\%$$

$$= \underline{78.54\%}$$

(d) $$\max P_{2Q} = \frac{2}{\pi^2}\cdot\frac{V_{CC}^2}{R_L} = \frac{2}{\pi^2}\cdot\frac{(30)^2}{8} = \underline{22.8\text{W}}$$

18. (a) $$P_o(\text{ac}) = \frac{V_L^2(\text{rms})}{R_L} = \frac{(18\text{V})^2}{8\Omega} = \underline{40.5\text{W}}$$

(b) $$P_i(\text{dc}) = V_{CC}I_{dc} = V_{CC}\left[\frac{2}{\pi}\cdot\frac{V_L(p)}{R_L}\right]$$

$$= (40\text{V})\left[\frac{2}{\pi}\cdot\frac{18\sqrt{2}\text{ V}}{8\Omega}\right] = \underline{81\text{W}}$$

(c) $$\%\eta = \frac{P_o}{P_i}\times 100\% = \frac{40.5\text{W}}{81\text{W}}\times 100\% \approx \underline{50\%}$$

(d) $$P_{2Q} = P_i - P_o = 81\text{W} - 40.5\text{W} = \underline{40.5\text{W}}$$

§16.6

20. $\%THD = \sqrt{D_2^2 + D_3^2 + D_4^2} \times 100\%$

$= \sqrt{(0.143)^2 + (0.048)^2 + (0.024)^2} \times 100\%$

$= \underline{15.3\%}$

22. $THD = \sqrt{D_2^2 + D_3^2 + D_4^2} = \sqrt{(0.15)^2 + (0.01)^2 + (0.05)^2}$

$\cong 0.16$

$P_1 = \dfrac{I_1^2 R_C}{2} = \dfrac{(3.3A)^2 (4\Omega)}{2} = \underline{21.8W}$

$P = (1 + THD^2) P_1 = [1 + (0.16)^2] 21.8W$

$= \underline{22.36W}$

§16.7

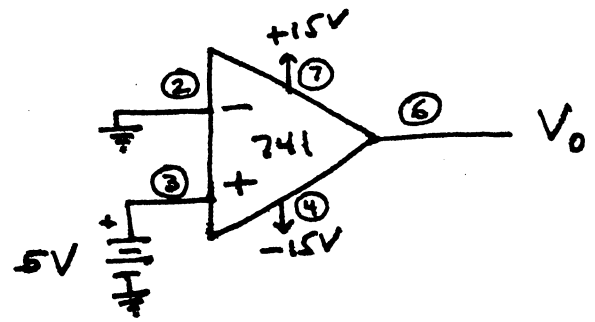
24. $P_D = \dfrac{T_J - T_A}{\theta_{JC} + \theta_{CS} + \theta_{SA}} = \dfrac{200°C - 80°C}{0.5\frac{°C}{W} + 0.8\frac{°C}{W} + 1.5\frac{°C}{W}}$

$= \dfrac{120°C}{2.8\frac{°C}{W}} = \underline{42.9W}$

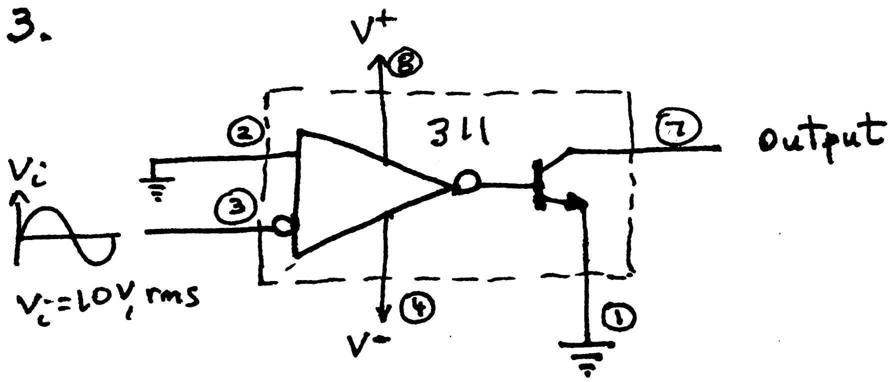
# Chapter 17. Linear-Digital ICs

§17.2

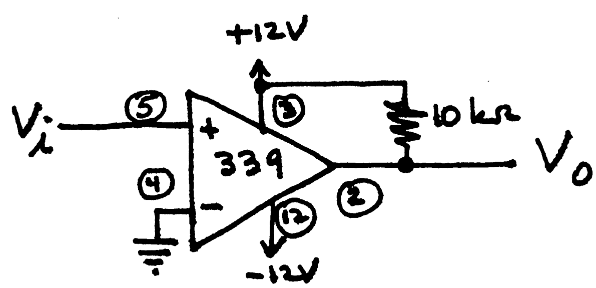
1.




3.




5.




7. Circuit operates as a window detector.

Output goes <u>low</u> for input <u>above</u> $\frac{9.1k}{9.1k+6.2k}(+12V) = \underline{7.1V}$

Output goes <u>low</u> for input <u>below</u> $\frac{1k}{1k+6.2k}(+12V) = \underline{1.7V}$

Output is <u>high</u> for input between +1.7V and +7.1V.

§17.3

9. $\frac{11010}{2^5}(16V) = \frac{26}{32}(16V) = \underline{13V}$

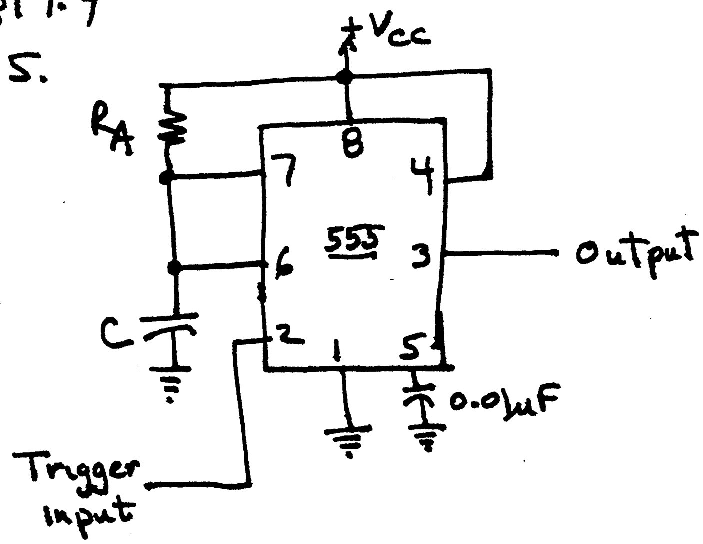
11. See section 17.3

13. $2^{12} = 4096$ steps at $T = \frac{1}{f} = \frac{1}{20MHz} = 50\ ns/count$

Period $= 4096$ counts $\times 50 \frac{ns}{count} = \underline{204.8\ \mu s}$

§17.4

15.




$T = 1.1 R_A C$

$20\mu s = 1.1(7.5k)\ C$

$C = \frac{20 \times 10^{-6}}{1.1(7.5 \times 10^3)}$

$= 2.4 \times 10^{-9}$

$= 2400 \times 10^{-12}$

$= \underline{2400\ pF}$

§17.5

17. $f_o = \frac{2}{R_1 C_1}\left(\frac{V^+ - V_C}{V^+}\right)$

$V^+ = 12V$

$V_C = \frac{R_3}{R_2 + R_3}(V^+) = \frac{11k}{1.8k + 11k}(+12V) = 10.3V$

$f_o = \frac{2}{(4.7k)(0.001\mu F)}\left[\frac{12V - 10.3V}{12V}\right]$

$= 60.3 \times 10^3 \cong \underline{60 \text{ kHz}}$

19. $V^+ = 12V$

$V_C = \frac{R_3}{R_2 + R_3}V^+ = \frac{10k}{1.5k + 10k}(12V) = 10.4V$

$f_o = \frac{2}{R_1 C_1}\left(\frac{V^+ - V_C}{V^+}\right) = \frac{2}{10k(C_1)}\left(\frac{12V - 10.4V}{12V}\right)$

$= 200 \text{kHz}$

$C_1 = \frac{2}{10k(200\text{kHz})}(0.133)$

$= 133 \times 10^{-12} = \underline{133 pF}$

§17.6

21. $C_1 = \frac{0.3}{R_1 f} = \frac{0.3}{(10k)(100\text{kHz})} = \underline{300 pF}$

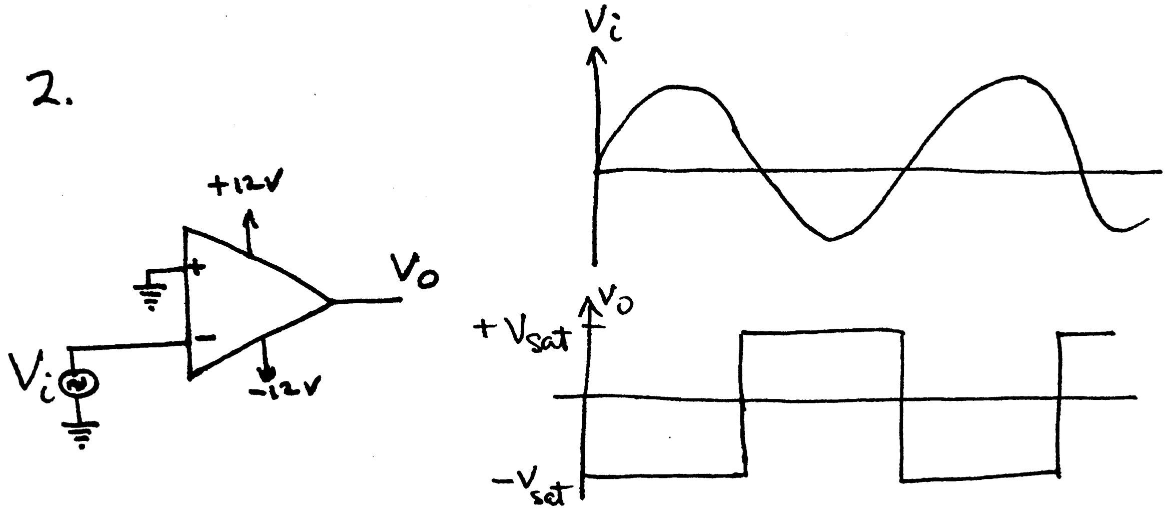
§17.7

23. For current loop: mark = 20 mA
space = 0 mA

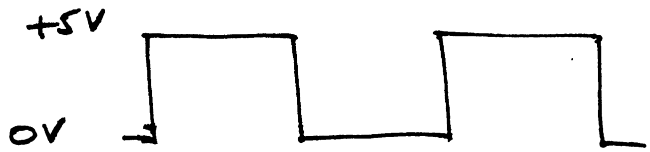
For RS-232C: mark = −12 V
space = +12 V

25. Open-collector is active low only.
tri-state is active-high or active-low.

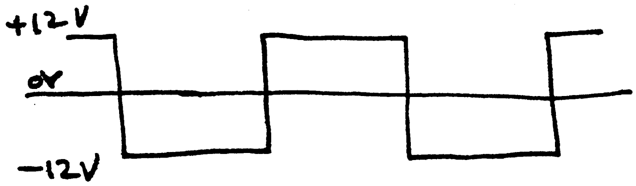
2.


+12V
-12V
$V_i$
$V_o$
+ $V_{sat}$
$-V_{sat}$

4.

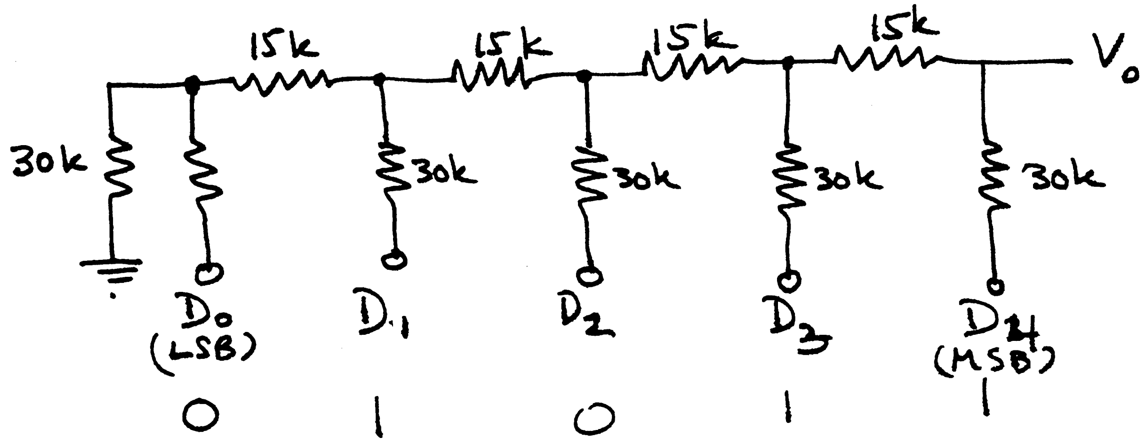

+5V
0V

6.


+12V
0V
-12V

§17-3

8.

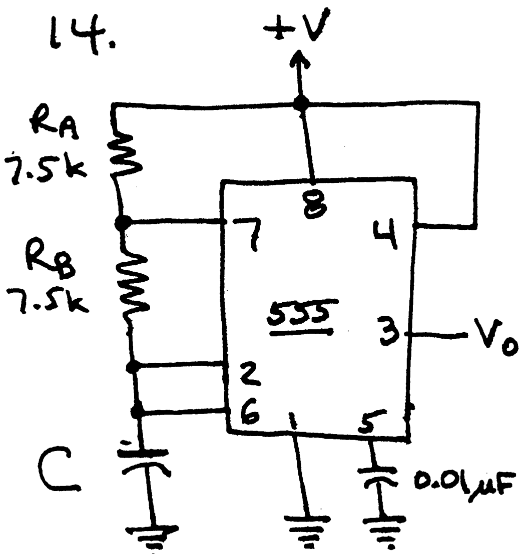

15k
15k
15k
15k
$V_o$
30k
30k
30k
30k
30k
$D_0$
(LSB)
$D_1$
$D_2$
$D_3$
$D_4$
(MSB)
0
1
0
1
1

10. $\text{Resolution} = \dfrac{V_{REF}}{2^n} = \dfrac{10V}{2^{12}} = \dfrac{10V}{4096} = \underline{2.4\,\text{mV/count}}$

12. Maximum number of count steps $= 2^{12} = \underline{4096}$

§17.4

14.



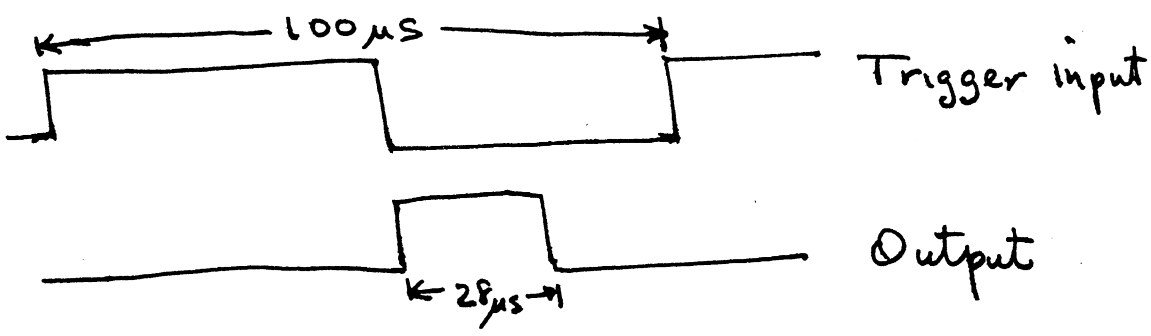

$$f = \frac{1.44}{(R_A + 2R_B)C} = 350\,\text{kHz}$$

$$C = \frac{1.44}{7.5k + 2(7.5k)(350\,\text{kHz})}$$

$$\cong \underline{183\,\text{pF}}$$

16. $T = \dfrac{1}{f} = \dfrac{1}{10\,\text{kHz}} = 100\,\mu s$

$T = 1.1 R_A C = 1.1(5.1\,k\Omega)(5\,nF) = 28\,\mu s$



18.

With potentiometer set at top:

$$V_C = \frac{R_3 + R_4}{R_2 + R_3 + R_4} V^+ = \frac{5\,k\Omega + 18\,k\Omega}{510\,\Omega + 5\,k\Omega + 18\,k\Omega}(12\,V)$$

$$= 11.74\,V$$

resulting in a lower cutoff frequency of

$$f_o = \frac{2}{R_1 C_1}\left(\frac{V^+ - V_C}{V^+}\right) = \frac{2}{(10 \times 10^3)(0.001\,\mu F)}\left(\frac{12V - 11.74V}{12V}\right)$$

$$= \underline{4.3\,kHz}$$

- - - - -

With potentiometer set at bottom:

$$V_c = \frac{R_4}{R_2 + R_3 + R_4}(V^+) = \frac{18\,k\Omega}{510\,\Omega + 5\,k\Omega + 18\,k\Omega}(12V)$$

$$= 9.19V$$

resulting in a higher cutoff frequency of

$$f_o = \frac{2}{R_1 C_1}\left(\frac{V^+ - V_c}{V^+}\right) = \frac{2}{(10\,k\Omega)(0.001\,\mu F)}\left[\frac{12V - 9.19V}{12V}\right]$$

$$= \underline{61.2\,kHz}$$

§17.6

20.

$$f_o = \frac{0.3}{R_1 C_1} = \frac{0.3}{(4.7\,k\Omega)(0.001\,\mu F)}$$

$$= \underline{63.8\,kHz}$$

22. $f_L = \pm \dfrac{8f_o}{V}$

$$= \pm \frac{8(63.8\times10^3)}{6\text{ V}}$$

$$= \underline{85.1\text{ kHz}}$$

$\left[ f_o = \dfrac{0.3}{R_1C_1} = \dfrac{0.3}{4.7\text{ k}\Omega(0.001\,\mu\text{F})} = 63.8\text{ kHz} \right]$

§17.7

24. A line (or lines) onto which data bits are connected.

# Chapter 18. Feedback & Oscillator Circuits

§18.2

1. $$A_f = \frac{A}{1+\beta A} = \frac{-2000}{1+(-\frac{1}{10})(-2000)} = \frac{-2000}{201} = \underline{-9.95}$$

3. $$A_f = \frac{A}{1+\beta A} = \frac{-300}{1+(-\frac{1}{15})(-300)} = \frac{-300}{21} = \underline{-14.3}$$

$$R_{if} = (1+\beta A)R_i = 21\,(1.5\,k\Omega) = \underline{31.5\,k\Omega}$$

$$R_{of} = \frac{R_o}{1+\beta A} = \frac{50\,k\Omega}{21} = \underline{2.4\,k\Omega}$$

§18.3

5. DC Bias:
$$I_B = \frac{V_{CC}-V_{BE}}{R_B+(\beta+1)R_E} = \frac{16\,V - 0.7\,V}{600\,k\Omega + 76(1.2\,k\Omega)}$$
$$= \frac{15.3\,V}{691.2\,k\Omega} = 22.1\,\mu A$$

$$I_E = (1+\beta)\,I_B$$
$$= 76(22.1\,\mu A) = 1.68\,mA$$

$$\left[V_{CE} = V_{CC} - I_C(R_C+R_E) = 16\,V - 1.68\,mA\,(4.7\,k + 1.2\,k) \cong 6.1\,V\right]$$

$$r_e = \frac{26\,mV}{I_E(mA)} = \frac{26}{1.68} \cong 15.5\,\Omega$$

$$h_{ie} \cong (1+\beta)\,r_e = 76(15.5\,\Omega) = 1.18\,k\Omega = Z_i$$

$$Z_o = R_C = 4.7\,k\Omega$$

$$A = \frac{-h_{fe}}{h_{ie} + R_E} = \frac{-75}{1.18\,k\Omega + 1.2\,k\Omega} = -31.5 \times 10^{-3}$$

$$\beta = -R_E = -1.2 \times 10^{3}$$

$$(1+\beta A) = 1 + (-1.2\times 10^{3})(-31.5\times 10^{-3})$$

$$= 38.8$$

$$A_f = \frac{A}{1+\beta A} = \frac{-31.5\times 10^{-3}}{38.8} = 811.86\times 10^{-6}$$

$$A_{v_f} = -A_f R_c = -(811.86\times 10^{-6})(4.7\times 10^{3}) = \underline{-3.82}$$

$$Z_{i_f} = (1+\beta A)Z_i = (38.8)(1.18\,k\Omega) = \underline{45.8\,k\Omega}$$

$$Z_{o_f} = (1+\beta A)Z_o = (38.8)(4.7\,k\Omega) = \underline{182.4\,k\Omega}$$

without feedback ($R_E$ bypassed):

$$A_v = \frac{-R_C}{r_e} = -\frac{4.7\,k\Omega}{15.5\,\Omega} = \underline{-303.2}$$

§18.6

7. $$f_o = \frac{1}{2\pi RC}\cdot\frac{1}{\sqrt{6+4\left(\frac{R_C}{R}\right)}}$$

$$= \frac{1}{2\pi(6\times 10^{3})(1500\times 10^{-12})}\cdot\frac{1}{\sqrt{6+4(18\times 10^{3}/6\times 10^{3})}}$$

$$= 4.17\,kHz \cong \underline{4.2\,kHz}$$

§18.8

9. $C_{eq} = \frac{C_1 C_2}{C_1 + C_2} = \frac{(750\,pF)(2000\,pF)}{750\,pF + 2000\,pF} = 577\,pF$

$$f_0 = \frac{1}{2\pi\sqrt{L\,C_{eq.}}} = \frac{1}{2\pi\sqrt{(40\times10^{-6})(577\times10^{-12})}}$$

$$= \underline{1.05\,MHz}$$

11. $f_0 = \frac{1}{2\pi\sqrt{L_{eq}\,C}}$ ,

$$= \frac{1}{2\pi\sqrt{(4\times10^{-3})(250\times10^{-12})}}$$

$$= \underline{159.2\,kHz}$$

$L_{eq} = L_1 + L_2 + 2M$
$= 1.5\,mH + 1.5\,mH + 2(0.5\,mH)$
$= 4\,mH$

§18.9

13. See Fig. 18.33a and Fig 18.34

§18.2

2. $$\frac{dA_f}{A_f} = \frac{1}{\beta A}\frac{dA}{A} = \frac{1}{\left(-\frac{1}{20}\right)(-1000)}(10\%) = \underline{0.2\%}$$

§18.3

4. $$R_L = \frac{R_o R_D}{R_o + R_D} = 40\,k\Omega \parallel 8\,k\Omega = 6.7\,k\Omega$$

$$A = -g_m R_L = -(5000\times10^{-6})(6.7\times10^{3}) = \underline{-33.5}$$

$$\beta = \frac{-R_2}{R_1+R_2} = \frac{-200\,k\Omega}{200\,k\Omega + 800\,k\Omega} = \underline{-0.2}$$

$$A_f = \frac{A}{1+\beta A} = \frac{-33.5}{1+(-0.2)(-33.5)} = \frac{-33.5}{7.7}$$

$$= \underline{-4.4}$$

§18.6

6. $$C = \frac{1}{2\pi R f\sqrt{6}} = \frac{1}{2\pi(10\times10^{3})(2.5\times10^{3})\sqrt{6}}$$

$$= 2.6\times10^{-9} = \underline{2600\,pF} = 0.0026\,\mu F$$

§18.7

8. $$f_o = \frac{1}{2\pi R C} = \frac{1}{2\pi(10\times10^{3})(2400\times10^{-12})}$$

$$= \underline{6.6\,kHz}$$

§18.8

10. $$f_0 = \frac{1}{2\pi\sqrt{L\,C_{eq.}}}, \quad \text{where } C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$$

$$= \frac{(0.005\mu F)(0.01\mu F)}{0.005\mu F + 0.01\mu F}$$

$$= 3300\,pF$$

$$= \frac{1}{2\pi\sqrt{(100\mu H)(3300\,pF)}}$$

$$= \underline{277\,kHz}$$

12. $$f_0 = \frac{1}{2\pi\sqrt{L_{eq} C}}, \quad \text{where } L_{eq} = L_1 + L_2 + 2M$$

$$= 750\mu H + 250\mu H + 2(150\mu H)$$

$$= 1800\,\mu H$$

$$= \frac{1}{2\pi\sqrt{(1800\mu H)(150\,pF)}}$$

$$= \underline{306.3\,kHz}$$

§18.10

14. $$f_0 = \frac{1}{R_T C_T \ln\left(1/(1-\eta)\right)}$$

for $\eta = 0.5$:

$$f_0 \cong \frac{1.5}{R_T C_T}$$

(a) Using $R_T = 1\,k\Omega$

$$C_T = \frac{1.5}{R_T f_0} = \frac{1.5}{(1\,k\Omega)(1\,kHz)} = \underline{1.5\mu F}$$

(b) Using $R_T = 10\,k\Omega$

$$C_T = \frac{1.5}{R_T f_0} = \frac{1.5}{(10\,k\Omega)(150\,kHz)} = \underline{1000\,pF}$$

# Chapter 19. Power Supplies (Voltage Regulators)

§19.2

1. $$\text{ripple factor} = \frac{V_r(\text{rms})}{V_{dc}} = \frac{2V/\sqrt{2}}{50V} = \underline{0.028}$$

3. $$V_{dc} = 0.318\, V_m$$

$$V_m = \frac{V_{dc}}{0.318} = \frac{20\text{ V}}{0.318} = 62.89\text{ V}$$

$$V_r = 0.385\, V_m = 0.385(62.89V) = \underline{24.2V}$$

§19.3

5. $$\%r = \frac{V_r(\text{rms})}{V_{dc}} \times 100\%$$

$$V_r(\text{rms}) = r \cdot V_{dc} = \frac{8.5}{100} \times 14.5V = \underline{1.2V}$$

7. $V_m = 18V$
$C = 400\,\mu F$
$I_L = 100\text{ mA}$

$$V_r = \frac{2.4\, I_{dc}}{C} = \frac{2.4(100)}{400} = \underline{0.6V, \text{rms}}$$

$$V_{dc} = V_m - \frac{4.17\, I_{dc}}{C}$$

$$= 18V - \frac{4.17(100)}{400} = \underline{16.96V}$$

$$\approx \underline{17V}$$

9. $$\left.\begin{array}{l} C = 100\,\mu F \\ V_{dc} = 12V \\ R_L = 2.4\text{k}\Omega \end{array}\right\} I_{dc} = \frac{V_{dc}}{R_L} = \frac{12V}{2.4\text{k}\Omega} = 5\text{mA}$$

$$V_r(\text{rms}) = \frac{2.4\, I_{dc}}{C} = \frac{2.4(5)}{100} = \underline{0.12V}$$

11. $C = 500\,\mu F$

$I_{dc} = 200\,mA$

$r = 8\% = 0.08$

Using $r = \frac{2.4\,I_{dc}}{C\,V_{dc}}$

$$V_{dc} = \frac{2.4\,I_{dc}}{r\,C} = \frac{2.4(200)}{0.08(500)} = 12\,V$$

$$V_m = V_{dc} + \frac{4.17\,I_{dc}}{C} = 12\,V + \frac{(200)(4.17)}{500}$$

$$= 12\,V + 1.7\,V = \underline{13.7\,V}$$

13. $C = 120\,\mu F$

$I_{dc} = 80\,mA$

$V_m = 25\,V$

$$V_{dc} = V_m - \frac{4.17\,I_{dc}}{C} = 25\,V - \frac{4.17(80)}{120}$$

$$= 22.2\,V$$

$$\%r = \frac{2.4\,I_{dc}}{C\,V_{dc}} \times 100\% = \frac{2.4(80)}{(120)(22.2)} \times 100\%$$

$$= \underline{7.2\%}$$

§19.4

15. $V_r = 2V$ $\quad \%r = \frac{V_r}{V_{dc}} \times 100\% = \frac{2V}{24V} \times 100\%$

$V_{dc} = 24V$ $\quad = \underline{8.3\%}$

$R = 33\Omega,\ C = 120\mu F$

$$X_C = \frac{1.3}{C} = \frac{1.3}{120} = 10.8\Omega$$

$$V_r' = \frac{X_C}{R} V_r = \frac{10.8}{33}(2V) = 0.65V$$

$$V_{dc}' = V_{dc} - I_{dc} R = 24V - 33\Omega(100\,mA)$$

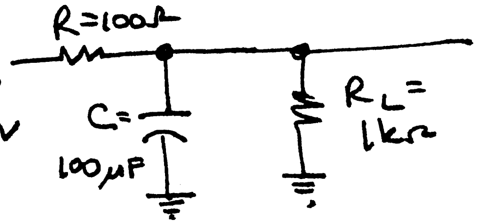
$$= 20.7V$$

$$\%r' = \frac{V_r'}{V_{dc}'} \times 100\% = \frac{0.65V}{20.7V} \times 100\% = \underline{3.1\%}$$

17.

$V_{dc} = 50V$

$V_r = 2.5V$




$$X_C = \frac{1.3}{C} = \frac{1.3}{100} = 13\Omega$$

$$V_r' = \frac{X_C}{R} V_r = \frac{13}{100}(2.5V)$$

$$= \underline{0.325 V_{rms}}$$

§19.5

19. $V_o = V_Z - V_{BE} = 8.3V - 0.7V = \underline{7.6V}$

$$V_{CE} = V_i - V_o = 15V - 7.6V = 7.4V$$

$$I_R = \frac{V_i - V_Z}{R} = \frac{15V - 8.3V}{1.8k\Omega} = 3.7\,mA$$

$$I_L = \frac{V_o}{R_L} = \frac{7.6V}{2k\Omega} = 3.8\,mA$$

$$I_B = \frac{I_C}{\beta} = \frac{3.8\,mA}{100} = 38\,\mu A$$

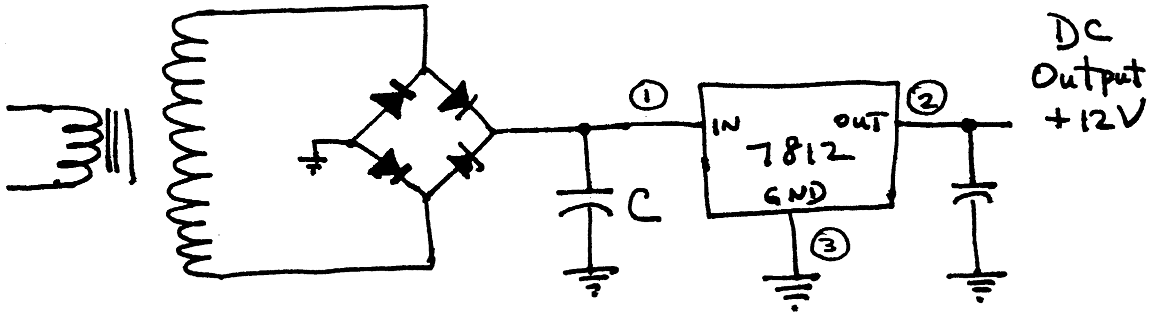
$$I_Z = I_R - I_B = 3.7\,mA - 38\,\mu A = \underline{3.66\,mA}$$

21. $V_o = \left(1 + \frac{R1}{R_2}\right) V_Z = \left(1 + \frac{12k}{8.2k}\right) 10V$

$= \underline{24.6V}$

§19.6

23.




25. To maintain $V_i(\text{min}) \geq 7.3V$ (see Table 19.1)

$V_r(P) \leq V_m - V_i(\text{min}) = 12V - 7.3V = 4.7V$

So that

$V_r(\text{rms}) = \frac{V_r(P)}{\sqrt{3}} = \frac{4.7V}{1.73} = 2.7V$

The maximum value of load current is then

$I_{dc} = \frac{V_r(\text{rms})\, C}{2.4} = \frac{(2.7V)(200)}{2.4} = \underline{225\,mA}$

27. $V_o = V_{ref}\left(1 + \frac{R_2}{R_1}\right) + I_{adj} R_2$

$= 1.25V\left(1 + \frac{1.5k\Omega}{220\Omega}\right) + 100\mu A(1.5k\Omega)$

$= \underline{9.9V}$

§19.2

2. $\% VR = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\% = \frac{28V - 25V}{25V} \times 100\% = \underline{12\%}$

4. $V_{dc} = 0.636 V_m$

$V_m = \frac{V_{dc}}{0.636} = \frac{8V}{0.636} = 12.6V$

$V_r = 0.308 V_m = 0.308(12.6V) = \underline{3.88 V}$

§19.3

6. $V_{NL} = V_m = 18V$

$V_{FL} = 17V$

$\% VR = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\% = \frac{18V - 17V}{17V} \times 100\%$

$= \underline{5.88\%}$

8. $V_r = \frac{2.4 I_{dc}}{C} = \frac{2.4(120)}{200} = \underline{1.44} V$

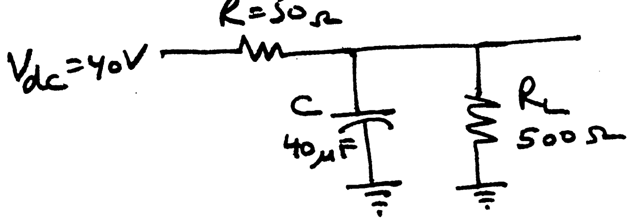
10. $C = \frac{2.4 I_{dc}}{r \ V_{dc}} = \frac{2.4(150)}{(0.15)(24)} = \underline{100 \mu F}$

12. $C = \frac{2.4 I_{dc}}{V_r} = \frac{2.4(200)}{(0.07)} = \underline{6857 \mu F}$

§19.4

14. $V_r' = \frac{r \cdot V_{dc}'}{100} = \frac{2(80)}{100} = \underline{1.6 V, rms}$

16.




$$V'_{dc} = \frac{R_L}{R+R_L} V_{dc}$$

$$= \frac{500}{500+50}(40V)$$

$$= 36.4V$$

$$I_{dc} = \frac{V'_{dc}}{R_L} = \frac{36.4V}{500\Omega} = \underline{72.8mA}$$

18. $V_{NL} = 60V$

$$V_{FL} = \frac{R_L}{R+R_L} V_{dc} = \frac{1k\Omega}{100\Omega + 1k\Omega}(50V) = 45.46V$$

$$\%VR = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\% = \frac{50V - 45.46V}{45.46V} \times 100\%$$

$$= \underline{10\%}$$

§ 19.5

20. $$V_o = \frac{R_1 + R_2}{R_2}(V_Z + V_{BE_2})$$

$$= \frac{33k\Omega + 22k\Omega}{22k\Omega}(10V + 0.7V)$$

$$= \underline{26.75V}$$

22. $$V_o = V_L = 10V + 0.7V = \underline{10.7V}$$

§19.6

24. $I_L = 250\text{ mA}$

$V_m = V_r(\text{rms}) \cdot \sqrt{2} = \sqrt{2}(20\text{ V}) = 28.3\text{V}$

$V_r(p) = \sqrt{3}\, V_r(\text{rms}) = \sqrt{3}\left(\frac{2.4\, I_{dc}}{C}\right)$

$= \sqrt{3}\left(\frac{2.4\,(250)}{500}\right) = 2.1\text{V}$

$V_{dc} = V_m - V_r(p) = 28.3\text{V} - 2.1\text{V} = 26.2\text{V}$

$V_i(\text{low}) = V_{dc} - V_r(p) = 26.2\text{V} - 2.1\text{V} = \underline{24.1\text{V}}$

26. $V_o = V_{ref}\left(1 + \frac{R_2}{R_1}\right) + I_{adj} R_L$

$= 1.25\text{V}\left(1 + \frac{1.8\text{k}\Omega}{240\Omega}\right) + 100\mu\text{A}(2.4\text{ k}\Omega)$

$= 1.25\text{V}(8.5) + 0.24\text{V}$

$= \underline{10.87\text{V}}$

Chapter 20 (Odd)

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.-

3. A surge current rating is typically 20:1 or higher. For the diodes of Fig. 20.5 a 30:1 ratio or better is typical except for the smaller and larger devices where a 10:1 and 20:1 ratio occurred. For some the ratio is 100:1. These high levels of surge current rating are possible because the surge currents only last for a relatively short period of time.

5. At $V_R = 5V$, $I_R \cong 58nA$

$V_R = 10V$, $I_R \cong 130nA$

$$\% \Delta \text{ in } I_R = \frac{130nA - 58nA}{58nA} \times 100\% = \underline{124\%} \text{ increase}$$

Extending the curves $V_R \cong \underline{25V}$

7. a. $$C_T(V_R) = \frac{C(0)}{(1+|V_R/V_T|)^n} = \frac{80pF}{\left(1+\frac{4.2V}{0.7V}\right)^{1/3}}$$

$$= \frac{80pF}{1.912} = \underline{41.85pF}$$

b. $$K = C_T(V_T + V_R)^n$$

$$= 41.85pF(\underbrace{0.7V + 4.2V}_{1.698})^{1/3}$$

$$\cong 71 \times 10^{-12}$$

9. a. $$f_o = \frac{1}{2\pi\sqrt{LC}} \Rightarrow C = \frac{1}{(2\pi f)^2 L} = \frac{1}{(2\pi(1.4\times 10^9 Hz))(2.5\times 10^{-9}H)}$$

$$= \underline{5.17pF}$$

b. Graph $\cong$ 5pF

11. $$TC_C = \frac{\Delta C}{C_o(T_1 - T_0)} \times 100\% \Rightarrow T_1 = \frac{\Delta C \times 100\%}{TC_C(C_o)} + T_0$$

$$= \frac{(0.11pF)(100)}{(0.02)(22pF)} + 25$$

$$= 50°C$$

13. $$Q = \frac{2\pi f L}{R} = \frac{2\pi(600\times 10^6 Hz)(2.5\times 10^{-9}H)}{0.35\Omega}$$

$$= \underline{26.93}$$

Q will drop with increase in frequency if $R_s$ remains constant. Fig. 20.10 reveals a significant drop in Q with frequency (increase).

15. The primary difference between the standard p-n junction diode and the tunnel diode is that the tunnel diode is doped at a level from 100 to several thousand times the doping level of a p-n junction diode, thus producing a diode with a "negative resistance" region in its characteristic curve.

17. The heavy doping greatly reduces the width of the depletion region resulting in lower levels of Zener voltage. Consequently, small levels of reverse voltage can result in significant current levels.

19. $I_{sat} = \frac{E}{R} = \frac{2V}{0.39k\Omega} \cong 5.13mA$

From Graph: Stable operating points - $I_T \cong 5mA, V_T \cong 60mV$
$I_T \cong 2.8mA, V_T \cong 900mV$

21.
$$f_s = \left(\frac{1}{2\pi\sqrt{LC}}\right)\sqrt{1 - \frac{R_e^2 C}{L}}$$
$$= \left(\frac{1}{2\pi\sqrt{(5\times10^{-3}H)(1\times10^{-6}F)}}\right)\sqrt{1 - \frac{(10\Omega)^2(1\times10^{-6}F)}{5\times10^{-3}H}}$$
$$= (2250.79\ Hz)(0.9899)$$
$$\cong 2228 Hz$$

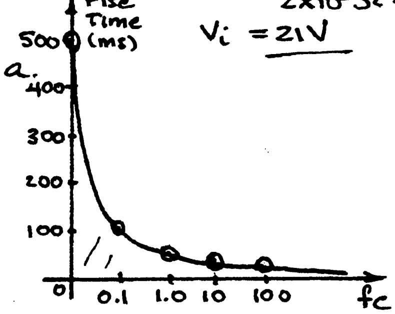
23. a. Visible spectrum: $3750Å \rightarrow 7500Å$
b. Silicon, peak relative response $\cong 8400Å$
c. $BW = 10{,}300Å - 6100Å = 4200Å$

25. a. silicon
b. $1Å = 10^{-10}m$, $\frac{6\times10^{-7}m}{10^{-10}m/Å} \Rightarrow 6000Å \rightarrow$ Orange

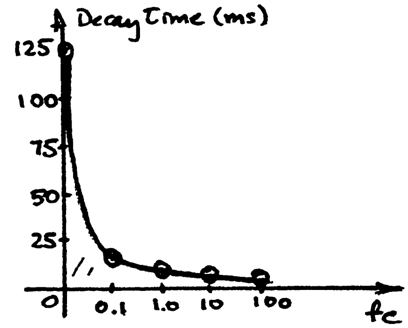
27. a. Extending the curve:
$0.1k\Omega \rightarrow 1000fc$, $1k\Omega \rightarrow 25fc$
$$\frac{\Delta R}{\Delta fc} = \frac{(1-0.1)\times10^3\Omega}{(1000-25)fc} = 0.92\ \Omega/fc \cong 0.9\Omega/fc$$
b. $1k\Omega \rightarrow 25fc$, $10k\Omega \rightarrow 1.3fc$
$$\frac{\Delta R}{\Delta fc} = \frac{(10-1)\times10^3\Omega}{(25-1.3)fc} = 379.75\Omega/fc \cong 380\Omega/fc$$
c. $10k\Omega \rightarrow 1.3fc$, $100k\Omega \rightarrow 0.15fc$
$$\frac{\Delta R}{\Delta fc} = \frac{(100-10)\times10^3}{(1.3-0.15)fc} = 78{,}260.87\Omega/fc \cong 78\times10^3\Omega/fc$$
The greatest rate of change in resistance occurs in the low illumination region.

29. $10fc \rightarrow R \cong 2k\Omega$
$$V_o = 6V = \frac{(2\times10^3\Omega)V_i}{2\times10^3\Omega + 5\times10^3\Omega}$$
$V_i = 21V$

31. a.




b.



c. Increased levels of illumination result in reduced rise and decay Times!

33. a. $\cong 5mW$ radiant flux

b. $\cong 3.5mW$ $\quad \dfrac{3.5mW}{1.496\times10^{-13}\frac{W}{lm}} = \underline{2.34\times10^{10}\ lms}$

35. At $I_F = 60mA$, $\Phi \cong 4.4mW$

At 5°, relative radiant intensity $= 0.8$

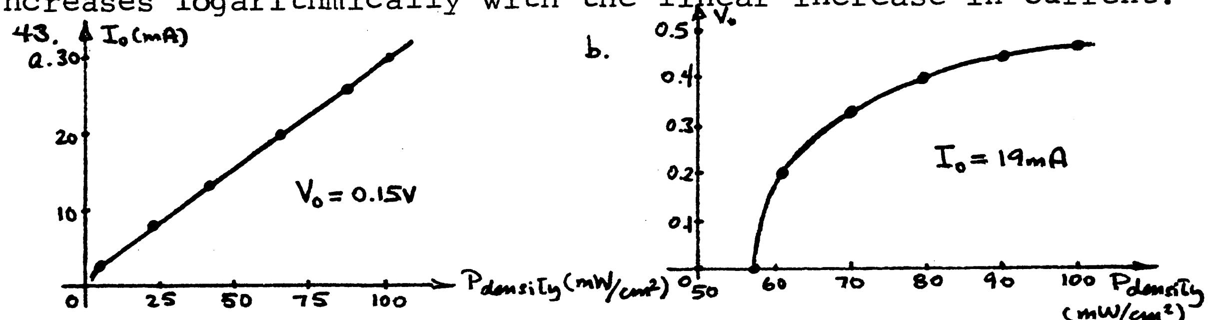
$(0.8)(4.4mW) = \underline{3.52\,mW}$

37. —

39. The LCD display has the advantage of using approximately 1000 times less power than the LED for the same display, since much of the power in the LED is used to produce the light, while the LCD utilizes ambient light to see the display. The LCD is usually more visible in daylight than the LED since the sun's brightness makes the LCD easier to see. The LCD, however, requires a light source, either internal or external, and the temperature range of the LCD is limited to temperatures above freezing.

41. The greatest rate of increase in power will occur at low illumination levels. At higher illumination levels, the change in $V_{OC}$ drops to nearly zero, while the current continues to rise linearly. At low illumination levels the voltage increases logarithmically with the linear increase in current.

43. a.



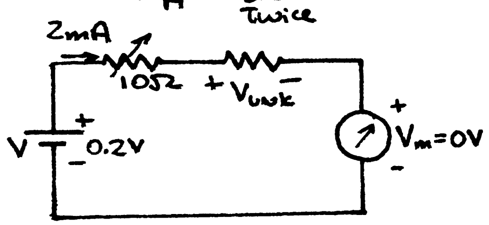

c. The curve of $I_o$ vs $P_{density}$ is quite linear while the curve of $V_o$ vs $P_{density}$ is only linear in the region near the optimum power locus (Fig 20.48).

45. No. 1 Fenwall Electronics thermistor material

Specific resistance $\cong 10^4 = 10{,}000\,\Omega\text{-cm}$

$R = \rho\dfrac{l}{A}$ → $\underset{\text{Twice}}{2x}$ $\quad \therefore R = 2\times(10{,}000\,\Omega) = \underline{20k\Omega}$

47.




$V = IR + IR_{unk} + V_m$

$V = I(R + R_{unk}) + 0V$

$R_{unk} = \dfrac{V}{I} - R$

$= \dfrac{0.2V}{2mA} - 10\Omega$

$= 100\Omega - 10\Omega$

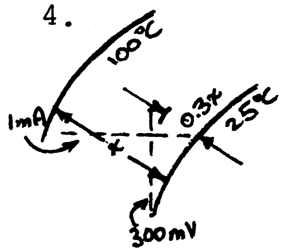
$= \underline{90\Omega}$

Chapter 20 (Even)

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.

4.




$0.3x = 0.3(100-25) = 22.5°C$

$T = 25°C + 0.3x = 25°C + 22.5°C = \underline{47.5°C}$

As indicated on the graph, at $I_F = 10\mu A$, $T_C = -2.3 mV/°C$ while at $I_F = 100 mA$, $T_C = -0.2 mV/°C$

therefore, the larger temperature coefficients occur at the lower current levels.

6. At $V_R = 0V$, $C_T \cong 1pF$; At $V_R = 2V$, $C_T \cong 0.67pF$

the magnitude of the change:

$$\left|\frac{1-0.67}{1}\right| \times 100\% \Rightarrow \underline{33\%}$$

At $V_R = 8V$, $C_T \cong 0.37pF$; At $V_R = 10V$, $C_T \cong 0.35pF$

The magnitude of the change:

$$\left|\frac{0.37-0.35}{0.37}\right| \times 100\% \Rightarrow \underline{5.4\%}$$

$33\% : 5.4\% = 6.1:1$ which is a significant difference in sensitivity to change in voltage.

8. a. At $-3V$, $C = \underline{40pF}$

At $-12V$, $C = \underline{20pF}$

$\Delta C = 40pF - 20pF = \underline{20pF}$

b. At $-8V$, $\frac{\Delta C}{\Delta V_R} = \frac{40pF}{20V} = \underline{2pF/V}$

At $-2V$, $\frac{\Delta C}{\Delta V_R} = \frac{60pF}{9V} = \underline{6.67pF/V}$

$\frac{\Delta C}{\Delta V_R}$ increases at less negative values of $V_R$.

10. $C(3V) = 30pF$ $\quad C_3/C_{25} = \frac{30pF}{5pF} = \underline{6}$

$C(25V) = 5pF$

| | min | Typ. | Max |
|---|---|---|---|
| Fig. 20.9: $C_3/C_{25}$ | 5.0 | 5.7 | 6.5 |

Center of Typical values —

12. Greatest change in capacitance per volt appears to be between 0 and 2-3 volts of reverse bias voltage

$\Delta C(0-2V) \cong 25pF$

$\Delta C(5-10V) \cong 10pF$

14. High power diodes have a higher forward voltage drop than low current devices due to larger IR drops across the bulk and contact resistances of the diode. The higher voltage drops result in higher power dissipation levels for the diodes which in turn may require the use of heat sinks to draw the heat away from the body of the structure.

16. At 1 MHz: $X_C = \dfrac{1}{2\pi f C} = \dfrac{1}{2\pi(1\times10^6\,Hz)(5\times10^{-12}F)}$

$= \underline{31.83k\Omega}$

At 100 MHz: $X_C = \dfrac{1}{2\pi(100\times10^6 Hz)(5\times10^{-12}F)}$

$= \underline{318.3\Omega}$

At 1 MHz: $X_{L_s} = 2\pi f L = 2\pi(1\times10^6 Hz)(6\times10^{-9}H)$

$= \underline{0.0377\Omega}$

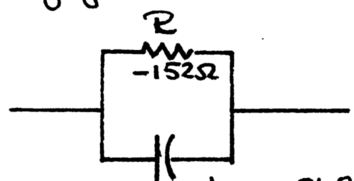
At 100 MHz: $X_{L_s} = 2\pi(100\times10^6 Hz)(6\times10^{-9}H)$

$= \underline{3.769\Omega}$

$L_s$ effect is negligible!

R+C in parallel:

f = 1 MHz




$X_C = \dfrac{1}{2\pi f C} = 31.83k\Omega$

$$Z_T = \frac{(152\angle 180^\circ)(31.83k\Omega\angle -90^\circ)}{-152 - j31.83k\Omega}$$

$= \underline{-152.05\angle 0.27^\circ} \;\; \underline{\cong -152\angle 0^\circ}$

f = 100 MHz

$$Z_T = \frac{(152\angle 180^\circ)(318.3\angle -90^\circ)}{-152 - j318.3}$$

$= -137.16\angle \underline{25.52} \neq -152\angle 0^\circ$

At very high frequencies $X_C$ has some impact!

18. At $V_T = 0.1V$,

$I_F \cong 5.5mA$

At $V_T = 0.3V$

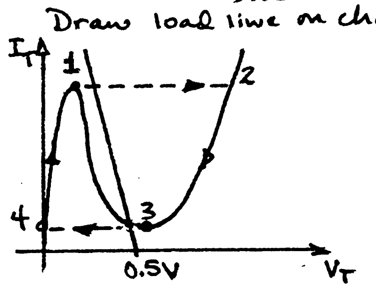
$I_F \cong 2.3mA$

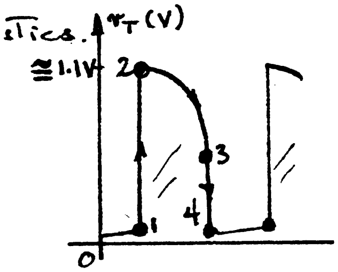
$$R = \frac{\Delta V}{\Delta I} = \frac{0.3V - 0.1V}{2.3mA - 5.5mA}$$

$$= \frac{0.2V}{-3.2mA} = \underline{-62.5\Omega}$$

20. $I_{sat} = \dfrac{E}{R} = \dfrac{0.5V}{51\Omega} = 9.8mA$

Draw load line on characteristics.



22. $W = hf = h\frac{v}{\lambda} = \frac{(6.624\times10^{-34}\,J\cdot s)(3\times10^{8}\,m/s)}{(5000)(10^{-10}\,m)}$

$= \underline{3.97\times10^{-19}\,J}$

$3.97\times10^{-19}\,\cancel{J}\left[\frac{1\,eV}{1.6\times10^{-19}\,\cancel{J}}\right] = \underline{2.48\,eV}$

24. $\frac{4\times10^{-9}\,W/m^2}{1.609\times10^{-12}} = 2{,}486\,fc$

From the intersection of $V_\lambda = 30V$ and $2{,}486\,fc$ we find

$I_\lambda \cong \underline{440\,\mu A}$

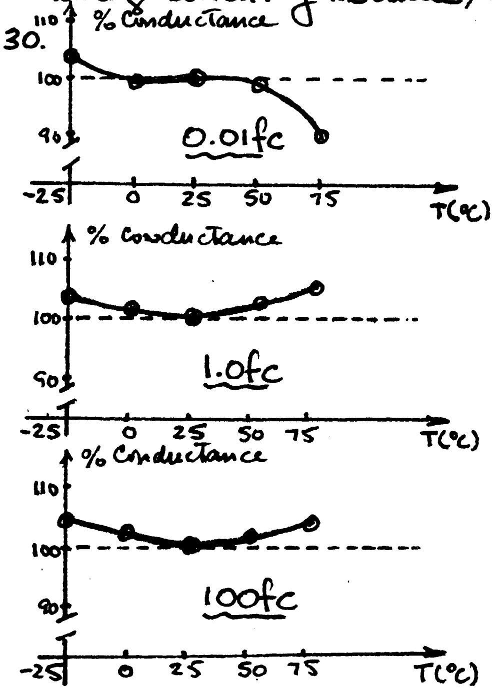
26. Note that $V_\lambda$ is given and not V

At the intersection of $V_\lambda = 25V$ and $3000\,fc$ we find $I_\lambda \cong 500\,\mu A$

$V_R = I_\lambda R = (500\times10^{-6}A)(100\times10^{3}\Omega) = \underline{50V}$

28. The "dark current" of a photodiode is the diode current level when no light is striking the diode. It is essentially the reverse saturation leakage current of the diode, comprised mainly of minority carriers.

30.



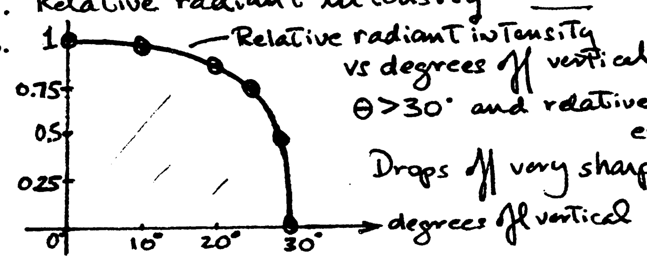

Except for low illumination levels (0.01fc) the % conductance curves appear above the 100% level for the range of temperature. In addition, it is interesting to note that for other than the low illumination levels the % conductance is higher above and below room temperature (25°C). In general, the % conductance level is not adversely affected by temperature for the illumination levels examined.

32. The highest % sensitivity occurs between 5250 Å and 5750 Å. Fig. 20.20 reveals that the CdS unit would be most sensitive to yellow.

The % sensitivity of the CdS unit of Fig. 20.30 is at the 30% level for the range 4800 Å → 7000 Å. This range includes green, yellow and orange in Fig. 20.20.

34. a. Relative radiant intensity $\cong \underline{0.8}$

b.




θ>30° and relative radiant intensity essentially zero

Drops off very sharply after 25°!

36. 6, 7, 8

38. The LED generates a light source in response to the application of an electric voltage. The LCD depends on ambient light to utilize the change in either reflectivity or transmissivity caused by the application of an electric voltage.

40. $$\eta\% = \frac{P_{max}}{(A_{cm^2})(100\,mW/cm^2)} \times 100\%$$

$$9\% = \frac{P_{max}}{(2\,cm^2)(100\,mW/cm^2)} \times 100\%$$

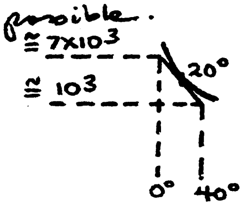
$$P_{max} = \underline{18\,mW}$$

42. a. Fig. 20.48 $\Rightarrow$ $\underline{79\,mW/cm^2}$

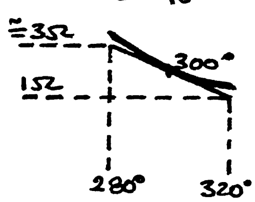
b. It is the maximum power density available at sea level.

c. Fig. 20.48 $\cong$ $\underline{12.7\,mA}$

44. Since log scales are present, the differentials must be as small as possible.




$$\frac{\Delta R}{\Delta T} = \frac{(7000-1000)\Omega}{(40-0)^\circ} = \frac{6000\Omega}{40^\circ} \cong \underline{150\Omega/^\circ C}$$




$$\frac{\Delta R}{\Delta T} = \frac{(3-1)\Omega}{40^\circ} = \frac{2\Omega}{40^\circ} = 0.05\Omega/^\circ C$$

From the above $150\Omega/^\circ C : 0.05\Omega/^\circ C = 3000:1$
therefore, the highest rate of change occurs at lower temperatures such as 20°C.

46. a. $\cong 10^{-5}A = \underline{10\,\mu A}$

b. Power $\cong \underline{0.1\,mW}$, $R \cong 10^7\Omega = \underline{10\,M\Omega}$

c. Log scale $\cong \underline{0.3\,mW}$

Chapter 21(Odd)

1. -
3. -
5. a. Yes
   b. No
   c. No. As noted in Fig. 21.8b the minimum gate voltage required to trigger all units is 3V.
   d. $V_G$ = 6V, $I_G$ = 800mA is a good choice(Center of preferred firing area).
   $V_G$ = 4V, $I_G$ = 1.6A is less preferable due to higher power dissipation in the gate. Not in preferred firing area.
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.
9. —
11. a. $\cong 0.7\text{mW/cm}^2$
   b. $0°C \rightarrow 0.82\text{mW/cm}^2$
   $100°C \rightarrow 0.16\text{mW/cm}^2$
   $\frac{0.82-0.16}{0.82} \times 100\% \cong \underline{80.5\%}$
13. —
15. —
17. a. $\eta = \left.\frac{R_{B_1}}{R_{B_1}+R_{B_2}}\right|_{I_E=0} \Rightarrow 0.65 = \frac{2k\Omega}{2k\Omega + R_{B_2}}$ $\quad R_{B_2} = \underline{1.08k\Omega}$
   b. $R_{BB} = (R_{B_1}+R_{B_2})|_{I_E=0} = 2k\Omega + 1.08k\Omega = \underline{3.08k\Omega}$
   c. $V_{R_{B_1}} = \eta V_{BB} = 0.65(20V) = \underline{13V}$
   d. $V_P = \eta V_{BB} + V_D = 13V + 0.7V = \underline{13.7V}$
19. $I_B = \underline{25\mu A}$
   $I_C = h_{fe} I_B = (40)(25\mu A) = \underline{1mA}$
21. a. $D_F = \frac{\Delta I}{\Delta T}$
   $= \frac{0.95 - 0}{25-(-50)} = \frac{0.95}{75} = \underline{1.26\%/°C}$
   b. Yes, curve flattens after 25°C.
23. $\frac{I_o}{I_i} = \frac{I_C}{I_F} = \frac{20mA}{\cong 45mA} = \underline{0.44}$
   Yes, relatively efficient
25. a. $I_C \geq \underline{3mA}$
   b. At $I_C$ = 6mA; $R_L = 1k\Omega$, $t = 8.6\mu s$
   $R_L = 100\Omega$, $t = 2\mu s$
   $1k\Omega : 100\Omega = 10:1$
   $8.6\mu s : 2\mu s = 4.3:1$
   $\Delta R : \Delta t \cong \underline{2.3:1}$
27. $V_P = 8.7V$, $I_P = 100\mu A$ $\qquad Z_P = \frac{V_P}{I_P} = \frac{8.7V}{100\mu A} = \underline{87k\Omega}$ ($\cong$ open)

$V_V = 1\text{V}$, $I_V = 5.5\text{mA}$ $\qquad Z_V = \dfrac{V_V}{I_V} = \dfrac{1\text{V}}{5.5\text{mA}} = 181.8\Omega$ (relatively low)

$87\text{k}\Omega : 181.8\Omega = 478.55:1 \cong \underline{500:1}$

29. a. Minimum $V_{BB}$:

$$R_{max} = \frac{V_{BB} - V_P}{I_P} \geq 20\text{k}\Omega$$

$$\frac{V_{BB} - (\eta V_{BB} + V_D)}{I_P} = 20\text{k}\Omega$$

$$V_{BB} - \eta V_{BB} - V_D = I_P 20\text{k}\Omega$$

$$V_{BB}(1-\eta) = I_P 20\text{k}\Omega + V_D$$

$$V_{BB} = \frac{I_P 20\text{k}\Omega + V_D}{1-\eta}$$

$$= \frac{(100\mu\text{A})(20\text{k}\Omega) + 0.7\text{V}}{1-0.67}$$

$$= \underline{8.18\text{V}}$$

10V $\underline{\text{ok}}$

b. $R < \dfrac{V_{BB} - V_V}{I_V} = \dfrac{12\text{V} - 1\text{V}}{5.5\text{mA}} = 2\text{k}\Omega$

$R < \underline{2\text{k}\Omega}$

c. $T \cong RC \log_e\left(1 + \dfrac{R_{B_1}}{R_{B_2}}\right)$

$$2\times10^{-3} = R(1\times10^{-6}) \log_e\underbrace{\left(1 + \frac{10\text{k}\Omega}{5\text{k}\Omega}\right)}_{\log_e 3 = 1.0986}$$

$$R = \frac{2\times10^{-3}}{(1\times10^{-6})(1.0986)}$$

$$R = \underline{1.82\text{k}\Omega}$$

Chapter 21 (Even)

2. –

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.

6. In the conduction state, the SCR has characteristics very similar to those of a p-n junction diode (where $V_T \cong 0.7V$).

8. a. $V_p = \left(\frac{V_{sec(rms)}}{2}\right)\sqrt{2}$

$= \frac{117V}{2}(\sqrt{2}) = 82.78V$

$V_{DC} = 0.636(82.78V)$

$= \underline{52.65V}$

b. $V_{AK} = V_{DC} - V_{BAT} = 52.65V - 11V = \underline{41.65V}$

c. $V_R = V_Z + V_{GK}$

$= 11V + 3V$

$= 14V$

At 14V, $SCR_2$ conducts and stops the charging process.

d. At least 3V to turn on $SCR_2$

e. $V_2 \cong \frac{1}{2}V_p = \frac{1}{2}(82.78V) = \underline{41.39V}$

10. a. Charge toward 200V but will be limited by the development of a negative voltage $V_{GK}$ ($= V_Z - V_{C_1}$) that will eventually turn the GTO off.

b. $\tau = R_3C_1 = (20k\Omega)(0.1\mu F)$

$= 2ms$

$5\tau = \underline{10ms}$

c. $5\tau' = \frac{1}{2}(5\tau) = 5ms = 5 R_{GTO}C_1$

$R_{GTO} = \frac{5ms}{5C_1} = \frac{5ms}{5(0.1\times10^{-6}F)} = \underline{10k\Omega}$ $\left(= \frac{1}{2}(20k\Omega - \text{above})\right)$

12. $V_C = V_{BR} + V_{GK} = 6V + 3V = 9V$

$V_C = 40(1 - e^{-t/RC}) = 9$

$40 - 40e^{-t/RC} = 9$

$40e^{-t/RC} = 31$

$e^{-t/RC} = 31/40 = 0.775$

$RC = (10\times10^3\Omega)(0.2\times10^{-6}F) = 2\times10^{-3}s$

$\log_e(e^{-t/RC}) = \log_e 0.775$

$-t/RC = -t/2\times10^{-3} = -0.255$

and $t = 0.255(2\times10^{-3}) = \underline{0.51ms}$

14. $V_{BR_1} = V_{BR_2} \pm 10\% V_{BR_2}$

$= 6.4V \pm 0.64V \Rightarrow \underline{5.76V \rightarrow 7.04V}$

16. $\dfrac{V - V_P}{I_P} > R_1$

$\dfrac{40V - [0.6(40V) + 0.7V]}{10\times10^{-6}} = \underline{1.53M\Omega} > R_1$

$\dfrac{V - V_V}{I_V} < R_1 \Rightarrow \dfrac{40V - 1V}{8\ mA} = 4.875k\Omega < R_1$

$\therefore \quad \underline{1.53M\Omega > R_1 > 4.875k\Omega}$

18. a. $\eta = \left.\dfrac{R_{B_1}}{R_{BB}}\right|_{I_E=0}$

$0.55 = \dfrac{R_{B_1}}{10k\Omega}$

$R_{B_1} = \underline{5.5k\Omega}$

$R_{BB} = R_{B_1} + R_{B_2}$

$10k\Omega = 5.5k\Omega + R_{B_2}$

$R_{B_2} = \underline{4.5k\Omega}$

b. $V_P = \eta V_{BB} + V_D = (0.55)(20V) + 0.7V = \underline{11.7V}$

c. $R_1 < \dfrac{V - V_P}{I_P} = \dfrac{20V - 11.7V}{50\mu A} = 166k\Omega$

OK : $68k\Omega < 166k\Omega$

d. $t_1 = R_1 C \log_e \dfrac{V - V_V}{V - V_P} = (68\times10^3)(0.1\times10^{-6}) \log_e \dfrac{18.8}{8.3} = 5.56ms$

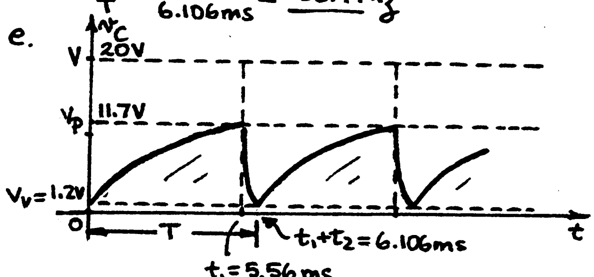
$t_2 = (R_{B_1} + R_2) C \log_e \dfrac{V_P}{V_V} = (0.2k\Omega + 2.2k\Omega)(0.1\times10^{-6}) \log_e \dfrac{11.7}{1.2}$

$= 0.546ms$

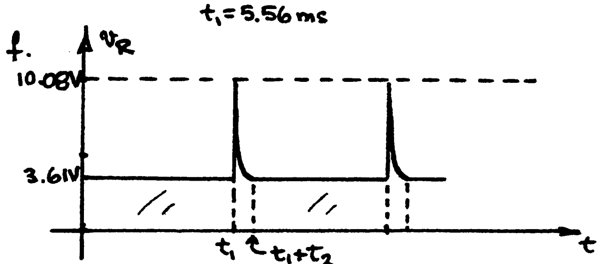
$T = t_1 + t_2 = 6.106ms$

$f = \dfrac{1}{T} = \dfrac{1}{6.106ms} = \underline{163.77Hz}$

e.




f.




$V_{R_2} = \dfrac{R_2 V}{R_2 + R_{BB}} = \dfrac{2.2k\Omega(20V)}{2.2k\Omega + 10k\Omega}$

$= 3.61V$

$V_{R_2} \cong \dfrac{R_2 (V_P - 0.7V)}{R_2 + R_{B_1}}$

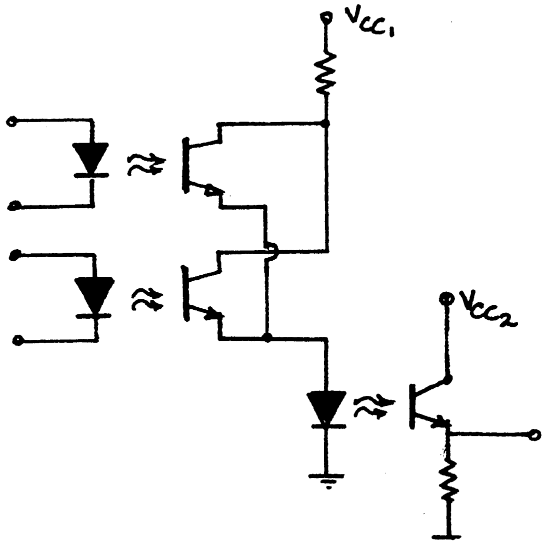
$= \dfrac{2.2k\Omega(11.7V - 0.7V)}{2.2k\Omega + 0.2k\Omega}$

$= \underline{10.08V}$

g. $f \cong \dfrac{1}{R_1 C \log_e(1/(1-\eta))} = \dfrac{1}{(6.8k\Omega)(0.1\mu F)\log_e 2.22} = \underline{184.16Hz}$

difference in frequency levels partly due to the fact that $t_2 \cong 10\%$ of $t_1$.

20.




22. a. At 25°C $I_{CEO} \cong 2nA$

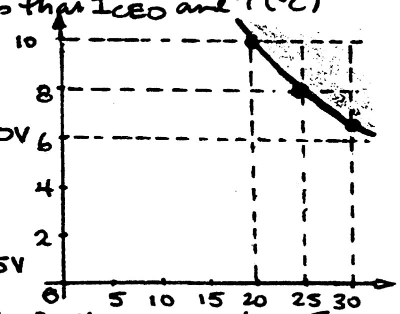
At 50°C $I_{CEO} \cong 30nA$

$$\frac{\Delta I_{CEO}}{\Delta T} = \frac{(30-2)\times 10^{-9}A}{(50-25)°C} = \frac{28nA}{25°C} = 1.12nA/°C$$

$$I_{CEO}(35°C) = I_{CEO}(25°C) + (1.12nA/°C)(35°C-25°C)$$
$$= 2nA + 11.2nA$$
$$= 13.2nA$$

From Fig. 21.55 $I_{CEO}(35°C) \cong 4nA$

Derating factors, therefore, cannot be defined for large regions of non-linear curves. Although the curve of Fig. 21.55 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.




24. a. $P_D = V_{CE}I_C = 200mW$

$$I_C = \frac{P_D}{V_{CE_{max}}} = \frac{200mW}{30V} = 6.67mA \text{ @ } V_{CE} = 30V$$

$$V_{CE} = \frac{P_D}{I_C} = \frac{200mW}{10mA} = 20V \text{ @ } I_C = 10mA$$

$$I_C = \frac{P_D}{V_{CE}} = \frac{200mW}{25V} = 8.0mA \text{ @ } V_{CE} = 25V$$

Almost the entire area of Fig. 21.57 falls within the power limits.

b. $\beta_{dc} = \frac{I_C}{I_F} = \frac{4mA}{10mA} = \underline{0.4}$, Fig. 21.56 $\frac{I_C}{I_F} \cong \frac{4mA}{10mA} = \underline{0.4}$

The fact that the $I_F$ characteristics of Fig. 21.57 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. 21.56 can be provided without any reference to the value of $V_{CE}$. As noted above, the results are essentially the same.

26. $\eta = \frac{3R_{B_2}}{3R_{B_2}+R_{B_2}} = \frac{3}{4} = \underline{0.75}$, $V_G = \eta V_{BB} = 0.75(20V) = \underline{15V}$

28. Eq. 21.23: $T = RC\log_e\left(\frac{V_{BB}}{V_{BB}-V_P}\right) = RC\log_e\left(\frac{V_{BB}}{V_{BB}-(\eta V_{BB}+V_D)}\right)$

Assuming $\eta V_{BB} >> V_D$ $T = RC\log_e\left(\frac{V_{BB}}{V_{BB}(1-\eta)}\right) = RC\log_e(1/1-\eta) = RC\log_e\left(\frac{1}{1-\frac{R_{B_1}}{R_{B_1}+R_{B_2}}}\right)$

$= RC\log_e\left(\frac{R_{B_1}+R_{B_2}}{R_{B_2}}\right) = \underline{RC\log_e(1+R_{B_1}/R_{B_2})}$ Eq. 21.24

# Solutions to Laboratory Experiments

**Prepared by Franz J. Monssen**

EXPERIMENT NO.1: OSCILLOSCOPE AND FUNCTION GENERATOR

PART 1

a. it focuses the beam on the screen
b. adjust the brightness of the beam on the screen
c. allows the moving of trace in either screen direction
d. selects volts/screen division on y-axis
e. unit of time/screen division on x-axis
f. selects
g. allows for ac or dc coupling of signal to scope and at GND position, establishes ground reference on screen
h. locates the trace if it is off screen
i. provide for the adjustment of scope from external reference source
j.
k. determines mode of triggering of the sweep voltage
l.
m. the input impedance of many scopes consists of the parallel combination of a 1 Meg resistance and a 30pf capacitor
n. measuring devices which reduces loading of scope on a circuit and effectively incrases input impedance of scope by a factor of 10.

Part 2: The function generator

d: T=1/f=1/1000Hz=1ms
e: (calculated): 1ms*[1cm/.2ms]=5cm
e: (measured):5cm=same
f: (calculated):1ms*[cm/.5ms]=2cm
f: (measured):2cm=same
g: (calculated): 1ms*[cm/1ms]=1cm
g: (measured): 1cm=same
h: .2ms/cm takes 5 boxes to display total wave
.5ms/cm takes 2 boxes to display total wave
1ms/cm takes 1 box to display total wave
i: 1. adjust timebase to obtain one cycle of the wave
2. count the number of cm's occupied by the wave
3. note the timebase setting
4. multiply timebase setting by number of cm's occupied by wave. This is equal to the period of the wave.
5. obtain its reciprocal; that's the frequency.

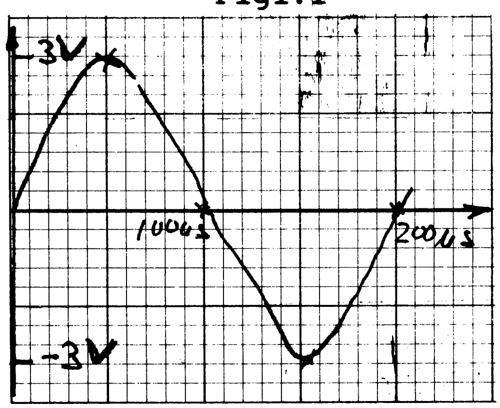
Part 3: Vertical sensitivity

j(calculated): 2cm*[2V/cm]=4Vp-p
k: 8*[.5V/cm]=4Vp-p
l: the signal occupied full screen; the peak amplitude did not change with a change in the setting of the vertical sensitivity
m: no: there is no voltmeter build into function generator

Part 3: Exercises

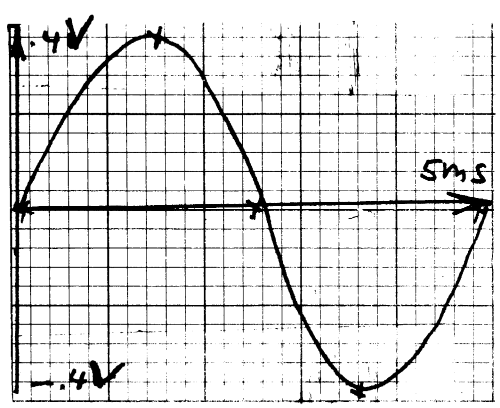
a: chosen sensitivities: Vert. Sens.=1V/cm
Hor. Sens.=50us/cm
T(calculated): 4cm*[50us/cm]= 200us

Fig1.1



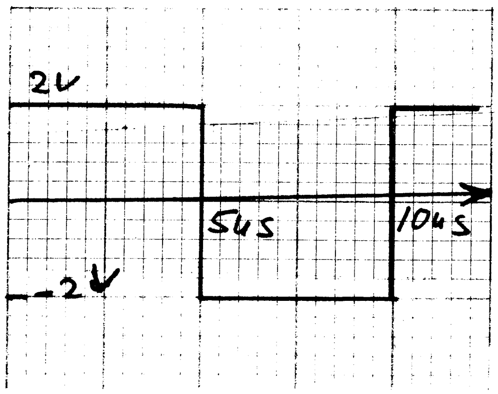

b: chosen sensitivities: Vert. Sens.=.1V/cm
Hor. Sens.= 1ms/cm
T(calculated):5cm*[1ms/cm]=5ms

Fig1.2



c: chosen sensitivities: Vert. Sens.=1v/cm
Hor. Sens.=1us/cm
T(calculated):10cm*[1us/cm]=10us

Fig1.3

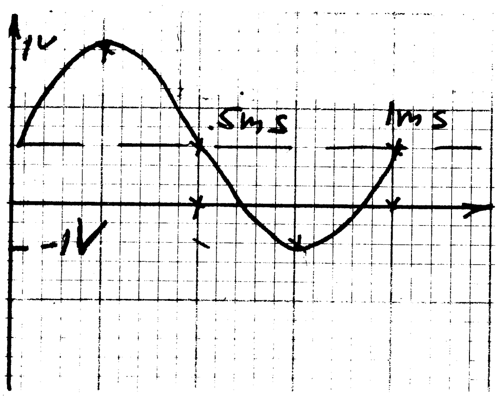



Part 4: Effect of DC Levels

a: $V_{(rms)}$ calculated:4V*1/2*.707=1.41 Volts
b: $V_{(rms)}$ measured=1.35 Volts
c: [(1.41-1.35)/1.41]*100=4.74%
d: no trace on screen
e: signal is restored, adjust zero level
f: no shift observed; the shift is proportional to dc value of waveform
g:(measured)dc level: 1.45 Volts

h:

Fig1.5

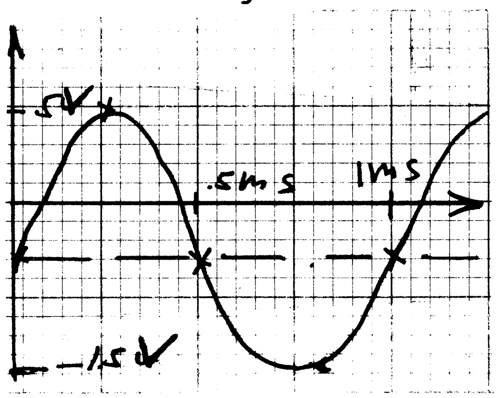



i: switch AC-GND-DC switch, make copy of waveform above
The vertical shift of the waveform was equal to the battery voltage.

The shape of the sinusoidal waveform was not affected by changing the positions of the AC-GND-DC coupling switch

j. The signal shifted downward by an amount equal to the voltage of the battery.

Fig1.6




PROBLEMS

1.

b: f=2000/(2*3.14)=318Hz
c: T=1/f=1/318=3.14ms
d: by inspection: V(peak)=20V
e: V(peak-peak)=2*Vpeak=40v
f: V(rms)=.707*20=14.1V
g: by inspection: Vdc=0V

2.

a: f=2*3.14*4000/(2*3.14*)=4KHz
c: T=1/f=1/4Khz=250us
d: by inspection:Vpeak)=8mV
e: V(peak-peak)=2*V(peak)=16mV
f: V(rms)=.707*8mV=5.66mV
g: by inspection: Vdc=0V

3. V(t)=1.7sin(2.51Kt) volts

EXPERIMENT NO.2: DIODE CHARACTERISTICS

Part 1:Diode Test
diode testing scale

Table 2.1

| Test | Si(mV) | Ge(mV) |
|---|---|---|
| Forward | 535 | 252 |
| Reverse | OL | OL |

Both diodes are in good working order.

Part 2. Forward-bias diode characteristics

b.

Table 2.3

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $V_R$(V) | .1 | .2 | .3 | .4 | .5 | .6 | .7 | .8 |
| $V_D$(V)mV | 453 | 481 | 498 | 512 | 528 | 532 | 539 | 546 |
| $I_D$mA | .1 | .2 | .3 | .4 | .5 | .6 | .7 | .8 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $V_R$(V) | .9 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| $V_D$(mV) | 551 | 559 | 580 | 610 | 620 | 630 | 640 | 650 | 650 | 660 | 660 |
| $I_D$(mA) | .9 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

d.

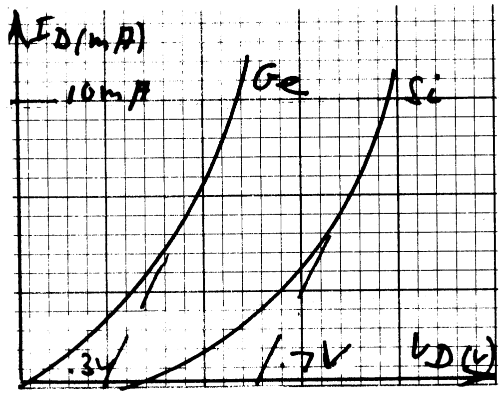
Table 2.4

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $V_R$(V) | .1 | .2 | .3 | .4 | .5 | .6 | .7 | .8 |
| $V_D$(mV) | 156 | 187 | 206 | 217 | 229 | 239 | 247 | 254 |
| $I_D$(mA) | .1 | .2 | .3 | .4 | .5 | .6 | .7 | .8 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $V_R$(V) | .9 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| $V_D$(mV) | 260 | 266 | 300 | 330 | 340 | 360 | 370 | 380 | 390 | 400 | 400 |
| $I_D$(mA) | .9 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

e.

Fig 2.5




f. Their shapes are similar, but for a given $I_D$, the potential $V_D$ is greater for the silicon diode compared to the germanium diode. Also, the Si has a higher firing potential than the germanium diode.

Part 3: Reverse Bias

b. $R_m$=9.9Mohms
$V_R$(measured) =9.1mV
$I_S$(calculated)=8.21nA

c. $V_R$(measured) =5.07mV
$I_S$(calculated)=4.58uA

d. the $I_S$ level of the germanium diode is approximately 500 times as large as that of the silicon diode.

e. $R_{DC}$(Si)=2.44*$10^9$ohms
$R_{DC}$(Ge)=3.28M*$10^6$ohms

These values are effective open-circuits when compared to resistors in the kilohm range

Part 4: DC Resistance

a.

Table 2.5

| $I_D$(mA) | $V_D$(mV) | $R_{DC}$(ohms) |
|---|---|---|
| .2 | 350 | 1750 |
| 1.0 | 559 | 559 |
| 5.0 | 630 | 126 |
| 10.0 | 660 | 66 |

b.

Table 2.6

| $I_D$(mA) | $V_D$(mV) | $R_{DC}$(ohms) |
|---|---|---|
| .2 | 80 | 400 |
| 1.0 | 180 | 180 |
| 5.0 | 340 | 68 |
| 10.0 | 400 | 40 |

Part 5: AC Resistance

a. (calculated) $r_{ac}$=3.4 ohms
b. (calculated) $r_{ac}$=2.9 ohms
c. (calculated) $r_{ac}$=27.0 ohms
d. (calculated) $r_{ac}$=26.0 ohms

Part 6: Firing Potential

$V_T$(silicon)=540mV
$V_T$(germanium)=260mV

Part 7: Temperature Effects

c. For an increase in temperature, the forward diode current will increase while the voltage $V_D$ across the diode will decline. Since $RD=V_D/I_D$, therefore, the resistance of a diode declines with increasing temperature.

d. As the temperature across a diode increases, so does the current. Therefore, relative to the diode current, the diode has a positive temperature coefficient.

## EXPERIMENT NO.3:SERIES & PARALLEL DIODE CONFIGURATIONS

Part 1: Threshold Voltage $V_T$

Fig 3.2
Firing voltage: Silicon: 595mV    Germanium: 310mV

Part 2: Series Configuration

b. $V_D$=.59 V
$V_O$(calculated)=5-.595=4.41V
$I_D$=4.41/2.2K=2mA

c. $V_D$(measured)=.59V
$V_O$(measured)=4.4V
$I_D$(from measured)=2mA

e. $V_D$=595mV
$V_O$(calculated)=(5-.595)1K/(1K+2.2K)=1.33V
$I_D$=1.36mA

f. $V_D$=.57V
$V_O$=1.36V
$I_D$(from measured)=1.36V/1K=1.36mA

g. $V_D$(measured)=5V
$V_O$(measured)=0V
$I_D$measured)=0A

h. $V_D$(measured)=5V
$V_O$(measured)=0V
$I_D$(measured)=0A

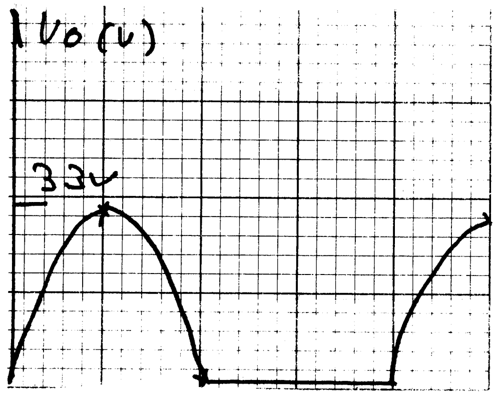
j. $V_1$(calculated)=.905V
$V_O$(calculated)=4.1V
$I_D$(calculated)=1.86mA

k.

## EXPERIMENT NO.4: HALF-WAVE AND FULL-WAVE RECTIFICATION

Part 1
a. $V_T$=.64V
b. Vertical sensitivity=1V/cm
Horizontal sensitivity=.2ms/cm

c. Fig 4.4



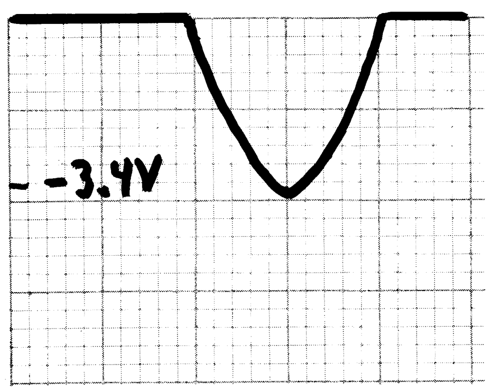

d. Both waveforms are in essential agreement.

e. $V_{dc}$=(4-.64)/3.14=1.07V

f. $V_{dc}$(measured)=.979V
%difference=(1.07-.979)/1.07*100=8.5%

g. For an ac voltage with a dc value, shifting the coupling switch from its DC to AC position will make the waveform shift down in proportion to the dc value of the waveform.

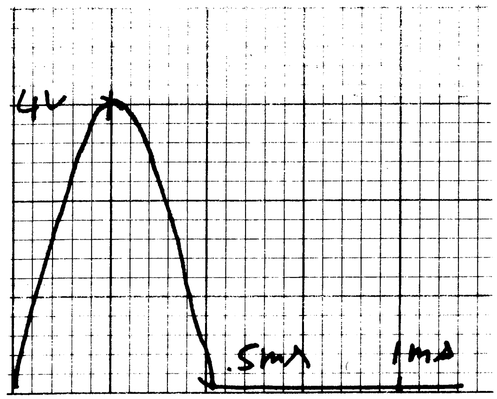
Fig 4.6



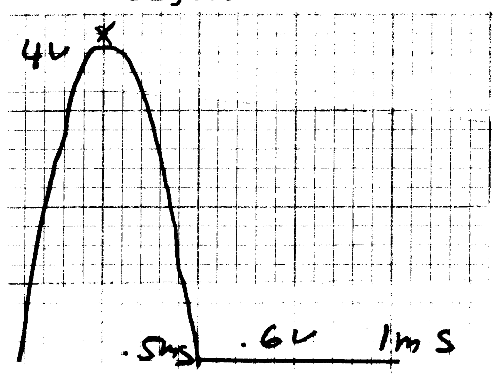

i. $V_{dc}$(calculated)=-1.07V
$V_{dc}$(measured) =-.970V

Part 3 Half-Wave Rectification(continued)

b. Fig 4.8




c. Fig4.9




the results are in reasonable agreement

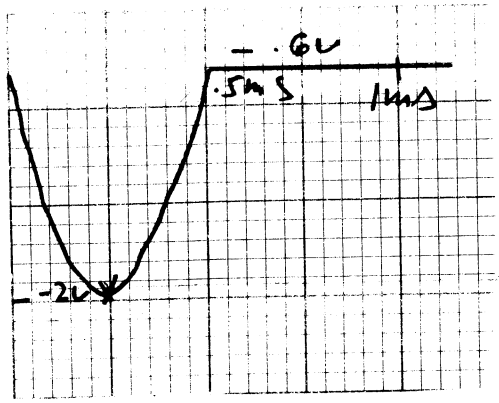
d. The significant difference is in the respective reversal of the two voltage waveforms. While in the former case the voltage peaked to a positive 3.4 volts, in the latter case, the voltage peaked negatively to the same voltage.

e. $V_{dc}$=(.318)*3.4=1.08Volts

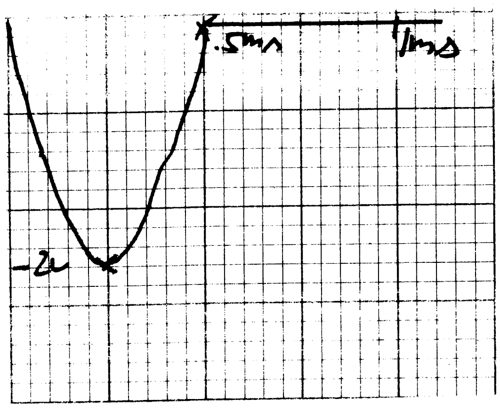
f. difference=[1.08-.979]/1.08*100=9.35%

Part 4: Half-Wave Rectification(continued)

b. Fig4.11

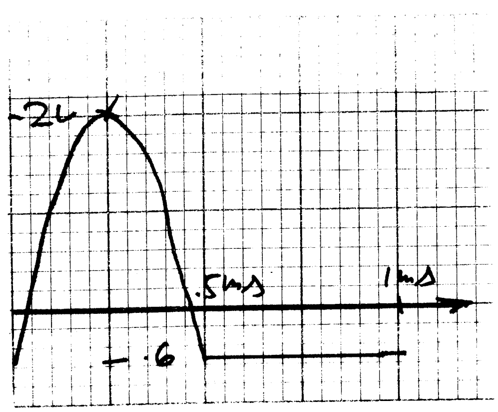



c. Fig4.12




There was a computed 2.1% difference between the two waveforms.

d. Fig4.13



We observe a reversal of the polarities of the two waveforms caused by the reversal of the diode in the circuit.

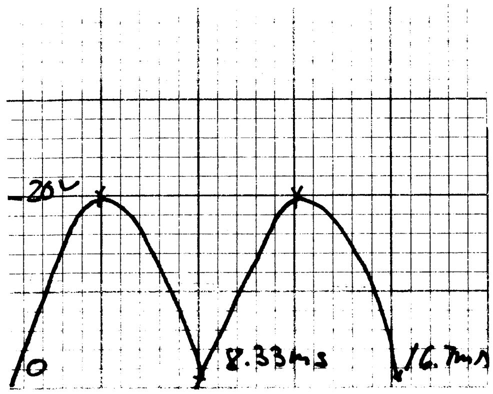
Part 5. Full-Wave Rectification(Bridge configuration)

a. $V_{(secondary)rms}$=14V

This value differs by 1.4V rms from the rated voltage of the secondary of the transformer

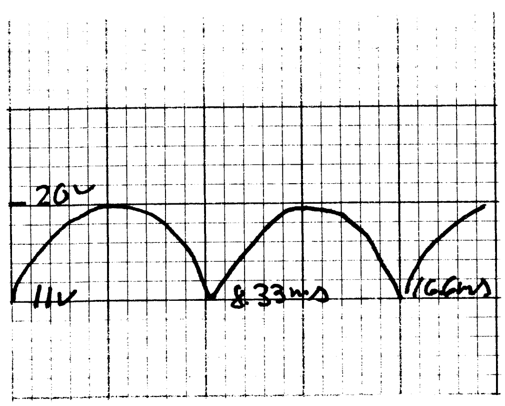
b. $V_{(peak)}$=1.41*14=20V

c. Fig 4.15




Vertical sensitivity: 5 V/cm
Horizontal sensitivity: 2ms/cm

d. Fig4.16

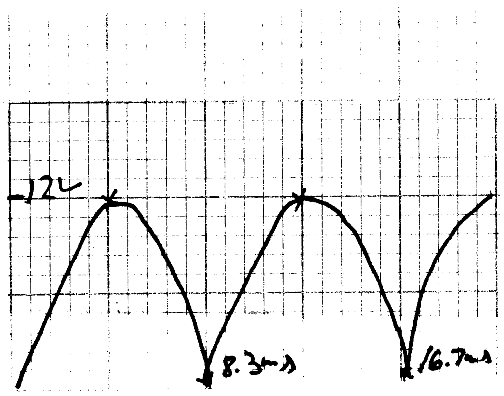


Again, the difference between expected and actual was very slight.

e. $V_{dc(calculated)} = (.6326)*(20) = 12.7V$
$V_{dc(measured)} = 11.36V$
% Difference = -10.6%

g. Vertical sensitivity=5V/cm
Horizontal sensitivity=2ms/cm

Fig4.17




i. $Vdc_{(calculated)} = (.636)*(12) = 7.63V$
$V_{dc(measuresd)} = 7.05V$
%Difference = -7.6%

l. The effect was a reduction in the dc level of the output voltage

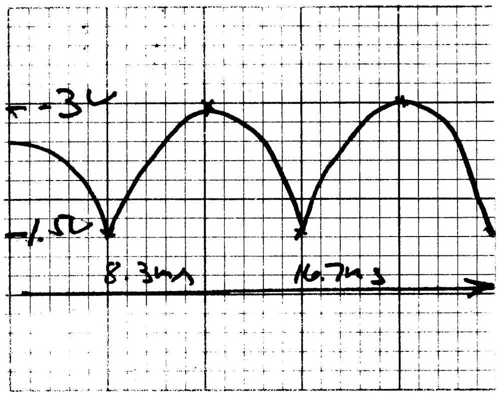
Part 6 Full-Wave Center-tapped Configuration

a. $V_{rms(measured)} = 6.93V$
$V_{rms(measured)} = 6.97V$

As is shown from the data, the difference for both halves of the center-taped windings from the rated voltage is .6volts.

b. Vertical sensitivity=5V/cm
   Horizontal sensitivity=2ms/cm

c. **Fig4.21**




d. $V_{dc(calculated)}$ =3.5v
   $V_{dc(measured)}$ =3.04V

EXPERIMENT 5:CLIPPING AND CLAMPING

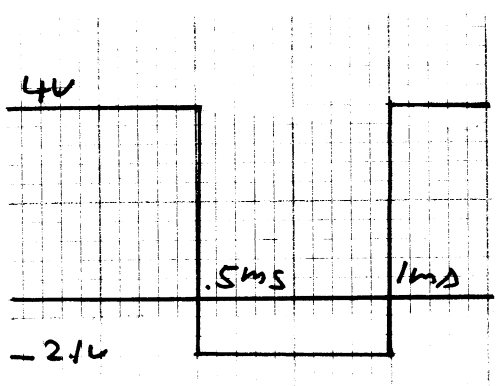
Part 1

$V_T$(Si)=.618V
$V_T$(Ge)=.299V

Part 2. Parallel Clippers

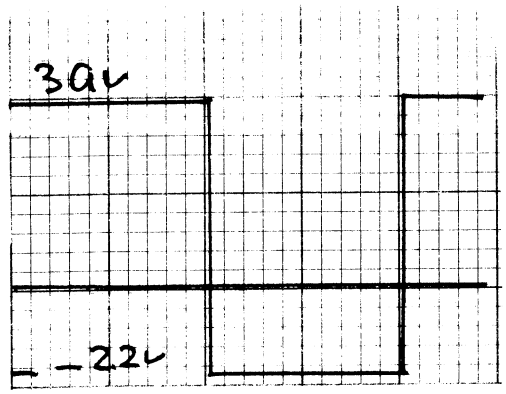
b. $V_O$(calculated)=4V
c. $V_O$(calculated)=-1.5-.618=-2.2V
d.

Fig.5.2



Vertical sensitivity=1V/cm
Horizontal sensitivity=.2ms/cm

e. Fig.5.3



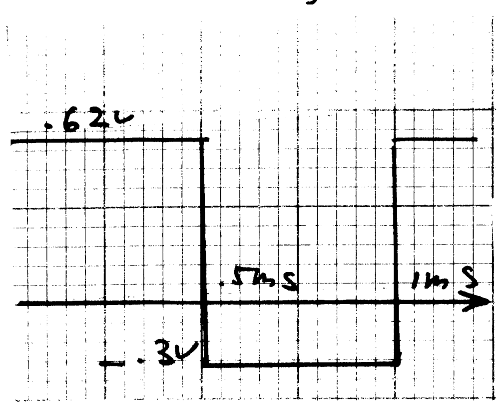

No measured differences appeared between expected and observed waveforms.

f. $V_O$(calculated)=4V
g. $V_O$(calculated)=.62V

Part 3 Parallel Clippers(continued)

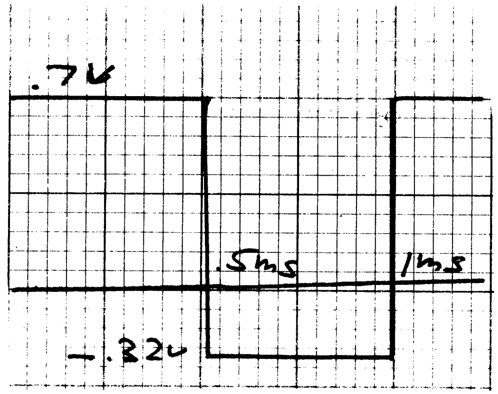
b. $V_O$(calculated=.61V
c. $V_O$(calculated)=.34V

d. Fig.5.7




Vertical sensitivity=1V/cm
Horizontal sensitivity=.2ms/cm

e. Fig.5.8

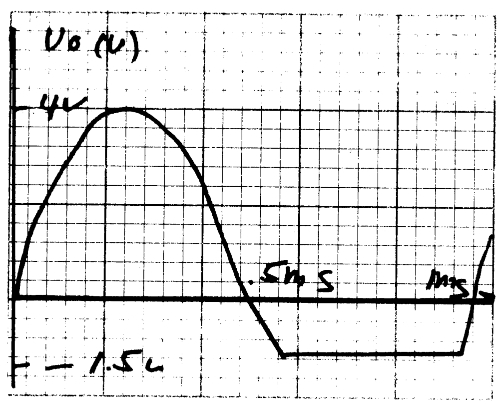



The waveforms agree

Part 4 Parallel Clippers(Sinusoidal Input)

b. $V_O$(calculated)=4V when $V_i$= 4V
$V_O$(calculated)=-2V when $V_i$=-4V
$V_O$(calculated)=0V when $V_i$= 0V

Fig.5.9

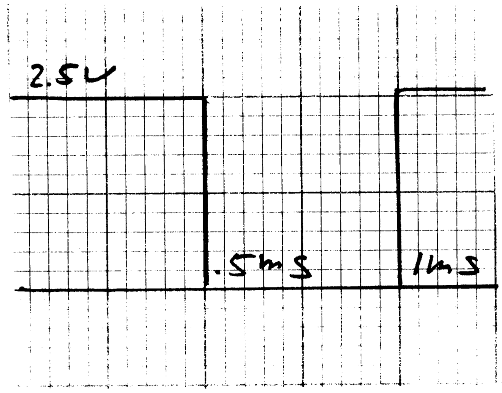



c. Waveforms agree within 6.5%

Part 5 Series Clippers

b. $V_O$(calculated)=2.5V when $V_i$=4V
c. $V_O$(calculated)=0v when $V_i$=0V

d. Fig.5.12

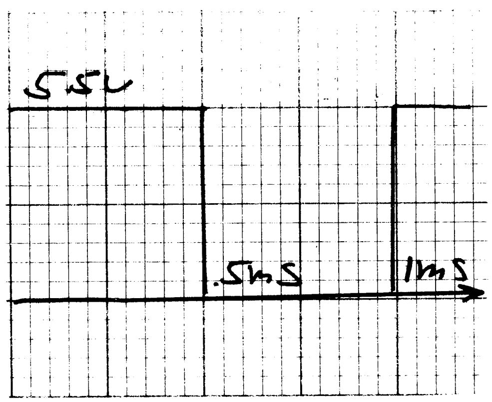



Vertical sensitivity=1V/cm
Horizontal sensitivity=.2ms/cm

e. agree within 5.1%

f. $V_O$(calculated)=5.5V when $V_i$=4V
g. $V_O$(calculated)=0V when $V_i$=-4V

h. Fig5.14



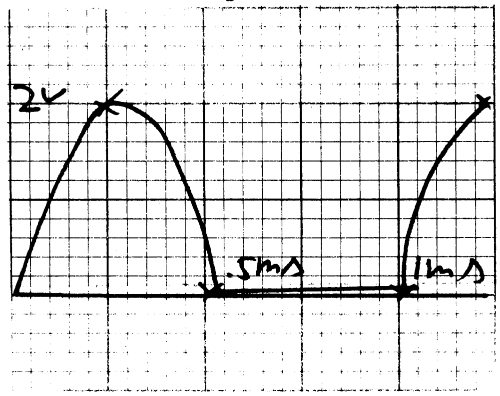

Vertical sensitivity=2V/cm
Horizontal sensitivity=.2ms/cm

i. no major differences

Part 6 Series Clippers(Sinusoidal Input)

b. $V_O$(calculated)=2V when $V_i$= 4V
$V_O$(calculated)=0V when $V_i$=-4V
$V_O$9(calculated)=0V when $V_i$= 0V

Fig.5.16




Vertical sensitivity=1V/cm
Horizontal sensitivity=.2ms/cm

## EXPERIMENT 6: CLAMPING CIRCUITS

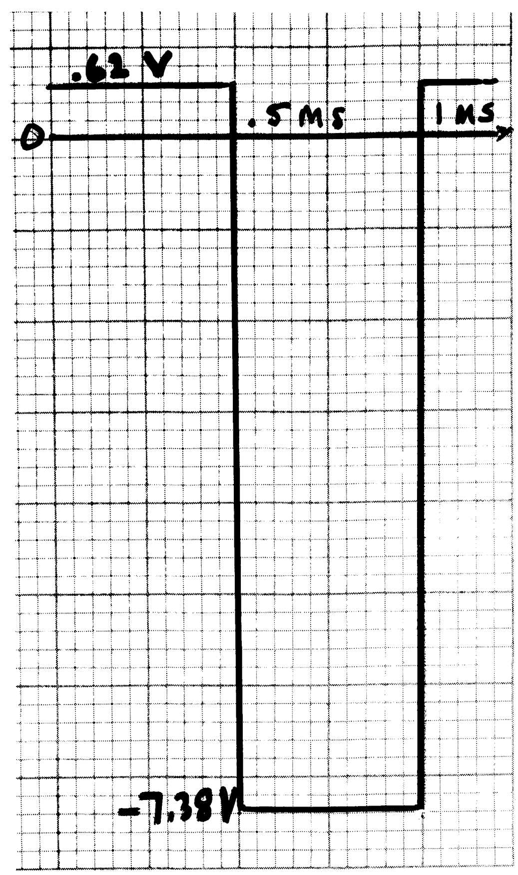
Part 1
$V_T$=.62V

Part 2

b. $V_C$(calculated)=4-0.62=3.38V
$V_O$(calculated)=0.62V

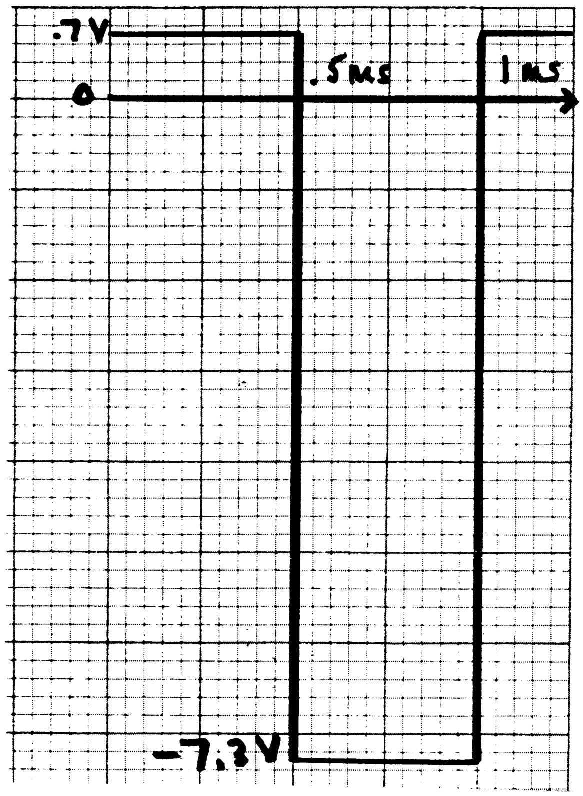
c. $V_O$(calculated)=-4-3.38V=-7.38V

d. Fig. 6.2



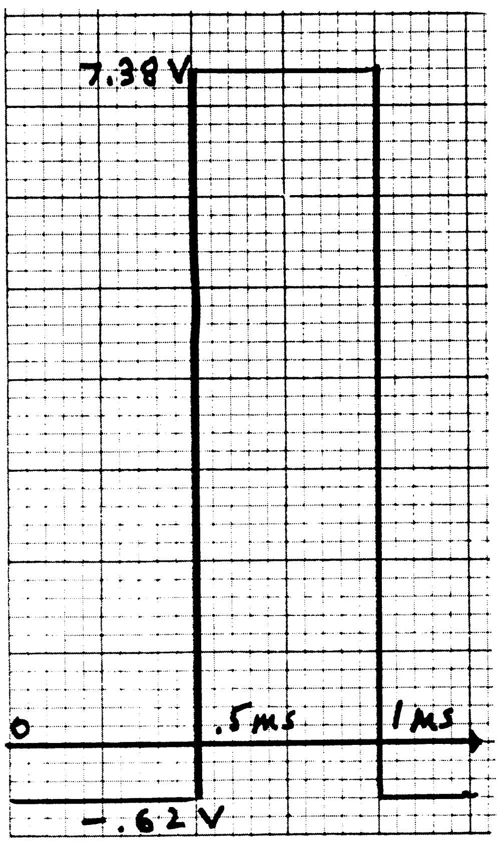

Vertical sensitivity=1V/cm
Horizontal sensitivity=.2ms/cm

e. Fig6.3



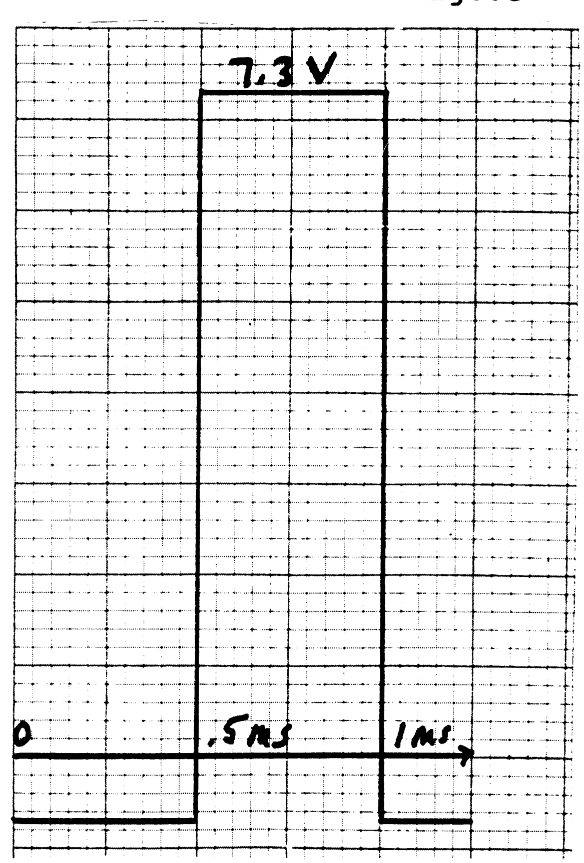

f. $V_C$(calculated)=-3.38
$V_O$(calculated)=-0.62V
g. $V_O$(calculated) =7.38V

h. Fig6.4




Vertical sensitivity =1V/cm
Horizontal senstivity+.2ms/cm

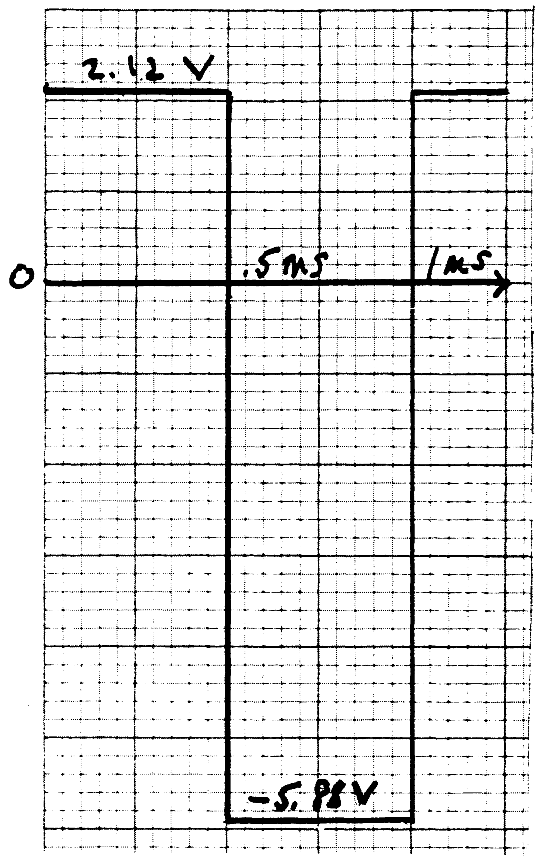
i. Fig6.5



Part 3 Clampers with a dc battery

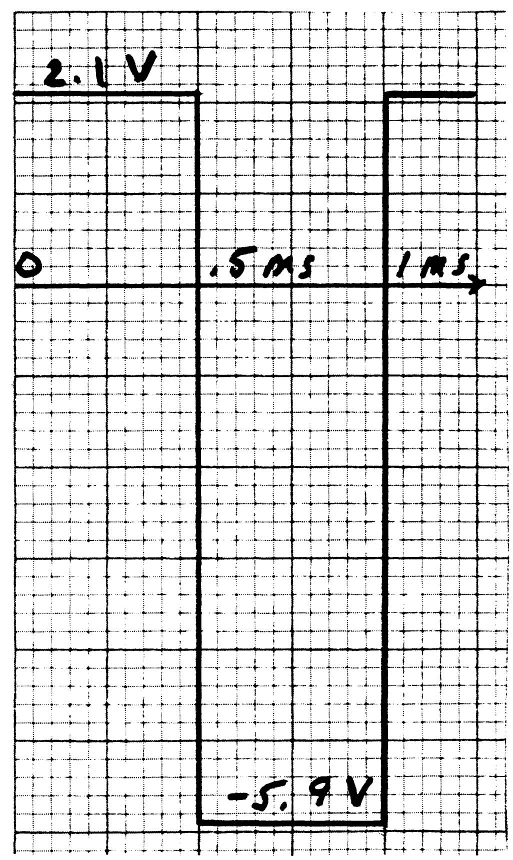
b. $V_C$(calculated)= 1.88V
$V_o$(calculated)=0.62V+1.5V=2.12V
c. $V_o$(calculated)=-1.88V-4V=-5.88V

d. Fig.6.7




Vertical sensitivity= 1V/cm
Horizontal sensitivity=.2ms/cm

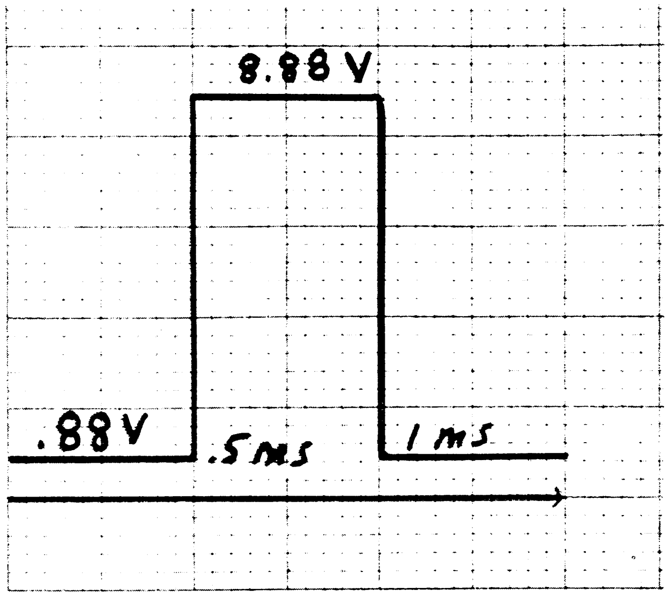
e. Fig.6.8




f. $V_C$(calculated)=4.88V
$V_o$(calculated)=1.5V-0.62V=0.88V

g. $V_o$(calculated)=4V+4.88V=8.88V

h. Fig.6.9

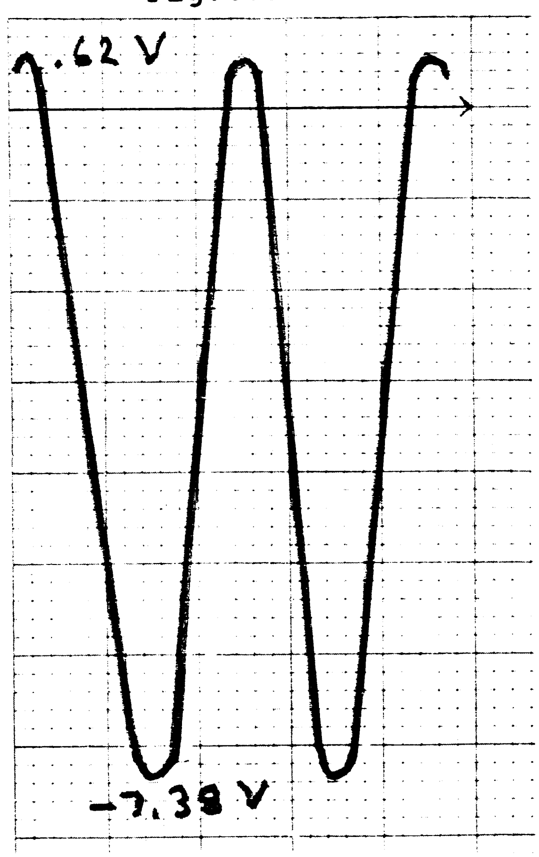



Vertical sensitivity= 2V/cm
Horizontal sensitivity= .2ms/cm

Part 4 Clampers(sinusoidal input)

b. $V_O$(calculated)= 0V when $V_i$=2V
$V_O$(calculated)=-2V when $V_i$=-3.6V
$V_O$(calculated)=-1.6V when $V_i$=0V

Fig.6.11



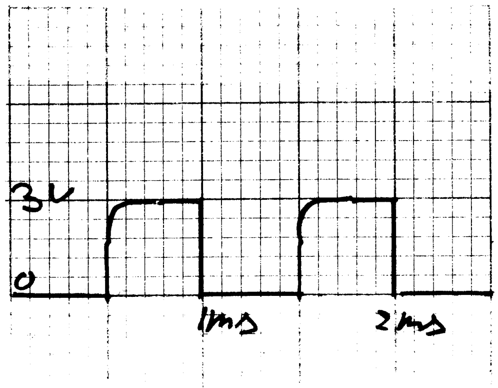

Vertical sensitivity =1V/cm
Horizontal sensitivity=.2ms/cm

Part 5 Clampers(Effect of R)

a.Tau(calculated)=R*C=103ms
b. T(calculated)=1/f=1ms
T/2(calculated)=1ms/2=.5ms
c. 5Tau(calculated)=5*103ms=515ms

d. otherwise the capacitor voltage will not remain constant
e. 5Tau(calculated)=5ms
f. 5ms/.5ms=10

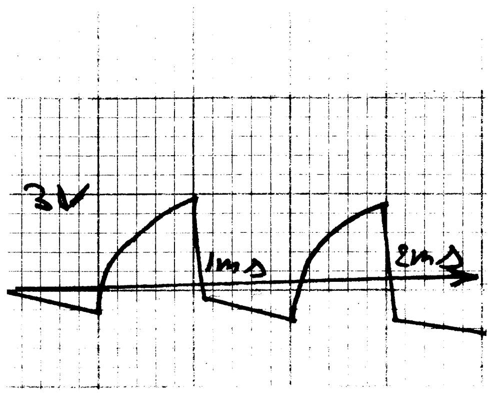
g. **Fig6.13**




Vertical sensitivity = 1V/cm
Horizontal sensitivity .2ms/cm

i. 5Tau=.5ms
j. .5ms/.5ms=1

k. **Fig6.14**




Vertical sensitivity=1V/cm
Horizontal sensitivity=.2ms/cm

m. 5Tau=2.5T or Tau=1/2T

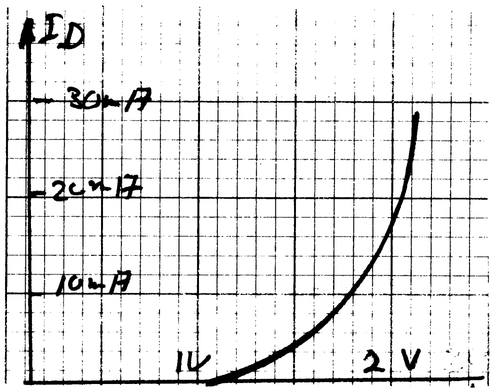
b. $V_{D(measured)}$=1.6V
$V_{R(measured)}$=49.1mV
$I_{D(calculated)}$=49.1mV/101.4ohms=484uA

c. $V_{D(measured)}$=1.9V
$V_{R(measured)}$=1.55V
$I_{D(calculated)}$=1.55V/101.4ohms=15.3mA

d.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| E(V) | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| VD(V) | 0 | 1 | 1.71 | 1.84 | 1.93 | 2.01 | 2.08 |
| VR(V) | 0 | 0 | .34 | 1.2 | 2.2 | 3.1 | 3.9 |
| ID=VR/R(mA) | 0 | 0 | 3.3 | 11.8 | 21.4 | 30.6 | 38.5 |

Fig7.2




h. The reversed biased Si diode prevents any current from flowing through the circuit, hence, the LED will not light.

k. $V_R$(V)=3.48V, therefore $I_D$(mA)=1.6mA and LED is in the "good brightness" region.

Part 2: Zener Diode Characteristics

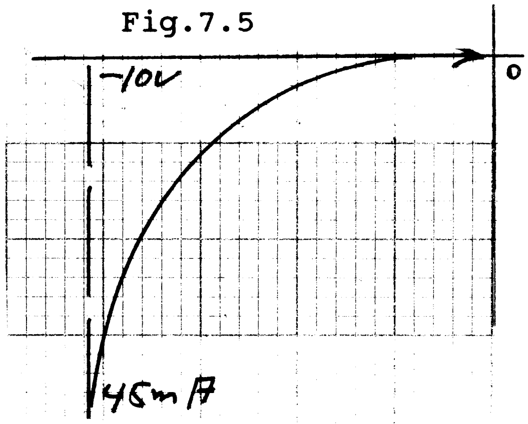
Table 7.2

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| E(V) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| $V_Z$(V) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| $V_R$(V) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | .1 | .97 |
| $I_Z$(mA) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | .99 | 9.6 |

Table 7.2 continued

| | | | | | |
|---|---|---|---|---|---|
| E(V) | 11 | 12 | 13 | 14 | 15 |
| $V_Z$(V) | 10 | 10.1 | 10.2 | 10.3 | 10.4 |
| $V_R$(V) | 1.9 | 2.8 | 3.7 | 4.6 | 4.6 |
| $I_Z$(mA) | 18.7 | 27.6 | 36.5 | 45.4 | 45.4 |

d. Fig.7.5




e. $V_Z(V)_{(approximated)}$= (10.4+9)/2=9.7V

f. $r_{av}$(ohms)=(10.4-9)/(.045-.0099)=39.9 ohms

g. $R_Z$(ohms)=39.9 ohms
$V_Z$(V)=9.7V

Part 3: Zener Diode Regulation

a. R(meas)=979 ohms
b. $R_L$(meas)=986 ohms
$V_Z$(V)=10.2V

$V_L$(V)=986*15/(979+986)=7.53V
$V_R$(V)=979*15/(979+986)=7.47V
$I_R$(mA)=7.47/979=7.64mA
$I_L$(mA)=7.53/986=7.63mA
$I_Z$(mA)=$I_R$-$I_L$=10uA

c. $V_{L(measured)}$=7.5V
$V_{R(measured)}$=7.49V
$I_{R(calculated)}$=7.65mA

$I_{L(calculated)}=7.60mA$
$I_{Z(calculated)}=50uA$

d. $V_{L(calculated)}=11.5V$
$V_{R(calculated)}=3.54V$
$I_{R(calculated)}=3.62mA$
$I_{L(calculated)}=3.48mA$
$I_{Z(calculated)}=.14mA$

e. $V_{L(measured)}=9.82V$
$V_{R(measured)}=3.54V$
$I_{R(calculated)}=3.54mA$
$I_{L(calculated)}=2.98mA$
$I_{Z(calculated)}=.56mA$

The difference is expressed as a percent with calculated value as the standard of reference.

percent change of: $V_L= -14.6\%$
$V_R= 0.\%$
$I_R= -2.21\%$
$I_L= -14.4\%$
$I_Z= 30.0\%$

f. $R_{min}/(R_{min}+979)*15=9.82V$
$R_{L(calculated)}=1.86Kohms$

g. Since 2.2Kohms>$R_{min}$=1.86Kohms, therefore, diode is in the "on" state.

Part 4: LED-Zener diode combination

b. $V_D=1.86V$
$I_D=15.8mA$
$V_Z=10.07V$
$V_{ab(calculated)}=11.9V$

c. $V_{L(calculated)}=11.9V$
$I_{L(calculated)}=5.41mA$

e. $E_{(calculated)}=V_R+V_L=6.93+11.9=18.9V$

f. $E_{(measured)}=19.1V$

The two values are in agreement within 1.06% using $E_{(calculated)}$ as reference.

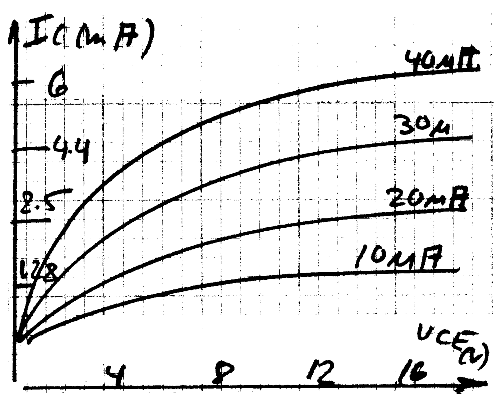
EXPERIMENT 8: BIPOLAR JUNCTION TRANSISTOR(BJT) CHARACTERISTICS

f.

| $V_{RB}$ V | $I_B$ uA | $V_{CE}$ V | $V_{RC}$ V | $I_C$ mA | $V_{BE}$ V | $I_E$ mA | ALPA | BETA |
|---|---|---|---|---|---|---|---|---|
| 3.3 | 10 | 2 | 1.18 | 1.21 | .65 | 1.22 | .99 | 124 |
| 3.3 | 10 | 4 | 1.19 | 1.22 | .65 | 1.23 | .99 | 125 |
| 3.3 | 10 | 6 | 1.21 | 1.24 | .65 | 1.25 | .99 | 125 |
| 3.3 | 10 | 8 | 1.22 | 1.24 | .65 | 1.26 | .99 | 125 |
| 3.3 | 10 | 10 | 1.23 | 1.26 | .65 | 1.27 | .99 | 125 |
| 3.3 | 10 | 12 | 1.25 | 1.28 | .65 | 1.28 | .99 | 125 |
| 3.3 | 10 | 14 | 1.26 | 1.29 | .65 | 1.29 | .99 | 125 |
| 3.3 | 10 | 16 | 1.27 | 1.30 | .65 | 1.31 | .99 | 125 |
| 6.6 | 20 | 2 | 2.39 | 2.45 | .65 | 2.46 | .99 | 125 |
| 6.6 | 20 | 4 | 2.42 | 2.48 | .65 | 2.49 | .99 | 125 |
| 6.6 | 20 | 6 | 2.45 | 2.51 | .65 | 2.49 | .99 | 125 |
| 6.6 | 20 | 8 | 2.48 | 2.54 | .65 | 2.55 | .99 | 127 |
| 6.6 | 20 | 10 | 2.52 | 2.58 | .65 | 2.59 | .99 | 127 |
| 6.6 | 20 | 12 | 2.56 | 2.62 | .65 | 2.63 | .99 | 127 |
| 6.6 | 20 | 14 | 2.59 | 2.65 | .66 | 2.66 | .99 | 127 |
| 9.9 | 30 | 2 | 4.28 | 4.38 | .66 | 4.39 | .99 | 138 |
| 9.9 | 30 | 4 | 4.31 | 4.41 | .66 | 4.42 | .99 | 144 |
| 9.9 | 30 | 6 | 4.36 | 4.46 | .69 | 4.47 | .99 | 149 |
| 9.9 | 30 | 8 | 4.41 | 4.51 | .69 | 4.52 | .99 | 149 |
| 9.9 | 30 | 10 | 4.48 | 4.59 | .69 | 4.60 | .99 | 150 |
| 13.2 | 40 | 2 | 5.82 | 5.96 | .69 | 5.97 | .99 | 152 |
| 13.2 | 40 | 4 | 5.94 | 6.08 | .69 | 6.09 | .99 | 152 |
| 13.2 | 40 | 6 | 6.01 | 6.15 | .69 | 6.16 | .99 | 154 |
| 13.2 | 40 | 8 | 6.17 | 6.32 | .69 | 6.33 | .99 | 153 |
| 16.5 | 50 | 2 | 7.20 | 7.37 | .70 | 7.38 | .99 | 147 |
| 16.5 | 50 | 4 | 7.33 | 7.50 | .70 | 7.51 | .99 | 150 |
| 16.5 | 50 | 6 | 7.48 | 7.66 | .70 | 7.67 | .99 | 153 |

i.

Fig8.3



Part 3: Variation of Alpha and Beta

b. the variations for Alpha and Beta for the tested transistor are not really significant, resulting in an almost ideal current source which is independent of the voltage $V_{CE}$.

c. The highest Beta's are found for relatively large values of $I_C$ and $V_{CE}$. This is a generally well known factor.

d. Beta did increase with increasing levels of $I_C$.

e. Beta did increase with increasing levels of $V_{CE}$.

Exercises

1.Beta(average)=141
The arithmetic average occurred in the center of Fig 8.3.

2. $V_{BE(average)}$=.678V
Given that .7V differs by only 3.14% from .678, and given that resistive circuit component can vary by as much as 20%, the assumption of a constant .7 V is entirely reasonable.

3. The Beta of the transistor is increasing. Table 8.3 does substantiate that conclusion.

4. Beta would be a constant anywhere along that line.

EXPERIMENT 9: FIXED AND VOLTAGE DIVIDER BIAS OF A BJT

Part 1

b. $V_{BE(measured)}$=.67V
$V_{RC(measured)}$=4.9V

c. $I_B=(V_{CC}-V_{BE})/R_B=(20-.67)/1.108M=17.4uA$
$I_C=V_{RC}/R_C=4.9/2.73K=1.79mA$

d. $Beta=I_C/I_B=1.79mA/17.4uA=105$

Part 2. Fixed-bias configuration

a. $I_{B(calculated)}$=17uA
$I_{C(calculated)}$=1.79mA

b. $V_{B(calculated)}=V_{CC}-I_B*R_B$=.67V
$V_{C(calculated)}=V_{CC}-I_C*R_C$=13.4V
$V_{E(calculated)}$=0V(emitter is at ground)
$V_{CE(calculated)}=V_C-V_E$=13.4V

c. $V_{B(measured)}$=.67V
$V_{C(measured)}$=13.4V
$V_{E(measured)}$=0V
$V_{CE(measured)}$=13.34V
the difference between measured and calculated values in every case is less than 10%. It's almost too good to be true.

d. $V_{BE(measured)}$=.68V
$V_{RC(measured)}$=16.7V
$I_{B(from\ measured)}$=17.4uA
$I_{C(from\ measured)}$=6.12mA
$Beta_{(calculated)}$=352

Table 9.1

| Transistor Type | $V_{CE}$(V) | $I_C$(mA) | $I_B$(uA) | Beta |
|---|---|---|---|---|
| 2N3904 | 13.34 | 1.79 | 17.4 | 105 |
| 2N4401 | 3.2 | 6.12 | 17.4 | 352 |

e.

Table 9.2

| % delta Beta | %delta $I_C$ | %delta $V_{CE}$ | %delta $I_B$ |
|---|---|---|---|
| 242 | 242 | -76.0 | 0 |

Part 3: Voltage-divider configuration

b.

Table 9.3

| 2N3904 | $V_B$(V) | $V_E$(V) | $V_C$(V) | $V_{CE}$(V) |
|---|---|---|---|---|
| (calculated) | 3.52 | 2.82 | 12.47 | 9.7 |
| (measured) | 3.3 | 2.6 | 12.9 | 10.1 |

Table 9.3 continued

| 2N3904 | $I_E$(mA) | $I_C$(mA) | $I_B$(uA) |
|---|---|---|---|
| (calculated) | 4.07 | 4.05 | 30 |
| (measured) | 3.76 | 3.87 | 36.5 |

c. The agreement between measured and calculated values fall entirely within reasonable limits.

d and e. Table 9.4

| Transistor type | $V_{CE}$(V) | $I_C$(mA) | IB(uA) | Beta |
|---|---|---|---|---|
| 2N3904 | 10.1 | 3.87 | 36.5 | 103 |
| 2N4401 | 9.6 | 4.03 | 17.2 | 234 |

f. Table 9.5

| %delta Beta | %delta $I_C$ | %delta $V_{CE}$ | %delta $I_B$ |
|---|---|---|---|
| 56 | 41 | 4.9 | 53 |

Problems and Exercises

1a. $I_{C(sat,fixed\ bias)}$=20/2.73K=7.33mA
1b. $I_{C(sat,volt\text{-}divider\ bias)}$=20/(1.86K+692)=7.83mA
1c. the saturation currents are not sensitive to the Beta's in either bias configuration.

2. In the case of the 2N4401 transistor, which had a higher Beta than the 2N3904 transistor, the Q point of the former shifted higher up the loadline toward saturation. (see data in Table 9.4)

3a. Table 9.6

| | $\frac{\text{\%delta } I_C}{\text{\%delta Beta}}$ | $\frac{\text{\%delta } V_CE}{\text{\%delta Beta}}$ | $\frac{\text{\%delta } I_B}{\text{\%delta Beta}}$ |
|---|---|---|---|
| Fixed bias | 1 | .314 | 0 |
| Volt-divider | .732 | .087 | .94 |

```
+-----------+------------+-------------+--------------+
```

The ideal circuit has Beta independence when the ratio of %delta$I_C$/%delta Beta is equal to 0. Thus, the smaller the ratio, the more Beta independent is the circuit. Using this as a criterion of stability, it becomes apparent that the voltage divider bias circuit is the more stable of the two.

4a. $I_C$=Beta($V_{CC}$-.67)/$R_B$ mA

4b. $I_C$= [$R_2$/($R_1$+$R_2$)*$V_{CC}$-.7]/[($R_1$//$R_2$)/BETA+$R_E$] mA

4c. In equation 4a, the Beta factor cannot be eliminated by a judicious choice of circuit components. In 4b however, if the quantity $R_1$//$R_2$/BETA is made much smaller than $R_E$, then $I_C$ is no longer dependent upon Beta. In particular:

$I_C$=[$R_2$/($R_1$+$R_2$)*$V_{CC}$-.7]/$R_E$ mA

In that case, we have achieved Beta independent biasing.

## EXPERIMENT 10:EMITTER AND COLLECTOR FEEDBACK BIAS OF BJT'S

Part1. Determination of Beta

b. $V_{B(measured)}$=5.04V
$V_{RC(measured)}$=4.04V
c. $I_{B(from\ measured)}$=(20-5.41)/1.1M=13.6uA
$I_{C(from\ measured)}$=4.04/2.2K=1.84mA
d. Beta=1.84mA/13.6uA=135

Part2. Emitter-bias configuration

a. Using KVL:

-20+$I_C$*(1.01M/BETA)+.67V+$I_C$*(2.23K)=0V
therefore: $I_C$=(20-.67)/9.1K=2.1mA
$I_B$=2.1mA/135=15uA

Table 10.1

| Calculated Values |
| --- |

| Transistor type | $V_B$(V) | $V_C$(V) | $V_E$(V) | $V_{BE}$(V) | $V_{CE}$(V) |
|---|---|---|---|---|---|
| 2N3904 | 5.4 | 15.3 | 4.7 | .70 | 10.6 |
| 2N4401 | 8.2 | 12.6 | 7.4 | .8 | 5.2 |

| Transistor type | $I_B$(uA) | $I_{C)}$ |
|---|---|---|
| 2N3904 | 15.0 | 2.1 |
| 2N4401 | 11.7 | 3.3 |

Measured Values

| Transistor type | VB(V) | $V_C$(V) | $V_E$(V) | $V_{BE}$(V) | $V_{CE}$(V) |
|---|---|---|---|---|---|
| 2N3904 | 4.75 | 15.9 | 4.2 | .66 | 11.8 |
| 2N4401 | 8.0 | 12.5 | 7.6 | .62 | 4.9 |

| Transistor type | $I_B$(uA) | $I_C$(mA) | Beta |
|---|---|---|---|
| 2N3904 | 14.7 | 2.2 | 150 |
| 2N4401 | 11.9 | 3.4 | 286 |

d. see Table 10.1

e. see Table 10.1

f. In every case, the difference between calculated and measured values were less than 10% apart.

g. Table 10.3

| %delta Beta | %delta $I_C$ | %delta $V_{CE}$ | %delta $I_B$ |
|---|---|---|---|
| 90.7 | 54.5 | -58.5 | -19 |

Part3: Collector Feedback Configuration(RE=0 ohms)

b. Using KVL:

-20+IC(3.2K)+IC(395K)/150+.7V=0V

from which: $I_B$=21uA and $I_C$=3.4mA

Table10.4

| Calculated Values |
|---|

| Transistor type | $V_B$(V) | $V_C$(V) | $V_{CE}$(V) | $I_B$(uA) | $I_C$(mA) |
|---|---|---|---|---|---|
| 2N3904 | .62 | 9.1 | 9.1 | 21.2 | 3.4 |
| 2N4401 | .55 | 6.2 | 6.2 | 14.4 | 4.3 |

Table 10.5

| Measured Values | | | | | |
|---|---|---|---|---|---|
| Transistor type | $V_B$(V) | $V_C$(V) | $V_{CE}$(V) | $I_B$(uA) | $I_C$(mA) |
| 2N3904 | .68 | 9.6 | 9.6 | 22.4 | 3.6 |
| 2N4401 | .63 | 5.8 | 5.8 | 15.1 | 4.4 |

Table 10.6

| %delta Beta | %delta $I_C$ | %delta $V_{CE}$ | %delta $I_B$ |
|---|---|---|---|
| 83 | 22.8 | -39.9 | -33 |

Part 4: Collector Feedback Configuration(with $R_E$)

a. for 2N3904:

$-20+I_C(3.2K)+I_C(395K/150)+I_C(2.2K)=0V$

from which: $I_B$=15uA and $I_C$=2.4mA

for 2N4401:

$-20+I_C(3.2K)+I_C(395K/286)+I_C(2.2K)=0V$

from which: IB=9.7uA and IC=2.8mA

b. see Table 10.7
c. see Table 10.8
d. see Table 10.7
e. see Table 10.8
f.

Table 10.7

| Calculated Values | | | | | | | |
|---|---|---|---|---|---|---|---|
| Transistor | $V_B$(V) | $V_C$(V) | $V_E$(V) | $V_{CE}$(V) | $I_C$(mA) | $I_E$(mA) | $I_B$(uA) |
| 2N3904 | 6.2 | 12.1 | 5.4 | 6.7 | 2.45 | 2.5 | 15 |
| 2N4401 | 6.9 | 10.8 | 6.3 | 4.5 | 2.8 | 2.9 | 9.7 |

Table 10.8

| Measured Values | | | | | | | |
|---|---|---|---|---|---|---|---|
| Transistor | $V_B$(V) | $V_C$(V) | $V_E$(V) | $V_{CE}$(V) | $I_C$(mA) | $I_E$(mA) | $I_B$(uA) |
| 2N3904 | 5.9 | 12.6 | 5.2 | 7.4 | 2.3 | 2.4 | 19 |
| 2N4401 | 7.0 | 10.8 | 6.5 | 4.3 | 2.8 | 2.9 | 9.2 |

Table 10.9

| %delta Beta | %delta $I_C$ | %delta $V_{CE}$ | %delta $I_B$ |
|---|---|---|---|
| 83.2 | 23.8 | -41.2 | -50.3 |

Problems and Exercises

1.
a. $I_{C(sat)}$=20/(2.2K+2.2K)=4.55mA
b. $I_{C(sat)}$=20/3K=6.67mA
c. $I_{C(sat)}$=20/5.2K=3.85mA
d. Beta does not enter into the calculations

2. The Q point shifts toward saturation along the loadline.

3.
a.

Table 10.10

| | | | |
|---|---|---|---|
| Emitter bias | %delta $I_C$ / %delta Beta | %delta $V_{CE}$ / %delta Beta | %delta $I_B$ / %delata Beta |

b. The smaller that ratio, the better is the Beta stability of a particular circuit. Looking at the results, which were computed from measured data, it appears that the collector feedback circuit with RE=0 ohms is the most stable. This is counter to expectations. Theoretically, the most stable of the two collector feedback circuits should be the one with a finite $R_E$. Since the stability figures of both of those circuits are so small, the apparent greater stability of the collector feedback circuit without $R_E$ is probably the result of measurement variability.

4. using KVL:
$-V_{CC}+I_C/BETA*R_B+V_{BE}+I_C*R_E=0V$

from this:

$IC=(V_{CC}-V_{BE})/(R_B/BETA+R_E)$ mA

this division results in:

$IC=Beta(V_{CC}-V_{BE})/(R_B+Beta*R_E)$ mA

If $Beta*RE>>R_B$ then $IC=(V_{CC}-V_{BE})/R_E$ mA

5. Using KVL:

$-V_{CC}+I_C*R_C+I_C/BETA*R_B+V_{BE}=0V$

from this:

$IC=(V_{CC}-V_{BE})/(R_C+_B/BETA)$

if $R_C>>R_B/Beta$ then $I_C=(V_{CC}-V_{BE})/R_C$ mA

6. Using KVL:

$-V_{CC}+I_C*R_C+I_C/BETA*R_B+V_{BE}+I_C*R_E=0V$

from this:

$IC=(V_{CC}-V_{BE})/(R_C+R_E+R_B/BETA)$ mA

if $(R_C+R_E)>>R_B/BETA$ then $I_C=(V_{CC}-V_{BE})/(R_C+R_E)$ mA

EXPERIMENT 11: DESIGN OF BJT BIAS CIRCUITS

Part 1

a. $R_C=(15-7.5)V/5mA=1.5Kohms$
$R_C$(commercial)=1.5ohms

d. $V_{RC}$(measured)=5.14V
$V_{CEQ}$(measured)=7.7V
$I_{CQ}$(from measured)=3.4mA
Beta(calculated)=104

e. The most critical values for proper operation of this design is the voltage VCEQ measured at 7.7V. It being within 2.7% of the design value makes this a workable design.

f. RB/(Beta*RC)=214K/(104*1.5K)=1.37

g. $R_{F1}+R_{F2}$=189K
$R_B$(commercial)+214K

h. No, the value of $R_B$ is fixed both by VCC and VBE, neither of which changed.

i. $V_{RC}$(measured)=5.64V
$V_{CEQ}$(measured)=9.27V
$I_{CQ}$(from measured)=3.76mA
Beta(calculated)=3.73mA/[(9.27-.7)/214K]=108

j. The measured voltage $V_{CE}$ is somewhat high due to the measured current IC being below is design value. In general, the lowest IC which will yield proper VCE is preferable since it keeps power losses down. For the given specifications, this design, for small signal operation, will probably work since most likely no clipping will be experienced.

k. $R_B/(Beta*R_C)$ (calculated)=214K/(108*1.5K)=1.4
RB/(Beta*$R_C$) (calculated)=1.34 (see above)

The parameters of the circuit do not change significantly with a change of transistor. Thus, the design is relatively stable in regard to any Beta variation.

l. S(Beta)=(3.76mA-3.4mA)/3.4mA=.8

Part 2: Emitter-bias Configuration

a. $R_{C(calculated)}$=[(VCC-(7.5+1.5)]V/5mA=1.2K
$R_{C(commercial)}$=1.2K

b. $R_{E(calculated)}$=1.5V/5mA=300ohms
$R_{E(commercial)}$=285ohms

d. $R_{B(measured)}=R_1+R_2$=392.K
$RB_{(commercial)}$=394K

e. $V_{RC(measured)}$=6.04V
$V_{CE(measured)}$=7.55V
$I_{C(from\ measured)}$=4.7mA
$Beta_{(calculated)}$=144

f. All measured values are well within a 10% tolerance of the design parameters. This is acceptable.

g. $R_B/(Beta*R_E)$=9.6

h. $R_{B(calculated)}$=950K

$R_{B(commercial)}=1M$

i. Yes, it changed from 214K to a value of 950K
The increase in Beta was compensated for by the increase in $R_B$ in such a way that $I_{CQ}$, and consequently $V_C$, $V_{CEQ}$ and $V_E$ remained constant. Hence, so did $R_C$ and $R_E$.

j. $V_{RC(measured)}=5.2V$
$V_{CEQ(measured)}$ 8.6V
$I_{CQ(calculated)}=4.2mA$
$Beta_{(calculated)}=372$

k. The important voltage $V_{CEQ}$ was measured at 8.61V while it was specified at 7.5V. Thus, it was larger by a about 12%. This is probably the largest deviation to be tolerated. If the design is used for small signal amplification, it is probably OK; however, should the design be used for Class A, large signal operation, undesirable cut-off clipping may result.

l. The magnitude of the Beta of a transistor is a property of the device, not of the circuit. All the circuit design does is to minimize the effect of a changing Beta in a circuit. That the Beta's differed in this case came as no surprise.

m. (calculated)$R_B/(Beta*R_E)_{(2N3904)}=10.4$
(calculated)$R_B/(Beta*R_E)_{(2N4401)}=9.6$

n. S(Beta)=.66

Part 3: Voltage-divider Configuration

a. $R_{C(calculated)}=[25-(1.5+7.5)]V/5mA=1.2K$
$R_{C(commerical)}=1.25K$

b. $R_E=1.5V/5mA=300$ ohms
$R_{E(commercial)}=285$ ohms

d. $R_{2(calculated)}=2.94K$
$R_{2(commercial)}=3.2K$
$R_{1(calculated)}=17.1K$
$R_{1(commercial)}=18.2K$

e. $V_{RC(measured)}=6.47V$
$V_{CEQ(measured)}=7.09V$
$I_{CQ(calculated)}=5.2mA$
$Beta_{(calculated)}=144$

The difference between the calculated and the measured values of $I_{CQ}$ and $V_{CEQ}$ are insignificant for the operation of this circuit.

f. $R_1//R_2/(Beta*R_E)$=.066

g. $V_{RC(measured)}$=6.98V
$V_{CEQ(measured)}$=6.47V
$I_{CQ(calculated)}$=5.6mA
$Beta_{(calculated)}$=368

h. The measured values of the previous part show that the circuit design is relatively independent of Beta.

i. The Beta's are about the same.

j. $R_1//R_2/(Beta*R_E)_{(2N4401)}$=.026
$R_1//R_2/(Beta*R_E)_{(2N3904)}$=.066

k. S(Beta)=.051

Problems and Exercises

1. Table 11.2

| Configuration | $I_{CQ}$(mA) | $V_{CEQ}$(V) |
|---|---|---|
| Collector-feedback | 3.4 | 7.7 |
| Emitter-bias | 4.7 | 7.5 |
| Voltage-divider | 5.2 | 7.1 |

The critical arameter for these design is the voltage $V_{CEQ}$. Given that its variation for the various designs is less than 10%, the results are satisfying.

2. Table 11.3

| configuration | stability factors | |
|---|---|---|
| | RB/(BetaRC) | S(Beta) |
| Collector-feedback | 1.4 | .8 |
| Emitter-bias | 0.6 | .66 |
| Voltage-divider | .06 | .051 |

The data in adjacent columns is consistent.

The voltage-divider bias configuration was the least sensitive to variations in Beta. This is expected since the resistor R2, while decreasing the current gain of the circuit, stabilized the circuit in regard to any current changes.

3. Using KVL:

$-V_{CC}+I_C*R_C+I_C/Beta*R_B+V_{BE}=0V$

from which: $I_C=(V_{CC}-V_{BE})/(R_C+R_B/Beta)$ mA for stable operation, make: $R_C >> R_B/Beta$

4. Using KVL:

$$-V_{CC}+I_C/Beta*R_B+I_C*R_E+V_{BE}=0V$$

from which: $IC=(V_{CC}-V_{BE})/(R_E+R_B/Beta)$ mA
for stable operation: make $R_E >> R_B/Beta$

5. Using KVL:

$$-V_{BB}+I_C/Beta*R_1//R_2+V_{BE}+I_C*R_E=0V$$

where: $V_{BB}=R_1/(R_1+R_2)*V_{CC}$

from which: $I_C=(V_{BB}-V_{BE})/(R_E+R_1//R_2/Beta)$ mA
for stable operation: make $R_E >> R_1//R_2/Beta$

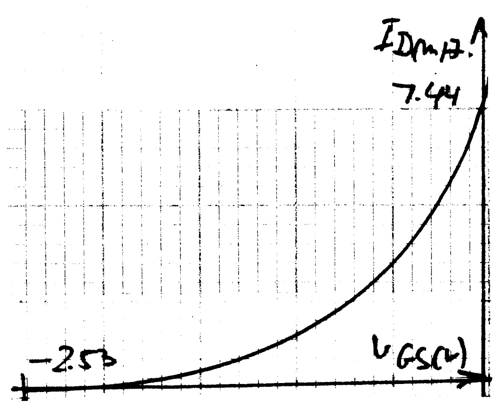
EXPERIMENT 12:JFET CHARACTERISTICS

Part 1

c. $V_{R(measured)}=.754V$
d. $ID_{SS}=7.44mA$
e. $V_{P(measured)}=-2.53V$
f.
  1. $ID_{SS}=8.3mA$, $V_P=-3.1V$
     $ID_{SS}=9.1mA$ $V_P=-3.9V$

It is extremely unlikely that two 2N4416 ever have the same saturation current and pinch-off voltage.

Fig12.1



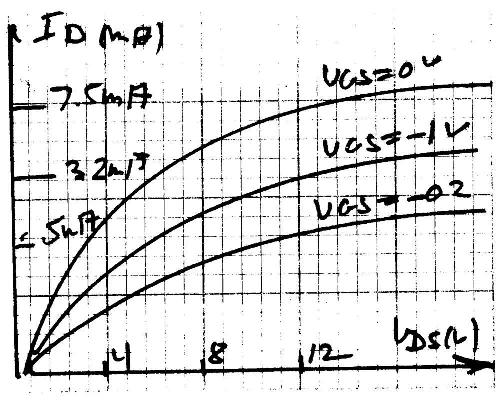

Part 2 Drain-Source characteristics

a through d.

Table 12.1

| $V_{GS}$(V) | 0 | -1.0 | -2.0 |
|---|---|---|---|
| $V_{DS}$(V) | $I_D$(mA) | $I_D$(mA) | $I_D$(mA) |
| 0.0 | 0.0 | 0.0 | 0.0 |
| 1.0 | 4.63 | 2.1 | .25 |
| 2.0 | 5.61 | 2.6 | .28 |
| 3.0 | 7.32 | 3.06 | .34 |
| 4.0 | 7.40 | 3.1 | .36 |
| 5.0 | 7.43 | 3.2 | .39 |
| 6.0 | 7.5 | 3.16 | .42 |
| 7.0 | 7.5 | 3.31 | .43 |
| 8.0 | 7.5 | 3.33 | .44 |
| 9.0 | 7.3 | 3.36 | .46 |
| 10.0 | 7.3 | 3.36 | .50 |
| 11.0 | 7.1 | 3.36 | .50 |
| 12.0 | 6.81 | 3.36 | .51 |
| 13.0 | 6.76 | 3.36 | .52 |
| 14.0 | 6.71 | 3.36 | .53 |

Fig12.3




$ID_{SS}$(Fig12.3)=7.5mA
$ID_{SS}$(Part1)=7.44mA
$V_P$(Fig12.3)=-3V
$V_P$(Part1)=-2.53V

Part 3:Transfer Characteristics

Table12.2

| $V_{DS}$(V) | 3V | 6V | 9V | 12V |
|---|---|---|---|---|
| $V_{GS}$(V) | $I_D$(mA) | $I_D$(mA) | $I_D$(mA) | $I_D$(mA) |
| 0 | 7.32 | 7.5 | 7.4 | 6.81 |
| -1 | 3.06 | 3.26 | 3.36 | 3.36 |
| -2 | .34 | .42 | .46 | .51 |

d. given that the various variables in the above Table vary by less than 10%, it is reasonable that the curves can be replaced on an approximate basis by a single curve defined by Shockley's equation if the average values of both $ID_{SS}$ and $V_{GS(off)}$ are used.

Problems and Exercises

1. Shockley's equation involves four parameters. Given two of them, such as $I_D$ and $V_{GS}$, an infinite number of curves can be drawn through their interception all of which can satisfy Shockley's equation for particular $ID_{SS}$ and $V_P$.

2. $V_G=V_P*[1-(I_D/ID_{SS})^{1/2}]$ V

3. For: $ID_{SS}$=10mA; $V_P$=-5V; and $I_D$=4mA

   $V_{GS}$(calculated)=(-5)*[(.4)$^{1/2}$]=-3.16V

4. a. $gm_O$(calculated)=2*(7.44mA)/2.53=5.88mS

   b. The slope of the Shockley curve is maximum at VGS=0V.

   c. gm(calculated)=$gm_O$(1-VP/VP)=0S when $V_{GS}=V_P$.

   The slope of the transfer curve at $V_{GS}=V_P$=0S

   d.

| | VGS/VP=1/4 | VGS/VP=1/2 | VGS/VP=3/4 |
|---|---|---|---|
| gm | 4.41mS | 2.94mS | 1.47mS |
| note:$gm_O$=5.88mS | | | |

   e. The slope is a constant value

   f. It is the proportional to the derivative of Shockley's equation.

EXPERIMENT 13:JFET BIAS CIRCUITS

Part 1: Fixed-Bias Network

b. $ID_{SS}$=12mA
c. $V_{P(measured)}$=-6V
d. $ID=12E-3(1-1/6)^{1/2}$=8.33mA
f. $V_{RD(measured)}$=8V
   $I_{DQ(measured)}$=8.2mA
   $R_{D(measured)}$=976 ohms

Part 2:Self-Bias Network

b. $I_{DQ}$=2.64mA
   $V_{GSQ}$=-3.3V
d. $V_{GS(calculated)}$=-3.3V
   $V_{D(calculated)}$=12.4V
   $V_{S(calculated)}$=3.1V
   $V_{DS(calculated)}$=9.3V
   $V_{G(calculated)}$=0V
e. $V_{GS(measured)}$=-3.4V
   $V_{D(measured)}$=12.2V
   $V_{S(measured)}$=2.1V
   $V_{DS(measured)}$=9.1V
   $V_{G(measured)}$=0V

The percent difference are determined with the calculated values as the reference.

$VG_{S(calculated\ \%)}$=3.1%
$V_{D(calculated\ \%)}$=-1.6%
$V_{S(calculated\ \%)}$=-.64%
$V_{DS(calculated\ \%)}$=-2.3%
$V_{G(calculated\ \%)}$=0%

Part 3:Voltage Divider-Bias Network

b. For voltage divider-bias-line see Fig.13.2

c. $I_{DQ(calculated)}$=4.8mA
   $V_{GS(calculated)}$=-2.4V
d. $V_{D(calculated)}$=10.3V
   $V_{S(calculated)}$=5.2V
   $V_{DS(calculated)}$=5.1V
e. $V_{GSQ(measured)}$=-2.3V
   $V_{D(measured)}$=10.4V
   $V_{S(measured)}$=5.3V

$V_{DS(measured)}=5.1V$

f. The percent difference are determined with the calculated values as the reference.

$V_{GS(calculated\ \%)}=-4.2\%$
$V_{D(calculated\ \%)}=.97\%$
$V_{S(calculated\ \%)}=1.9\%$
$V_{DS(calculated\ \%)}=1.2\%$

g. $I_{DQ(measured)}=4.8mA$
$I_{DQ(calculated\ \%)}=.4\%$

EXPERIMENT 14:DESIGN OF JFET BIAS CIRCUITS

Part 1. Determining $ID_{SS}$ and $V_P$

b. $ID_{SS(measured)}=10.8mA$
c. $V_{P(measured)}=-6V$

Part 2. Self-bias Circuit Design

a. $ID_{Q(calculated)}=5.4mA$
$V_{DSQ(calculated)}=15V$
$V_{DD(calculated)}=30V$
b.

d. $R_{S(calculated)}= 1/g_m=333$ ohms
$R_{S(commercial)}=330$ ohms
e. $V_{RD}=V_{DD}-V_{DSQ}-V_{RS}=30-15-1.8=13.2V$
$R_D=2.4K$
f. $V_{DSQ(measured)}=14.7V$
$I_{DQ(measured)}=5.6mA$
$V_{DSQ(calculated)}=15V$
$I_{DQ(calculated)}=5.4mA$
g. Agreements between calculated and measured values are within 10% of each other and thus are within acceptable limits.
h. $V_{DSQ(measured)}=13.7V$
$I_{DQ(measured)}=6mA$
$ID_{SS(borrowed\ JFET)}=9.8mA$
$V_{P(borrowed\ JFET)}=-5.1V$

Even though in our case, the variations between JFETs was relatively small, such may not be the case in general. Thus, the values of the biasing resistors for the same bias design but employing different JFETs may differ considerably.

Best is not to use the arithmetic but the geometric average for the range of $ID_{SS}$ and $V_P$. Thus in our case, the geometric averages would be:

$ID_{SS}$(geometric average)= $[IDSS(min)*IDSS(max)]^{1/2}=[5mA*15mA)]^{1/2}=8.66mA$

And for $V_P$(geometric average)=$[1*6]^{1/2}=2.45V$

Statistically, these values are most likely the ones encountered.

Part 3: Voltage-divider Circuit Design

$V_{GS(calculated)}=-2.6V$

$R_S=(V_{GG}-V_{GS})/I_{DQ}=(6-2.6)V/4mA=850$ ohms
$R_{S(commercial\ value)}=820$ ohms
$V_{G(calculated)}=V_{GS}+I_D*R_S=2.6+4mA*820=5.85V$

c.

$V_{RD(calculated)}=V_{DD}-V_{DSQ}-V_{RS}=20-8-3.28=8.72V$
where $V_{RS}=I_{DQ}*R_S=4mA*820=3.28V$

$R_D=[V_{DD}-(V_{DSQ}+V_{RS})]/I_D=[20-(8+3.28)]=2.18$Kohms
$R_{D(commercial\ value)}=2$Kohms

d.

$R_2=10*R_S=10*820=8.2$Kohms
$R_{2(commercial\ value)}=10$Kohms

Solving equation 14.3 for $R_1$ we obtain:

$R_1=R_2*(V_{DD}-V_G)/V_G=10K*(20-5.85)/5.85=24.2$Kohms
$R_{1(commercial\ value)}=22$Kohms

e.

$V_{DSQ(measured)}=7.9V$
$ID_{Q(measured)}=4.2mA$
$V_{DSQ(specified)}=8V$
$I_{DQ(specified)}=4mA$

f.

$\%I_{DQ}$(calculated)=5%
$\%V_{DSQ}$(calculated)=-1.25%

Such relative small percent deviations are almost too good to be true.

The voltage divider bias line is parallel to the self-bias line. To shift the Q point in either direction, it is easiest to adjust the bias voltage $V_G$ to bring the circuit parameters within an acceptable range of the circuit design.

g.
In the present case, the percent differences for IDQ and VDSQ were well within the 10% tolerance allowed. If not, the easiest adjustment would be the moving of the voltage-divider bias line parallel to itself by means of raising or lowering of VG. This could best be accomplished by a change of the voltage divider $R_2/(R_1+R_2)*V_{DD}$. Its value determines the voltage $V_G$ which in turn determines the Q point for the design.

h.
$V_{DSQ(measured)}=13.7V$
$I_{DQ(measured)}=3.68mA$
$I_{DSS(borrowed\ JFET)}=9.8mA$
$V_{P(borrowed\ JFET)}=-5.1V$

Problems and Exercises

1.
$R_{D(commercial\ value)}=2.7Kohms$
$R_{S(commercial\ value)}=180\ ohms$

2. $R_{D(commercial\ value)}=2.4Kohms$
$R_{S(commercial\ value)}=680\ ohms$
$R_{1(commercial\ value)}=6.8Kohms$
$R_{2(commercial\ value)}=33Kohms$

3. In the design, use the geometric mean of both the given ranges on IDSS and VP for a given type JFEF.

EXPERIMENT 15: COMPOUND CONFIGURATIONS

Part 1

a. $R_{B(measured)}=982Kohms$
$R_{C(measured)}=2.6Kohms$

$I_B=(V_{CC}-V_{BE})/R_B=(20-.7)/982K=19.7uA$

$V_{RC(measured)}=6.45V$
$I_C=V_{RC}/R_C=6.45/2.6K=2.48mA$
$Beta_{(calculated)}=1.48mA/19.7uA=126$

Part 2 Coupled Multistage system with Voltage-Divider Bias

b.

$V_{B1}=4.7K/(4.7K+15K)*20=4.8V$
$V_{E1}=4.8-.7=4.1V$
$I_{E1}=I_{C1}=V_{E1}/R_{E1}=4.1/1K=4.1mA$
$V_{C1}=V_{CC}-I_{C1}*R_{C1}=20-4.1mA*2.7K=9.2V$
$V_{B2}=2.4K/(2.4K+15k)*20=2.8V$
$V_{E2}=2.8-.7=2.1V$
$I_{E2}=I_{C2}=V_{E2}/R_{E2}=2.1/470=4.6mA$
$V_{C2}=V_{CC}-I_{C2}*R_{C2}=20-4.6mA*1.2K=14.5V$

Table 15.1

| | $V_{B1}$(V) | $V_{C1}$(V) | $V_{B2}$(V) | $V_{C2}$V) |
|---|---|---|---|---|
| Calculated Values | 4.8 | 9.2 | 2.8 | 14.5 |
| Measured Values | 4.7 | 9.1 | 2.7 | 14.2 |
| % Difference | -1.1 | -1.1 | -1.8 | -2.1 |

As can be seen from the above data, the differences between the calculated and measured values were much less than 10%.

f.

We note that the voltages $V_{C1}$ and $V_{B2}$ are not the same as they would be if the voltage across capacitor $C_C$ was 0 Volts, indicating a short circuit across that capacitor.

Part 3 DC-Coupled Multistage Systems

Use the same equations to determine the circuit parameters as in Part 2 except that $V_{B2}=V_{C1}$.

b.

Table 15.2

| | $V_{B1}$(V) | $V_{C1}$(V) | $V_{B2}$(V) | $V_{C2}$(V) |
|---|---|---|---|---|
| Calculated Values | 4.8 | 9.2 | 9.2 | 13.0 |
| Measured Values | 4.7 | 9.1 | 9.1 | 12.9 |
| % Difference | -1.7 | -1.0 | -1.0 | -.8 |

+------------------------------------------------------+

Again, the percent differences between calculated and measured values are less than 10% in every instance.

f.

The dc collector voltage of stage 1 determines the dc base voltage of stage 2. Note that no biasing resistors are needed for stage 2.

## Part 4 A BJT-JFET Compound Configuration

b.

$V_B$=4.7K/(4.7k+15k)*30=7.2V
$V_E$=$V_B$-.7V=6.5V
$I_E$=$I_D$=6.5V/1.2K=5.4mA
$V_D$=$V_{CCD}$*$R_D$=30-5.4mA*985=24.7V

For the JFET used: $ID_{SS}$=10.1mA
$V_P$=-3.2V

determine VGS:

$I_D/ID_{SS}=[1-V_{GS}/V_P]^{1/2}mA=5.4mA/10.1mA=[1-V_{GS}/3.2]^{1/2}mA$

therefore:

$[5.4mA/10.1mA]^2=[1-VGS/3.2]$

$.286=[1-V_{GS}/3.2]$

from which: $V_{GS}$=(1-.286)*3.2=-2.28V
remember: $V_{GS}$ is a negative number!

$V_C=V_B-V_{GS}=7.2-(-2.28)=9.5V$

Table 15.3

| | $V_B$(V) | $V_D$(V) | $V_C$(V) |
|---|---|---|---|
| Calculated Values | 7.2 | 23.6 | 9.5 |
| Measured Values | 7.1 | 24.4 | 8.7 |
| % Difference | -.56 | 3.4 | -8.4 |

d. see Table 15.3
e. differences were less than 10%
f.

$V_{GS(\text{calculated from measured values})}=V_B-V_C=7.1-8.7=-1.6V$
$V_{GS(\text{measured})}=-1.7V$

g.

$V_{RD}=V_{DD}-V_D=30-24.7=5.3V$
$I_D=5.3V/985=5.4mA$
$I_{D(\text{measured})}=6.4mA$

The percent difference between the measured and the calculated values of $I_D$ were 18.5%, with the calculated value of $I_D$ used as the standard of reference.

$V_{E(\text{calculated})}=7.2-.7=6.5V$
$I_{C(\text{calculated})}=6.5V/1.26K=5.2mA$
$I_{C(\text{measured})}=5.06mA$

The percent difference between the measured and the calculated values of $I_C$ were -2.7%, with the calculated value of $I_D$ used as the standard of reference.

Problems and Exercises

1.

a. There will be a change of $V_B$ and $V_C$ for the two stages if the two voltage divider configurations are interchanged.

b. The voltage divider configuration should make the circuit Beta independent, if it is well designed. Thus, there should not be much of a change in the voltage and current levels if the transistors are interchanged.

2. Again, depending how good the design of the voltage divider bias circuit is, the changes in the circuit voltages and currents should be kept to a minimum.

EXPERIMENT 16: MEASUREMENT TECHNIQUES

DC MEASUREMENT

e. $V_{O(calculated)}$=2K/(2K+3.9K)*12=3.86V
f. $V_{O(measured)}$=3.78V
%Diff.$_{(calculated)}$=-2%
g. $V_{O(measured\ shift)}$=3.8V
The shift was down from the center of the screen.

There is almost complete agreement between the two sets of measurements.

The measurement taken with the DMM is the more accurate of the two, especially for a DMM, since it reads to 1/100 of a volt.

AC MEASUREMENTS

i. $V_{i(rms)(calculated)}$=8/2*.707=2.82V

$V_{O(rms)(calculated)}$=
[(2K//3.9K+j0)*(2.82+j0)]/(2.41K-j1.59K)=1.34$\underline{/33.4}$V

j. $V_{O(measured)}$=1.31V
%diff.(calculated)=-1.51%

k. $V_{O(p-p)(measured)}$=3.72V

l. If we convert the measured rms value of VO to peak value we obtain 3.78 volts. Comparing that to the measured peak value of $V_O$ which was 3.72 V, we can be satisfied with the results.

Part 2 Measurements of the Periods and Fundamental Frequencies of Periodic Waveforms

b. Horizontal sensitivity=100us/div
c. number of divisions=5.6
d. Period(T)=100us/div*5.6div=560us
e. Frequency(f)=1/T=1/560us=1800Hz
f. f(dial setting)=1750Hz
g. The dial setting on the signal generator at best can only give an approximate setting of the frequency.
h. f(counter)=1810Hz.
i. Indeed it is, the difference between calculated and measured values is only 10 Hz using the counter, whereas the difference between signal generator setting and calculated values was 50 Hz. That measurement which is closest to that of the counter is the better measurement. In our case, the scope measures better than the signal

generator.

Part 3 Phase-Shift Measurements

b. $V_{i(rms)(calculated)}=6/2*.707=2.12V$

c. $V_{O(rms)}=(0-j1.59K)*(2.12+j0)/(1k-j1.59K)=1.81\angle -31.6V$
$V_{O(p-p)(rms)}=1.81*1.41*2=5.1V$
f. $A_{(number\ of\ divisions)}=.8$
$B_{(number\ of\ divisions)}=10$
h. angle $theta_{(calculated)}=-31.6$ degrees
j. The network is a lag network, i.e., the output voltage VO lags the input voltage by the angle theta, in our case it lags it by -31.6 degrees.
k. $V_{R(rms)(calculated)}=1.1V$
$V_{R(p-p)(calculated)}=3.1V$
angle theta=58.4 degrees
l. The output voltage VO leads the input voltage by 58.4 degrees. Note that an angle of 58.4 is the complement of an angle of 31.6 degrees.

$V_{R(p-p)(measured)}=3V$
angle theta=58 degrees
it's a lead angle

Part 4 Loading Effects

c. $V_{O(p-p)(calculated)}=1K/(1K+1K)*8=4V$
d. $V_{O(p-p)(measured)}=3.98V$
f. $V_{O(p-p)(calculated)}=1M/(1M+1M)*8=4V$
$V_{O(p-p)(measured)}=2.7V$

g.
The real part of the input impedance of the scope is now in parallel with the R2 resistor and since for many scopes, that real part is about 1Mohm, therefore, $R_{scope}//R_2=500kohms$.
Thus, $V_O$ is considerably reduced.

$R_{(prime)}=1M/[Vi/VO-1]=1M/[8/2.7-1]=588kohms$

$R_{(scope)}=-R_{(prime)}*R_2/[R_{(prime)}-R_2]=1.43Megohms$

Most general purpose oscilloscopes have an input impedance consisting of a real part of 1Megohms in parallel with a 30pf capacitor. The result obtained for the real part of that impedance is reasonably close to that.

i. $V_{O(p-p)(calculated)}$=1K/(1K+1M)*8=8mV
j. $V_{O(p-p)(measured)}$=7.9mV
k. The results agree within 1.25 percent.

PROBLEMS AND EXERCISES

1. No. for the frequency of operation, the capacitor represents an impedance of 1.59k$\underline{/-90}$ ohms. Therefore, in relationship to the existing resistors in the circuit, it cannot be neglected without making a serious error.

2. It depends upon the waveform. In case of sinusoidal voltages, the advantage is probably with the DMM. For more complex waveforms, the nod goes to the oscilloscope.

3. For measuring sinusoidal waves, the DMM gives a direct reading of the rms value of the measured waveform. However, for non-sinusoidal waves, a true rms DMM must be employed. The oscilloscope only gives peak-peak values, which, if one wants to obtain the power in an ac circuit, must be converted to rms.

4. T=5div*.1ms/div=.5ms
f=1/T=1/.5ms=2KHz

5. angle theta=1.5/8*360=67.5 degrees

$V_O/V_i=R'/(R'+R_1)$

therefore: $V_i/V_O=(R'+R_1)/R'$
solving for R': $R'(V_i/V_O)=R'+R_1$
$R'(V_i/V_O-1)=R_1$
Hence: $R'=R_1/(V_i/V_O-1)$ ohms

EXPERIMENT 17: COMMON-EMITTER TRANSISTOR AMPLIFIER

b. $V_{BB}=R_2/(R_1+R_2)*V_{CC}$=10K/(10K+33K)*10=2.33V
$V_E=V_{BB}-.7$=1.63V
$V_C=V_{CC}-I_C*R_C$=10-1.63mA*3K=5.1V
$I_E=V_E/R_E$=1.63/1K=1.63mA
$r_e=26mV/I_E$=26mV/1.63mA=16 OHMS
c. $V_{B(measured)}$=2.25V

$V_{E(measured)}=1.57V$
$V_{C(measured)}=4.95V$
$I_E=V_E/R_E=1.57/978=1.6mA$
$r_e=26mV/1.6mA=16.2$ ohms

The two values for $r_e$ obtained are within .2 ohms. This represents a 1.25 percent difference.

Part 2. Common-Emitter AC Voltage Gain

a. $A_{V(no\ load)}=-RC/re=3.2K/16=198$
b. $V_{sig}=8.3mv(rms)$
$V_{O(no\ load)}=1.47V(rms)$
$A_{V(no\ loa)}=177$
The two values of $A_V$ agree within 10.6 percent of each other.

Part 3. AC Input Impedance, $Z_i$

$Z_{in}=R_1//R_2//Beta*r_e=10K//33K//(150*16)=1.8Kohms$
$V_i$ (measured) 12mV(rms)
$V_{sig}=20mV(rms)$
$Z_{in}=[12mV/(20mV-12mV)]*1K=1.5Kohms$
The two values of the input impedance were within 18.9% of each other. This relatively large divergence is in part the result of using an assumed value of Beta for our transistor. For a 2N3904 transistor, the geometric average of Beta is closer to 126.

Part 4. Output Impedance

a. $Z_{O(calculated)}=R_C=3.2Kohms$
b. $V_{sig(rms)}=10mV(rms)$
$V_{O(no\ load)(rms)}=1.8V(rms)$
$V_{O(loaded)(rms)}=.913V(rms)$
$R_L=3.2Kohms$
$Z_O=[(V_O-V_L)/V_L]*R_L=[(1.8-.913)/.913]*3.2K=3.1K$
The two values for $Z_O$ are within 3.15% of each other.

EXPERIMENT 18: COMMON BASE AND EMITTER-FOLLOWER (COMMON COLLECTOR) TRANSISTOR AMPLIFIERS

a. $V_{B(calculated)}=10K/(10K+33K)*10=2.33V$
$V_E=V_B-.7V=1.63V$
$I_E=I_C=V_E/R_E=1.63V/1K=1.63mA$
$V_C=10-I_C*R_C=10-(1.63mA)*3K=5.1V$
$r_e=26mV/I_E=26mV/1.63mA=16ohms$

b. $V_{B(measured)}=2.26V$
$VE_{(measured)}=1.57V$
$VC_{(measured)}=4.95V$
$I_{E(from\ measured\ values)}=V_E/R_E=1.57V/978=1.6mA$
$r_{e(from\ measured\ values)}=26mV/IE=26mV/1.6=16.3ohms$

In every case, the differences between the two sets of values are less than 10% apart. Such divergence is not excessive given the variability of electronic components.

Part 2. Common-Base AC Voltage Gain

a. $A_{V(calculated)}=R_C/r_e=3.2K/16.3=197$
b. $V_{sig}=50mV$
$V_O=2.43V$
$A_V=2.43/V_{sig}=2.43/.05=122$

The two gains differed by -38 percent with the calculated gain used as the standard of comparison.

Part 3.CB Input Impedance, Zi
a. $Z_i=r_e=16.3$ ohms
b. Vsig=50mV
Vi=9.9mV
RX=100 ohms
$Z_i=[V_i/(V_{sig}-V_i)]*R_X=[9.9mV/(50mV-9.9mV)]*100=23.7$ ohms

The two values of the input impedance differed by 45 percent with the theoretical value of $r_e$(16.3 ohms) used as the standard of comparison.

Part 4.CB Output Impedance, $Z_O$

a. $Z_O=R_C=3.2K$
b. $V_{sig}=20mV$
$V_{O(measured,no\ load)}=2.43V$
$V_L$(measured, loaded)=1.22V
$Z_O=[(V_O-V_L)/V_L]*R_L=[(2.43-1.22)/1.22]*3K=3.18Kohms$

The agreement between the two values of the output impedance is within less than 1 percent.

Part 5. Emitter-Follower DC Bias

a. $V_{B(calculated)}$=2.33V
$V_{E(calculated)}$=1.63V
$I_{E(calculated)}$=1.63V
$V_{C(calculated)}$=10V
$r_{e(calculated)}$=26mV/IE=26mV/1.63mA=16 ohms

b. $V_{B(measured)}$=2.26V
$V_{E(measured)}$=1.78V
$V_{C(measured)}$=10.1V
$I_E=V_E/R_E$=1.78V/1K=1.78mA
$r_e$=26mV/1.78mA=14.3 ohms

Part 6. Emitter-Follower AC Voltage Gain

a. $A_V=R_E/(R_E+r_e)$=1K/(1K+14.3)=.986
b. Vsig=1V
$V_{O(measured)}$=.987V
$A_V=V_O/V_{sig}$=.987/1=.987

The two values of gain are within .1 percent of each other.

Part 7. Emitter Follower(EF) Input Impedance, Zi
a. $Z_i=R_1||R_2||(Beta*(1K+r_e)$=7.31Kohms
b. $V_{sig}$=2V
$R_X$=10Kohms
f=1KHz
$V_{i(measured)}$=.85V
$Z_i=[V_i/(V_{sig}-V_i)]*R_X$=[.85/(2-.85)]*10K=7.39Kohms

The input impedance calculated from measured values is within 1.1 percent of the theoretically calculated value of $Z_i$.

Part 8. Emitter Follower(EF) Output Impedance, $Z_O$
a. $Z_O=r_e$=16 ohms
b. $V_{O(measured)}$=19.8mV
$V_{L(measured)}$=11.2mV
$Z_O=[(V_O-V_L)/V_L]*R_L$=[(19.8mV-11.2mV)/11.2mV]*100=76.8ohms

In the theoretical formulation, $Z_O$ was equated with $r_e$, this is an approximation. A better expression for the output impedance is: $Z_O$=re+(RG||R1||R2)/Beta. Thus it can be seen that the given formulation was actually a minimum value of the output impedance.

EXPERIMENT 19: DESIGN OF COMMON-EMITTER AMPLIFIER

Part 3. Build and Test CE Circuit

b. $V_{B(measured)}$=1.54V
$V_{E(measured)}$=.87V
$V_{C(measured)}$=7.15V
$I_C=I_E=V_E/R_E$=.87V/979=.89mA
$r_e$=26mV/$I_E$=26mV/.89mA=29.3 ohms

c. Vsig=10mV
$V_{L(measured)}$=.815V
$A_V=(R_C||R_L)/r_e$=(3.2K||10.2K)/29.3=80.7

d. $V_{sig}$=20.5mV
$R_X$=3.17Kohms
$V_{i(measured)}$=8.8mV
$Z_i=(R_1||R_2||$BETA*$r_e$)=(100.2K||21.6K||100*29.3=2.4Kohms

e. $V_{O(measured)}$=1.08V
$Z_O=(V_O-V_L)/V_L*R_L$=(1.08-.82)/.82*10.2K=3.25Kohms

f.

| | Design parameter | Measured value |
|---|---|---|
| AV | 100min. | 80.7 |
| $Z_i$(Kohms) | 1Kmin. | 2.38K |
| $Z_O$(Kohms) | 10Kmax. | 3.35K |
| $V_O$max(p-p) | 3Vp-p min. | 7.1Vp-p |

The design of the circuit was succesful with all parameters, but the gain, meeting and even exceeding the design specification. The gain is about 20 percent below the expected value. To increase it, the supply voltage $V_{CC}$ could be increased. This would increase the quiescent current, lower the dynamic resistance $r^e$ and consequently increase the gain of the amplifier.

EXPERIMENT 20:COMMON SOURCE TRANSISTOR AMPLIFIER

Part 1. Measurement of $I_{DSS}$ and $V_P$

a. $I_{DS}$=9.1mA
$V_P$=-2.9V

Part 2.

a. $V_{GS}$=-1.33V
$I_D$=2.55mA
VD=VDD-ID*RD=20-2.55mA*2.2K=13.8V

c. $V_{G(measured)}$=0V
$V_{S(measured)}$=1.46V
$V_{D(measured)}$=13.8V
$V_{GS(measured)}$=-1.37V
$I_D$=$V_D$/$R_S$=13.8/488=2.99mA

The agreement between calculated and measured values was in most cases within 10 percent of each other, the exception being the 17.3 percent difference between the calculated and measured value of $I_D$.

Part 3. AC Voltage Gain of Common-Source Amplifier

a. $A_V=-g_mR_D$

where
$g_m=I_{DSS}/(2*|V_P|)*(1-V_{GS}/V_P)^2$=2*9.1mA/2.9*(1-1.33/2.9)
= 3.4mS

therefore: $A_V$=-3.4mS*2.2K=7.48

b. $V_{sig}$=100mV
f=1KHz
$V_{O(measured)}$=758mV
$A_V=V_O/V_{sig}$=758mV/100mV=7.58

The difference between the theoretical gain and the gain calculated from measured values was only 1.34 percent.

Part 4. Input and Output Impedance Measurements

a. $Z_i=R_G$
$Z_{i(expected)}$=1Megohm

b. $Z_O=R_D$
$Z_{O(expected)}$=2.25Kohms

c. $V_{i(measured)}$=37.2mV
$Z_{i(calculated)}$=Vi*RX/(Vsig-Vi)=592Kohms

d. $V_{O(measured)}$=760mV
$R_{L(measured)}$=9.9Kohms
$V_{L(measured)}$=620mV
$Z_O=(V_O-V_L)*R_L/V_L$=(760mV-620mV)*9.9K/620mV=2.24Kohms

The infinite input impedance of the JFET is predicated upon the assumption of the zero reverse gate current. Such may not be entirely true. Hence, we observe a 41 percent difference between the theoretical input impedance and the input impedance calculated from measured values.

The two values of the output impedance are in far better agreement. They differ only by .44 percent.

EXPERIMENT 21: MULTISTAGE AMPLIFIER:RC COUPLING

Part 1. Measurement of $I_{DSS}$ and $V_P$

$I_{DSS}$=10.4mA
$V_P$=-3.2V

Part 2. DC Bias of Common-Source Circuit

a. $V_{GS1(calculated)}$=-1.36V
$I_{D1(calculated)}$=3.1mA
$V_{D1(calculated)}=V_{DD}-I_{D1}*R_{D1}$=20V-3.1mA*2.2K=13.2V
$V_{GS2(calculated)}$=-1.38V
$I_{D2(calculated)}$=3.54mA
$V_{D2(calculated)}=V_{DD}-I_{D2}*R_{D2}$=20V-3.54mA*2.2K=12.2V

c. $V_{G1(measured)}$=0V
$V_{S1(measured)}$=1.49
$V_{D1(measured)}$=13.81V
$V_{GS1(measured)}$=-1.04V
$I_{D1}=V_{S1}/R_{S1}$=1.49V/496=3mA
$V_{G2(measured)}$=0V
$V_{S2(measured)}$=1.52V
$V_{D2(measured)}$=11.3V
$V_{GS2(measured)}$=-.8V
$I_{D2}=V_{S2}/R_{S2}$=1.52V/468=3.25mA

The theoretical and the measured bias values were consistently in close agreement.

Part 3. AC Voltage Gain of Amplifier

a. for stage 2:
$A_{V2}=-g_{m2}(R_{D2}||R_L)$=(-3.64mS)(2.2K||10K)=6.6

for stage 1:

$A_{V1}=-g_{m1}(R_{D1}||Z_{i2})=(-3.51mS)(2.2K||1M)=7.72$
note: $Z_{i2}=R_{G2}=1Megohm$

$A_V=A_{V1}*A_{V2}=6.6*7.72=50.7$

b. $V_{sig(measured)}=20mV$
$V_{L(measured)}=945mV$
$A_V=V_L/V_{sig}=945mV/20mV=47.3$
VO1(measured)=145mV
Vsig(measured)=20mV
$A_{V1}=V_{O1}/V_{sig}=145mV/20mV=7.25$
$A_{V2}=V_L/V_{O1}=945mV/145mV=6.52$

The voltage gains differed by less than 10 percent from each other.

Part 4. Input and Output Impedance Measurements

a. $Z_i=R_{G1}=1Megohm$
b. $Z_O=R_{D2}=2.2Kohms$
c. $V_{i1(measured)}=7.5mV$
$V_{sig}=20mV$
$R_X=1Megohm$
$Z_i=V_{i1}*R_X/(V_{sig}-V_{i1})=7.5mV*1M/(20mV-7.5mV)=600Kohms$
d. $V_{L(measured)}=330mV$
$V_{O(measured)}=410mV$
$Z_O=(V_O-V_L)*R_L/V_L=(410mV-330mV)*10K/330mV=2.42Kohms$

Again, the input impedance calculated from measured values is about 40 percent below that which we expected from the assumption that the JFET was ideal and had no reverse gate current. This seems not to be the case in actuality. There is a reverse leakage current at the gate which reduces the effective input impedance below that of $R_G$ by being in parallel with it.

The output impedances again are in reasonable agreement, differing by no more than 9 percent from each other.

EXPERIMENT 22:CMOS CIRCUITS

Part 1. CMOS Inverter Circuit

Table 22.1

| IN | OUT |
|---|---|
| 0V | 5V |

Table 22.2

| IN | OUT |
|---|---|
| 0V | 5V |

| | | | |
|---|---|---|---|
| 5V | .3V | 5V | .3V |

Part 2. CMOS Gate

Table 22.3

| A | B | OUTPUT |
|---|---|---|
| 0V | 0V | 5V |
| 0V | 5V | 0V |
| 5V | 0V | 0V |
| 5V | 5V | 0V |

Part 3. CMOS Input-Output Characteristics

a.

| IN(V) | 0.0 | .2 | .4 | .6 | .8 | 1.0 | 1.2 | 1.4 | 1.8 |
|---|---|---|---|---|---|---|---|---|---|
| OUT(V) | 5.0 | 5.0 | 5.0 | 5.0 | 4.9 | 4.8 | 4.8 | 4.7 | 4.4 |

| IN(V) | 2.2 | 2.4 | 2.6 | 2.8 | 3.0 | 3.2 | 3.4 | 3.6 |
|---|---|---|---|---|---|---|---|---|
| OUT(V) | 3.9 | 3.4 | 1.6 | 1.1 | .75 | .6 | .4 | .3 |

| IN(V) | 3.8 | 4.0 | 4.2 | 4.4 | 4.6 | 4.8 | 5.0 |
|---|---|---|---|---|---|---|---|
| OUT(V) | .1 | .1 | .08 | .02 | .02 | .005 | 0 |

## EXPERIMENT 23: DARLINGTON AND CASCODE AMPLIFIER

Part 1 Darlington Emitter-Follower Circuit

a. $V_{B(calculated)}=2.21V$
$V_{E(calculated)}=1.01V$
$A_V=R_E/(R_E+r_e)=47/(47+10)=.83$

b. $V_{B(measured)}=5.9V$
$V_{E(measured)}=4.94V$
$I_{B(calculated)}=199uA$
$I_{E(calculated)}=106mA$
$Beta_{(calculated)}=106mA/199uA=535$

c. $V_{i(measured)}=350mV$
$V_{O(measured)}=340mV$
$A_V=V_O/V_i=340mV/350mV=.97$

Part 2 Darlington Input and Output Impedance

a. $Z_{i(calculated)}=20.6K||(535*47)=11.3Kohms$
$Z_O=r_e+(R_G||R_B)/Beta=9ohms$

b. $V_{sig}=500mV$

$V_{i(measured)}$=55.6mV
Zi=[Vi/(Vsig-Vi)]*Rx=
[55.6mV/(500mV-55.6mV)]*100K=12.5Kohms

c. $V_{O(measured)}$=492mV
$V_{L(measured)}$=476mV
$R_L$=100ohms
$Z_O=[(V_O-V_L)/V_L]*R_L$=[(492mV-476mV)/476mV]*100=4.2ohms

The two values of the input impedance differed by about 10.6 percent while the two values of the output impedance differed by 53 percent. It is to be noted however that with such small values the difference in just one ohm manifests itself as a large percent change. Given the tolerances of electronic circuit due to their components and that of the Darlington chip, the results are quite satisfactory.

Part 3 Cascode Circuit

a. $V_{B1(calculated)}$=5.5V
$V_{E1(calculated)}$4.8V
$V_{C1(calculated)}$=11V
$V_{B2(calculated)}$=12V
$V_{E2(calculated)}$=11.3V
$V_{C2(calculated)}$=12.5V
$I_{E1}=V_{E1}/R_{E1}$=4.8V/1k=4.8mA
$I_{E2}$=11.3/1.8K=6.24mA
$r_{e1}$=26mV/IE1=26mV/4.8mA=5.4ohms
$r_{e2}$=26mV/IE2=26mV/6.24mA=4.2ohms

b. $V_{B1(measured)}$=4.69V
$V_{E1(measured)}$=4.0V
$V_{C1(measured)}$=10.7V
$V_{B2(measured)}$=12.0V
$V_{E2(measured)}$=10.5V
$V_{C2(measured)}$=12.3V
$I_{E1(calculated)}=V_{E1}/R_{E1}$=4V/1K=4mA
$I_{E2(calculated)}$=VE2/RE2=10.5/1.8K=5.2mA
$r_{e1}$=26mV/IE1=26mV/4mA=6ohms
$r_{e2}$=26mV/IE2=26mV/5.2mA=5ohms

c. $A_{V1}$=-1(as per equation 23.5)
$A_{V2}=R_C/R_{E2}$=1.8K/5=180

d. Vsig=10mV
Vi(measured)=8mV
VO1(measured)=7.91mV
VO2(measured)=948mV
$A_{V1(calculated)}=-V_{O1}/V_i$=7.91/8mV=-.98
$A_{V2(calculated)}=V_{O2}/V_{O1}$=948mV/7.91mV=120
$A_V=V_{O2}/V_i$=VO2/Vi=-948mV/8mV=-119

The voltage gains for stage 1 were within 2 percent of each other, while the overall theoretical gain of 180 differs from the calculated gain from measured values by 34 percent.

## EXPERIMENT 24. CURRENT SOURCE AND CURRENT MIRROR

### Part 1 JFET Current Source

a. $V_{DS(measured)}$=9.64V

b. $I_L=(V_{DD}-V_{DS})/R_L$=(10-9.64)/51.2=7.03mA

c.

Table 24.1

| | | | | | |
|---|---|---|---|---|---|
| $R_L$(ohms) | 20 | 51 | 82 | 100 | 150 |
| $V_{DS}$(Volts) | 9.88 | 9.64 | 9.44 | 9.34 | 8.85 |
| $I_L$(mA) | 6.1 | 7.03 | 6.83 | 6.60 | 7.57 |

### Part 2 BJT Current Source

a. $I_L$=1.9mA

b. $V_{E(measured)}$=-.68V
$V_{C(measured)}$= .404V

c. $I_{E(calculated)}$=2.13mA
$I_{L(calculated)}$=1.88mA

d.

Table 24.2

| | | | |
|---|---|---|---|
| $R_L$(kohms) | 3.6 | 4.3 | 5.1 |
| $V_E$(Volts) | -.68 | -.67 | -.68 |
| $V_C$(Volts) | 3.03 | 1.74 | .404 |
| $I_E$(mA) | 2.14 | 2.17 | 2.13 |
| $I_L$(mA) | 1.94 | 1.92 | 1.88 |

### Part 3 Current Mirror

a. $I_X$=.9mA

b. $V_{B1}$=.669V
$V_{C2}$=2.24V
$I_X$=.89mA
$I_L$=1.0mA

c. $I_X$(calculated)=1mA
$V_{B1}$(measured)=.669V
$V_{C2}$(measured)=4.1V
$I_X$=.9mA
$I_L$=1.5mA

## Part 4. Multiple Current Mirrors

a. $I_{X(calculated)}$=1mA
b. $V_{B1(measured)}$=.672V
$V_{C2(measured)}$=1.67V
$V_{C3(measured)}$=1.65V
$I_X$=1.01mA
$I_{L1}$=1.58mA
$I_{L2}$=1.78mA
c. $I_X$(calculated)=1mA
$V_{B1}$(measured)=.672V
$V_{C2}$(measured)=3.81V
$V_{C3}$(measured)=2.87V
$I_X$=1.02mA
$I_{L1}$=1.73mA
$I_{L2}$=1.44mA

# EXPERIMENT 25: FREQUENCY RESPONSE OF A COMMON-EMITTER AMPLIFIER

## Resume

$f_{L,1}$=1/(2*3.24*1.39K*10uf)=11.5Hz
$f_{L,2}$=1/(2*3.24*6.1K*1uf)=26Hz
$f_{L,E}$=1/(2*3.14*2.2K*20uf)=3.62Hz
$f_{H,i}$=1/(2*3.14*1.68K*960uf)=98.7KHz
$f_{H,o}$=1/(2*3.14*1.43K*45pf)=2.43MHz

## Part 1. Low-Frequency Response Calculations

a. $C_{be(specified)}$=100pf
$C_{bc(specified)}$=10pf
$C_{ce(specified)}$=15pf
$C_{W,i(approximated)}$=20pf
$C_{W,o(approximated)}$=30pf
b. Beta$_{(measured)}$=126
c. $V_{B(calculated)}$=4.08V
$V_{E(calculated)}$=3.38V
$V_{C(calculated)}$=14V
$I_{E(calculated)}$=1.54mA
$r_e$=26mV/$I_E$=26mV/1.54mA=16.9ohms
d. $A_{V(mid)}$=($R_C$||$R_L$)/$r_e$=(3.9K||2.2K)/16.9=83.2
e. $f_{L,1(calculated)}$=11.5Hz
$f_{L,2(calculated)}$=26.2Hz
$f_{L,E(calculated)}$=3.62Hz

## Part 2. Low Frequency Response Measurements

b. $V_{sig(measured)}$=30mV
$V_{O(measured)}$=2.1v
$A_{V(mid)}$=70

Table 25.1

| f(Hz) | 50 | 100 | 200 | 400 | 600 | 800 | 1K | 2K | 3k | 5K | 10K |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $V_{O(p-p)}$ | .4 | .5 | .9 | 1.6 | 1.8 | 1.9 | 2.0 | 2.1 | 2.1 | 2.1 | 2.2 |

Table 25.2

| f(Hz) | 50 | 100 | 200 | 400 | 600 | 800 | 1K | 2K | 3K | 5K | 10K |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $A_V$ | 13.2 | 16.7 | 30 | 53.3 | 60 | 63.3 | 66.7 | 70 | 70 | 70 | 73.3 |

## Part 3. High Frequency Response Calculations

a. $f_{H,i(calculated)}$=98.7KHz
$f_{H,O(calculated)}$=2.47MHz

b. Table 25.3

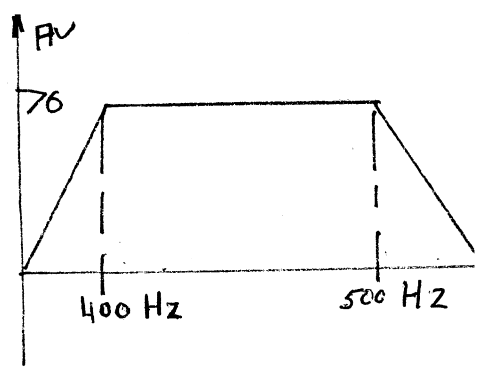
| f(KHz) | 10 | 50 | 100 | 300 | 500 | 600 | 700 | 900 | 1000 | 2000 |
|---|---|---|---|---|---|---|---|---|---|---|
| VO(p-p) | 2.2 | 2.2 | 2.1 | 1.9 | 1.6 | 1.5 | 1.4 | 1.3 | 1.3 | .8 |

Table 25.4

| f(KHz) | 10 | 50 | 100 | 300 | 500 | 600 | 70 | 900 | 1000 | 2000 |
|---|---|---|---|---|---|---|---|---|---|---|
| $A_V$ | 73 | 73 | 70 | 63 | 53 | 20 | 46 | 40 | 40 | 27 |

## Part 4. Plotting Bode Plot and Frequency Response

Fig25.2




from plot: $f_1$=400Hz
$f_2$=500KHz

# EXPERIMENT 26:CLASS A AND CLASS B AMPLIFIERS

## Part 1. Class A Amplifier: DC Bias

a. $V_{B(calculated)}$=1.53V
$V_{E(calculated)}$=.83V
$I_{E(calculated)}$=IC=VE/RE=.83/20=41mA

$V_{C(calculated)}=5.1V$

b. $V_{B(measured)}=1.59V$
$V_{E(measured)}=.88V$
$V_{C(measured)}=5.3V$
$I_{E(calculated)}=I_C=V_E/R_E=.88/20=44mA$

Part 2. Class-A Amplifier: AC Operation

a. $P_{i(calculated)}=400mW$
$V_{O(calculated)}=5.3Vp\text{-}p$
$PO(calculated)=29.3mW$
%efficiency(calculated)=7.3 percent

b. $V_{i(measured)}=65mV$
$V_{o(measured)}=5Vp\text{-}p$

c. $P_i=400mW$
$P_O=26mW$
% efficiency$_{(calculated)}$=6.5 percent

While the values for the power and the efficiency are fairly consistent between the theoretical and those calculated from measured values, the low efficiency of the amplifier is an undesirable feature. In general, Class A amplifiers operate close to a 25 percent efficiency. This circuit would need to be redesigned to make it a practical circuit.

d. $V_{i(measured)}=32.5mVp\text{-}p$
$V_{O(measured)}=3Vp\text{-}p$

e. $P_{i(calculated)}=400mW$
$P_{O(calculated)}=9.38mW$
% efficiency$_{(calculated)}$=2.3 percent

f. $P_i=400mW$
$P_O=93mW$
% efficiency=2.3 percent

As stated previously, while the data is consistent, the values of the efficiency makes this not a practical circuit.

Part3. Class-B Amplifier Operation

a. for $V_O=1V_{peak}$
$P_{i(calculated)}=1.59W$
$P_{O(calculated)}=50mW$
% efficiency$_{(calculated)}$=3.1 percent

for $V_O=2V_{peak}$
Pi=1.59W
PO=200mW
% efficiency(calculated)=12.6 percent

b. $V_{i(measured)}$=2.9Vp-p
$V_{O(measured)}$=2.7Vp-p
Pi=890mW
PO=91mW
%efficiency=10.2%

c. $V_{i(measured)}$=5Vp-p
$V_{O(measured)}$=4Vp-p
$I_{dc(measured)}$=159mA
Pi=1.27W
PO=637mW
%efficiency=50.2%

Note that the efficiency of the Class B amplifier increases with increasing input signal and consequent increasing output signal. Also observe that the two stages of the Class B amplifier shown in Figure 26.2 are in the emitter follower configuration. Thus, the voltage gain for each stage is near unity. This is what the data of the input and the output voltages show. Note also, that as the output voltage approaches its maximum value that the efficiency of the device approaches its theoretical efficiency of about 78 percent.

## EXPERIMENT 27: DIFFERENTIAL AMPLIFIER CIRCUITS

### Part 1. DC Bias of BJT Differential Amplifier

a. $V_{B(calculated)}$=0V
$V_{E(calculated)}$=-.7V
$V_{C(calculated)}$=5.43V
$I_{E(calculated)}$=457uA
$r_{e(calculated)}$=57 ohms

b.

| | Q1 | Q2 |
|---|---|---|
| $V_{B(measured)}$ | -.10V | 0V |
| $V_{E(measured)}$ | -.65V | -.65V |
| $V_{C(measured)}$ | 5.10V | 4.9V |
| IE(calculated) | 490uA | 510uA |
| re | 53ohms | 51ohms |

Part 2. AC Operation of BJT Differential Amplifier

a. $A_{V,d(calculated)}=179$
   $A_{V,c(calculated)}=.5$

b. $V_{O1(measured)}=1.48V$
   $V_{O2(measured)}=1.43V$
   $V_{O,d}=(V_{O,1}+V_{O,2})/2=(1.48+1.43)/2=1.46V$
   $A_{V,d}=V_{O,d}/V_i=72.8$

c. $V_{O,c(measured)}=.55V$
   $A_{V,c}=V_{O,c}/V_i=.55$

Part 3. DC Bias of BJT Differential Amplifier with Current Source

a. For either Q1 or Q2:
   $V_{B(calculated)}=0V$
   $V_{E(calculated)}=-.7V$
   $V_{C(calculated)}=9V$
   $I_{E(calculated)}=.5mA$
   $r_{e(calculated)}=52$ ohms

   For Q3:
   $V_{B(calculated)}=-5V$
   $V_{E(calculated)}=-5.7V$
   $V_{C(calculated)}=-.7V$
   $I_{E(calculated)}=1mA$
   $r_{e(calculated)}=26$ ohms

b. For Q1,Q2 and Q3:

| | Q1 | Q2 | Q3 |
|---|---|---|---|
| $V_{B(measured)}$ | 47mV | 0mV | -4.69V |
| $V_{E(measured)}$ | -.64V | -.64V | -5.35V |
| $V_{C(measured)}$ | 7.91V | 2.97V | -.64V |
| $I_{E(calculated)}$ | 110uA | 612uA | 783uA |
| $r_{e(calculated)}$ | 236ohms | 42.5 ohms | 33.2 ohms |

Part 4. AC Operation of Differential Amplifier with Transistor Current Source

a. AV,d=RC/(2*re)=10K/(2*57.8)=173

Part 5. JFET Differential Amplifier

a. For Q1 : $I_{DSS}=7.9mA$
   $V_P=-3.1V$

For Q2: IDSS=8.1mA
VP=-3.4V
For Q3: IDSS=11.2mA
VP=-4.2V

b. $V_{D,1(calculated)}$=9.84v
$V_{D,2(calculated)}$=9.84V
$V_{S,1(calculated)}$=.845V

c. $V_{G,1(measured)}$=0V
$V_{D,1(measured)}$=9.71V
$V_{D,2(measured)}$=9.72V
$V_{D,3(measured)}$=.84V

d. $A_{V,d}$=.184

e. $V_{O,1(measured)}$=50mV
$V_{O,2(measured)}$=46mV
$A_{V1,d}$=.5
$AV_{2,d}$=4.6

## EXPERIMENT 28: LINEAR OP-AMP CIRCUITS

### Part 1: Inverting Amplifier

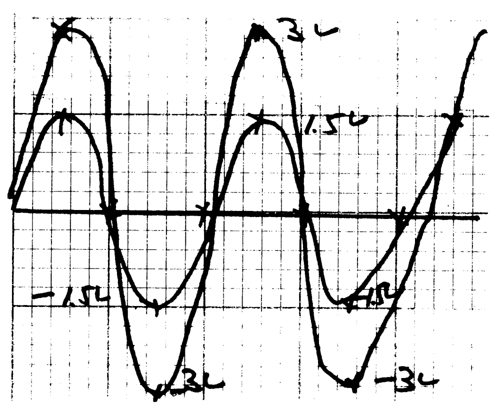
a. $V_O/V_{i(calculated)}=-R_O/R_i$=100K/20K=-5

b. $V_{O(measured)}$=-4.87
$A_V=-V_O/V_i$=4.87/1=-4.87

c. $V_O/V_{i(calculated)}$=-RO/Ri=-100K/100K=-1
$V_{O(measured)}$=1V
AV=-VO/Vi=-1.06/1=-1.06

d.

Fig.28.6




### Part 2. Noninverting Amplifier

a. $A_{V(calculated)}=(1+R_O/R_i)=(1+100K/20K)=6$
b. $V_{O(measured)}=5.24V$
$A_V=V_O/V_i=5.25/1=5.25$

The two gains are within 12.5 percent of agreement.

c. $A_{V(calculated)}=(1+100K/100K)=2$
$V_{O(measured)}=2.17V$
$V_O/V_i=2.17$

The two gains are within 8.5 percent of agreement.

Part 3. Unity-Gain Follower

a. $V_{i(measured)}=2.06V$
$V_{O(measured)}=2.05V$

The ratio of the computed gain from measured values is equal to .995, which is practically identical to the theoretical unity gain.

Part 4. Summing Amplifier

a. $V_{O(calculated)}=-[100K/100K*1+100K/20K*1]=-6V$
b. $V_{O(measured)}=-5.02V$ .

The difference between the two values of VO is equal to 16.3 percent.

c. $V_{O(calculated)}=-[100K/100K*1+100K/100K*1]=-2V$
$V_{O(measured)}=-2.01V$

The difference between the two values of Vo is equal to .5 percent.

EXPERIMENT 29:ACTIVE FILTER CIRCUITS

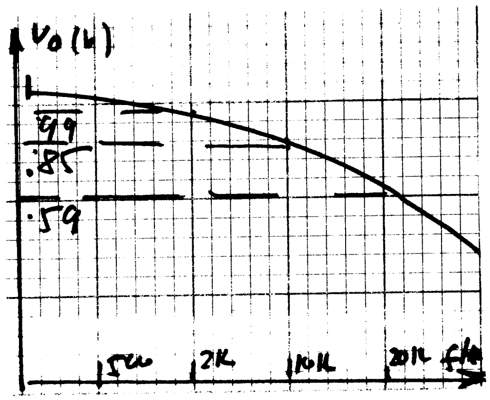
Part 1.Low-Pass Active Filter

a. $f_{L(calculated)}=1/(2*3.14*10K*.001uf)=15.9KHz$
b.

Table 29.1 Low Pass Filter

| f(HZ) | 100 | 500 | 1K | 2K | 5K | 10K | 15K | 20K | 30K |
|---|---|---|---|---|---|---|---|---|---|
| $V_O$(V) | 1.0 | 1.0 | 1.0 | .99 | .95 | .85 | .74 | .59 | .52 |

Fig 29.4




d. $f_L$(from graph)= 15KHz

Part 2. High-Pass Filter

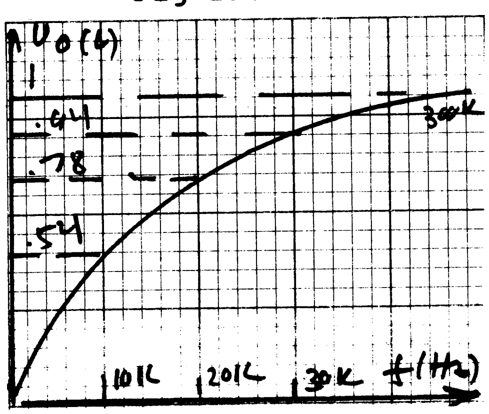
a. $f_H$=1/(2*3.14*R2*C2)=1/(2*3.14*10K*.001uf)=15.9KHz

b.

Table 29.2 High-Pass Filter

| f(Hz) | 1K | 2K | 5K | 10K | 20K | 30K | 50K | 1K | 300K |
|---|---|---|---|---|---|---|---|---|---|
| VO(V) | .06 | .13 | .31 | .54 | .78 | .94 | 1.0 | 1.0 | 1.0 |

c. Fig 29.5




d. $f_H$(from graph)=15KHz

Part 3. Band-Pass Active Filter

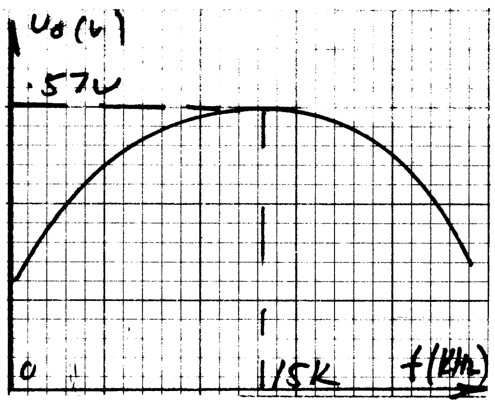
a.

c. Table 29.3 Band-Pass Filter

| f(Hz) | 100 | 500 | 1K | 2K | 5K | 10K | 15K | 20K | 30K |
|---|---|---|---|---|---|---|---|---|---|
| $V_O$(V) | .01 | .035 | .07 | .15 | .32 | .51 | .57 | .57 | .49 |

| f(Hz) | 50K | 100K | 200K | 300K |
|---|---|---|---|---|
| $V_O$(V) | .35 | .10 | | |

d. Fig29.6




EXPERIMENT 30:COMPARATOR CIRCUIT OPERATION

Part 1.

a. $R_3$=10Kohms, $V_{ref}$=5V
$R_3$=20Kohms $V_{ref}$=6.7V

c. $V_{ref(measured)}$=4.97V

d. $V_{i(measured)}$(LED goes on)=5.01V
$V_{i(measured)}$(LED goes off)=4.98V

e. $V_{ref(measured)}$=6.63V
$V_{i(measured)}$(LED goes on)=6.65V
$V_{i(measured)}$(LED goes off)=6.61V

All values of voltages measured and calculated relative to a particular $R_3$ are in very close agreement.

Part 2. Comparator IC Used as a Level Detector

a. $R_3$=10Kohms $V_{ref(calculated)}$=4.98V
$R_3$=20Kohms $V_{ref(calculated)}$=6.63V

c. $V_{ref(measured)}$=4.97V(R3=10Kohms)
d. $V_{i(measured)}$ (LED goes on)=5.01V
$V_{i(measured)}$ (LED goes off)=4.97V
e. Replace R1 with 20Kohm resistor.
$V_{ref(measured)}$=6.67V(R3=20Kohms)
$V_{i(measured)}$ (LED goes on)=6.69V
$V_{i(measured)}$ (LED goes off)=6.65V
f. $V_{i(measured)}$ (LED goes on)=6.65V
$V_{i(measured)}$ (LED goes off)=6.67V

The agreement between calculated and measured values in every case was near perfect.

Part 3. Window Comparator
a. $V^+$(pin5, calculated)=7.5V
$V^-$(pin6, calculated)2.5V
c. Vi(pin1, measured)=7.6V
$V^+$(pin5, measured)=7.36V
$V^-$(pin6, measured)=2.3V
d. $V_{i(measured)}$ (LED goes on)=7.6V
$V_{i(measured)}$ (LED goes off)=2.6V
e. $V_{i(measured)}$ (LED goes on)=7.46V
$V_{i(measured)}$ (LED goes off)=2.2V
f. $V_{i(measured)}$ (LED goes on)=7.46V
$V_{i(measured)}$ (LED goes off)=5.01V

Again as in the previous case, the agreement between measured and calculated values was excellent.

EXPERIMENT 31:OSCILLATOR CIRCUITS

Part 1.Phase-Shift Oscillator
b. $R_{F(measured)}$=347Kohms
c. Period,$T_{(measured)}$=1.51ms
d. f=1/T=1/1.51ms=663Hz
e. Period,T(measured)=15ms
f=1/T=1/15ms=66.3Hz
f. $f_{(calculated,C=.001uF)}$=650KHz
$f_{(calculated,C=.01uF)}$=65Hz

All values agreed within less than 10 percent of each other.

Part 2. Wien Bridge Oscillator

c. $T_{(measured)}$=305us
d. f=1/T=1/305us=3.28KHz

e. $T_{(measured, C= 0.01uF)}$=3ms
$f_{(calculated,C=0.01uF)}$=328Hz

f. $f_{(calculated,C=.001uF)}$=3.12KHz
$f_{(calculated,C=.01uF)}$=312Hz

Again, the agreement between the two sets of values was well within 10 percent.

Part 3. 555 Timer Oscillator

c. $T_{(measured)}$=20.1us

d. f=1/T=49.3KHz

e. $T_{(measured,C=0.01uF)}$=203us
f=1/T=4.93Khz

f. k=fRC=.48
f=4.91KHz

The agreement between the two values differed by only .4 percent.

Part 4. Schmitt-trigger Oscillator

c. $T_{(measured)}$=21us

d. f=1/T=46.9KHz

e. $T_{(measured, C=0.01uF)}$=210us
f=1/T=4.69KHz

f. $f_{(calculated,C=0.001uF)}$=46KHz
$f_{(calculated,C=0.01uF)}$=4.6KHz

The measured and calculated values of the frequency for each capacitor were within 2 percent of each other.

EXPERIMENT 32:VOLTAGE REGULATION-POWER SUPPLIES

Note: The data obtained in this experiment was based on the use of a 10 volt Zener diode.

Part 1. Series Voltage Regulator

a. VL=VZ-VBE=10V-.7V=9.3V

b. VO(measured)=9.3V

Table32.1

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Vi(V) | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| VO(V) | 9.25 | 9.26 | 9.28 | 9.30 | 9.32 | 9.33 | 9.35 |

The voltage regulation of the system was -.54 percent.

Part 2 Improved Series Regulator

a. $A=1+R1/R2=1+1K/2K=1.5$
$VL=AVZ$
$VL(calculated)=15V$

b. Table 32.2

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Vi(V) | 10 | 12 | 13 | 14 | 16 | 18 | 20 | 22 | 24 |
| VL(V) | 9.44 | 9.44 | 9.60 | 9.64 | 14.7 | 14.8 | 14.9 | 14.9 | 14.9 |

Upon coming near the nominal voltage level, the regulation of the system was -2 percent.

Part 3. Shunt Voltage Regulator

a. $VL=(R1+R2)*VZ/R1=3K/2K*10V=15V$
b. $VL(measured)=14.7V$

Table32.3

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Vi(V) | 24 | 26 | 28 | 30 | 32 | 34 | 36 |
| VL(V) | 14.3 | 14.4 | 14.5 | 14.7 | 14.7 | 14.9 | 15.1 |

The regulation of this system was 2.7 percent.

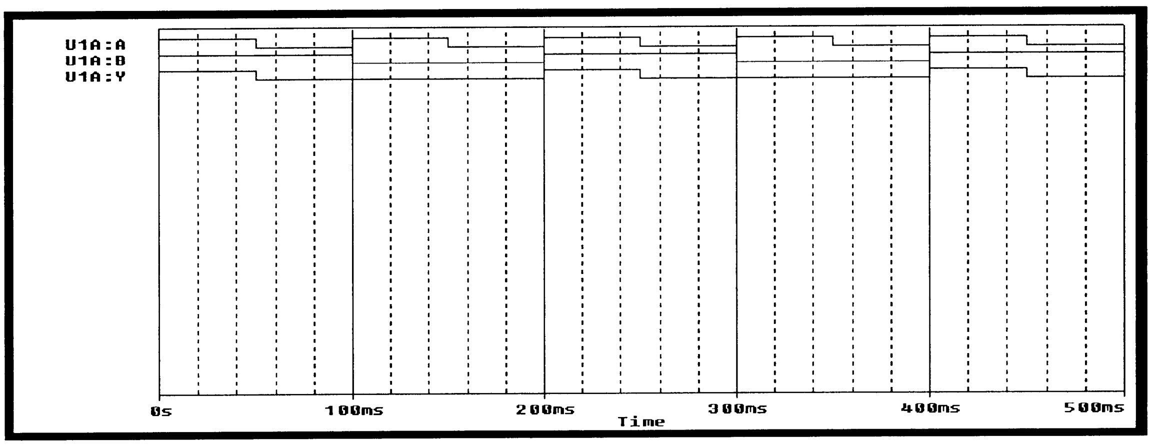
EXPERIMENT 33: Analysis of **AND**, **NAND** and **INVERTER** Logic Gates

Part 1: The **AND** Gate: Computer Simulation

**a.**

Table 33-1

| Input terminal 1 | Input terminal 2 | Output terminal 3 |
|---|---|---|
| 1 | 1 | 1 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 0 | 0 | 0 |




Traces **U1A:A** and **U1A:B** are the inputs to the gate.
Trace **U1A:Y** is the output of the gate.

**b.** The output is at a logical **HIGH** if and only if both input are **HIGH**

**c.** Over the period investigated, the **Off** state is the prevalent one.

**d.**

| Terminal | 25 ms | 125 ms | 375 ms |
|---|---|---|---|
| 1 | 1 | 1 | 0 |
| 2 | 1 | 1 | 0 |
| 3 | 1 | 0 | 0 |

Part 2. The **AND** Gate: Experimental Determination of Logic States

**a.** Ideally, the same.

**b.** 10 Hz

**c.** Should be the same as that for the simulation.

**d.** The amplitude of the **TTL** pulses are about 5 volts, that of the Output terminal 3 is about 3.5 volts.

**e.** The internal voltage drop of across the gate causes the difference between these voltage levels.

Part 3: Logic States versus Voltage Levels

**a.** Example of a calculation: assume: V(V1A:Y) = 3.5 volts, VY = 3.4 volts

$$\%deviation = \frac{3.5V - 3.4V}{3.5V} * 100 = 2.86 percent$$

**b.** For this particular example, the calculated percent deviation falls well within the permissible range.

Part 4: Propagation delay

**a.** For the current case, the propagation delay at the lagging edge of the applied **TTL** pulse should be identical to that at the leading edge of that pulse. Thus, it should measure about 18 nanoseconds.

**b.** Ideally, the propagation delays determined by the simulation should be identical to that determined in the laboratory.

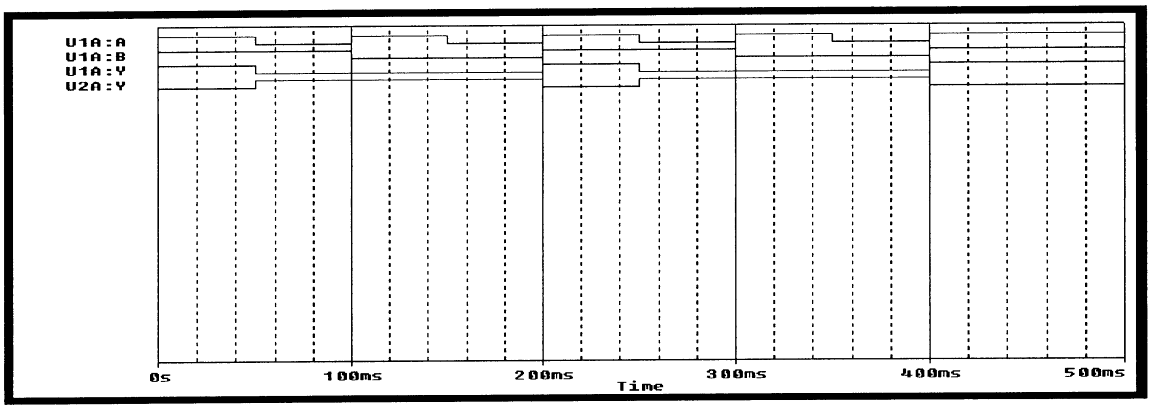
**c.** From Laboratory data, determine the percent deviation using the same procedure as before.

Part 5: **NOT-AND** Logic

**a.**

Table 33-2

| Input1(7408) | Input 2(7408) | Input1(7404) | Output(7404) |
|---|---|---|---|
| 1 | 1 | 1 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 |
| 0 | 0 | 0 | 1 |

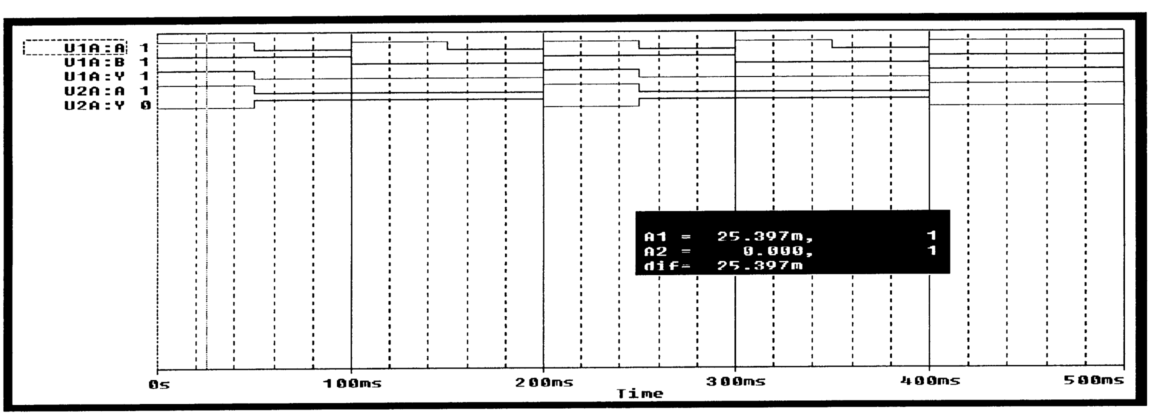



Traces **U1A: A** and **U1A:B** are the inputs to the 7408 gate, **U1A:Y** its output trace. Trace **U2A:Y** is the output of the 7404 gate.

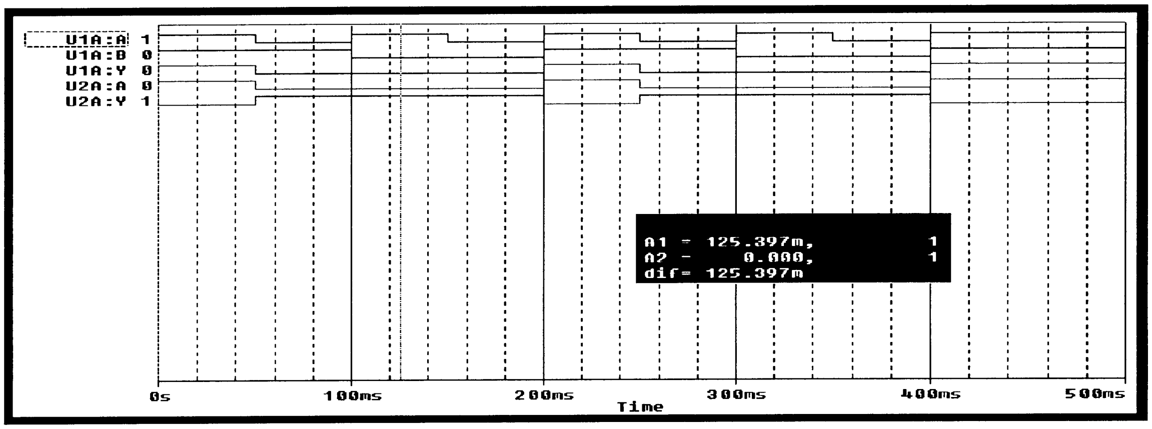
**b.** The Output of the 7404 gate will be **HIGH** if and only if the input to both terminals of the 7408 gate are **HIGH**, otherwise, the output of the 7404 gate will be **LOW**.

**c.** The most prevalent state of the Output terminal of the 7404 gate is **HIGH.**

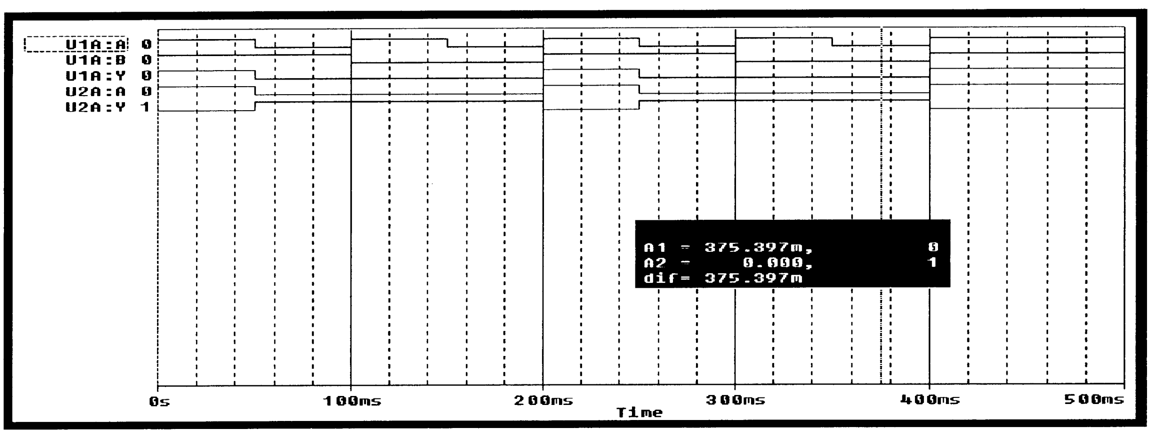
c. The **PSpice** cursor was used to determine the logic states at the requested times. The logic states are indicated at the left margin.
At t = 25 milliseconds:



At t = 125 milliseconds




At t = 375 milliseconds




B. Experimental Determination of Logic States

**a**. They should be relatively close to each other

**b**. They are identical

d. The output of the 7404 gate is the negation of the output of the 7408 gate.

Part 6: the 7400 **NAND** Gate

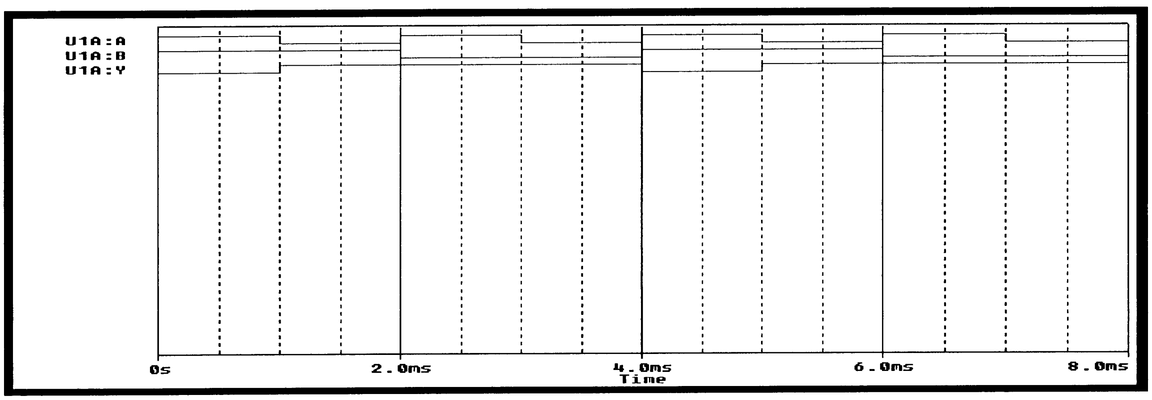
A. Computer Simulation

Table 33-3

**a.**

| Input terminal 1 | Input terminal 2 | Output terminal 3 |
|---|---|---|
| 1 | 1 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 0 | 0 | 1 |

**b.**




B. Experimental Determination of Logic States

Table 33-4

| Input terminal 1 | Input terminal 2 | Output terminal 3 |
|---|---|---|
| 1 | 1 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 0 | 0 | 1 |

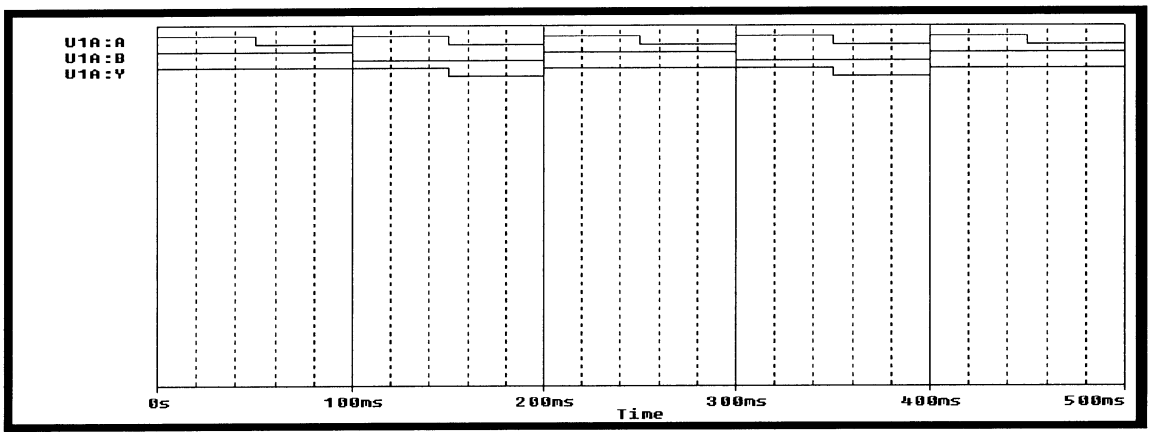
EXPERIMENT 34: Analysis of **OR**, **NOR** and **XOR** Logic Gates

Part 1: the **OR** Gate: Computer Simulation

**a.**

Table 34-1

| Input terminal 1 | Input terminal 2 | Output terminal 3 |
|---|---|---|
| 1 | 1 | 1 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 0 | 0 | 0 |



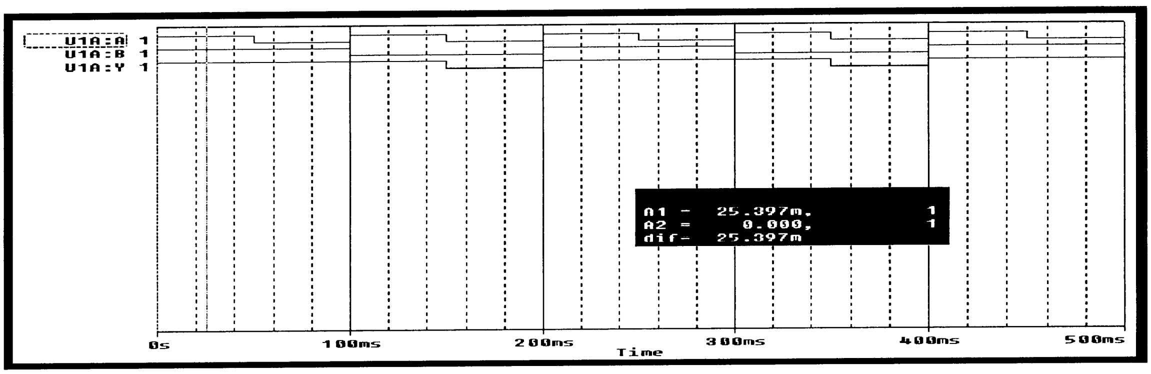

Traces U1A:A and U1A:b are the inputs to the gate
Trace U1A:Y is the output of the gate.

**b.** The output is a logical **LOW** if and only if both inputs are **LOW**, otherwise the output is **HIGH**.

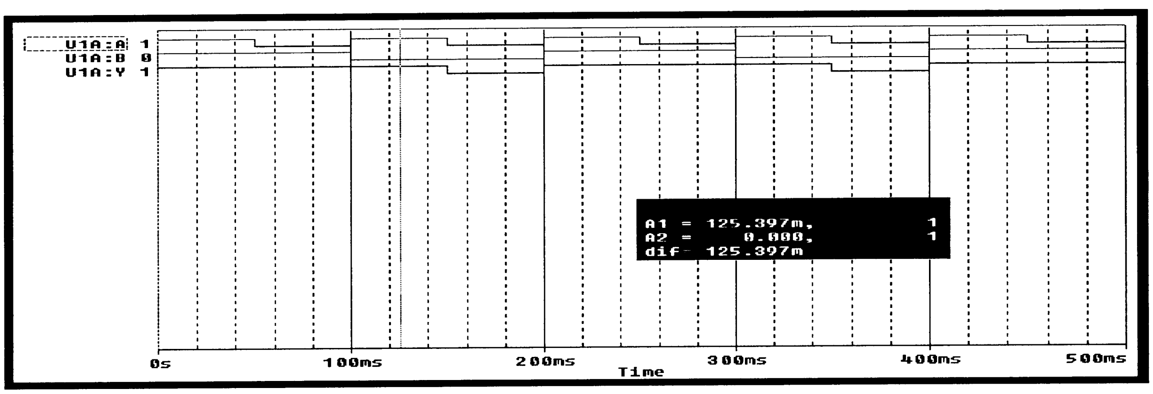
**c.** Over the period investigated, the **ON**, or **HIGH,** state is the prevalent one. This differs from that of the **AND** gate. Its prevalent state was the **OFF** or **LOW** state.

**d.** The **PSpice** cursor was used to determine the logic states at the requested times. The logic states are indicated at the left margin.

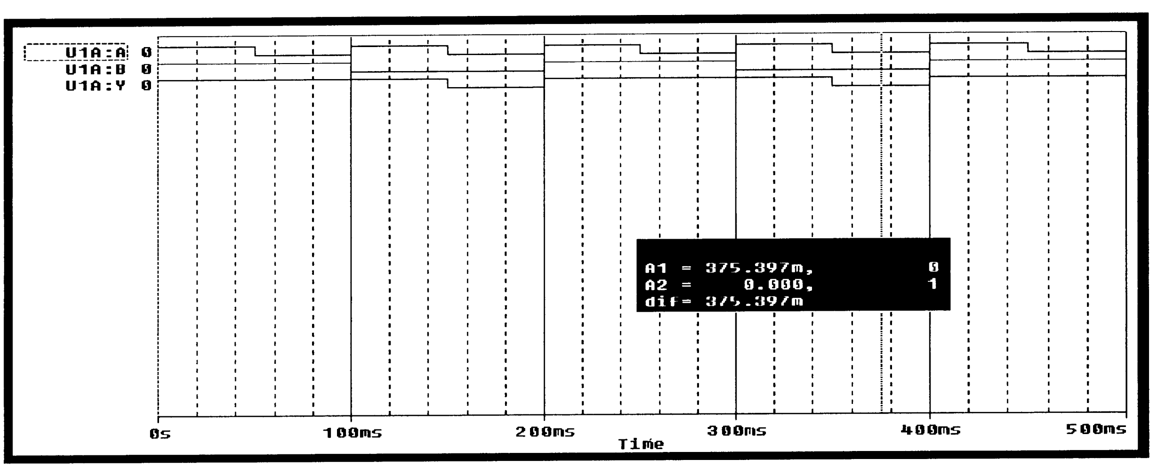
At t = 25 milliseconds:




At t = 125 milliseconds




At t = 375 milliseconds



Part 2: the OR Gate: Experimental Determination of Logic States

**a.** The pulse of 100 milliseconds of the **TTL** pulse is identical to that of the simulation pulse.

**b.** The frequency of 10 Hz of the **TTL** pulse is identical to that of the simulation pulse.

**c.** They were determined to be the same at the indicated times.

**d.** The voltage of the **TTL** pulse was 5 volts. The voltage at the output terminal was 3.5 volts.

**e.** The difference in these two voltages is caused by the internal voltage drop across the 7432 gate.

Part 3: Logic States versus Voltage Levels

**a.** The PSpice simulation produced the identical traces as sown on the PROBE plot for Figure 34-2.

**b.** Example of a calculation: assume V(V1A:Y) = 3.6 volts, VY = 3.4 volts

$$\%deviation = \frac{3.6V - 3.4V}{3.6V} * 100 = 5.56 percent$$

**c.** It is larger by (5.56-2.86) = 2.7 percent.

Part 4: Combining **AND** with **OR** Logic

A. Computer Simulation

**a.**

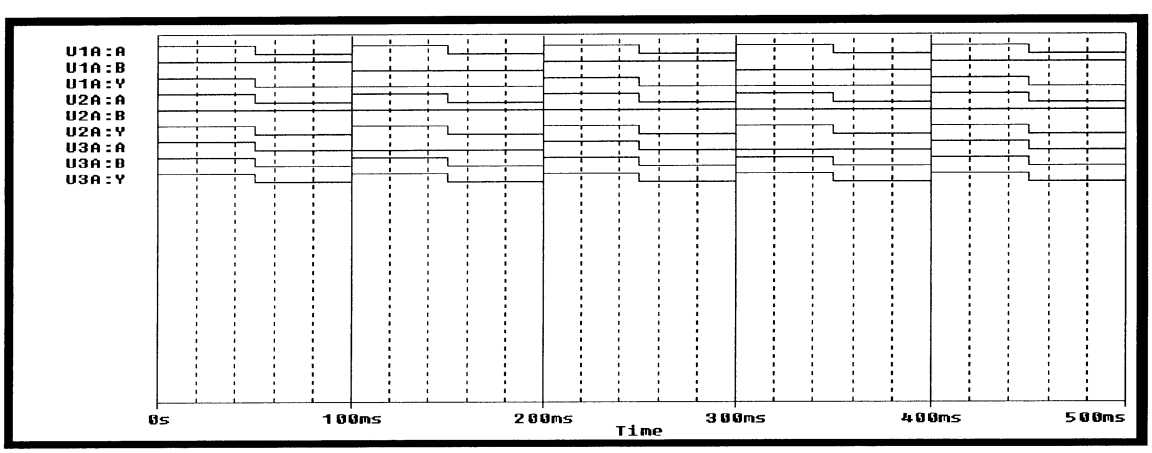
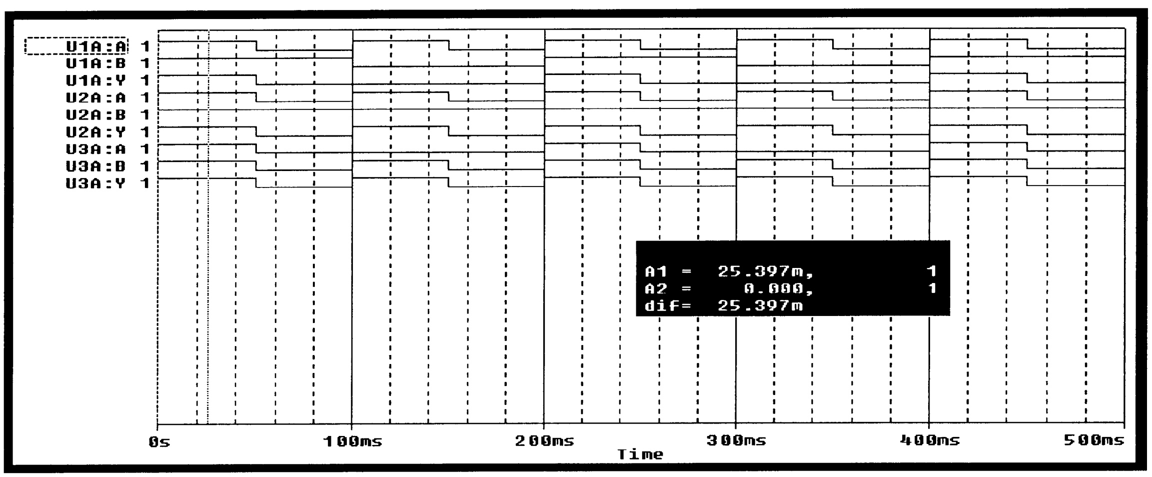


Table 34-2

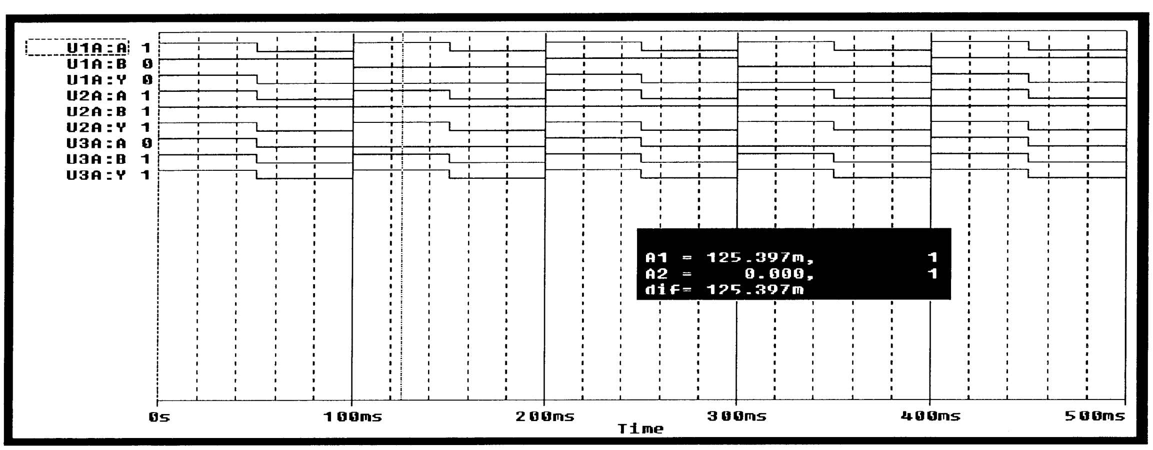
| U1A:A | U1A:B | U1A:Y | U2A:A | U2A:B | U2A:Y | U3A:A | U3A:B | U3A:Y |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 |
| 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |

**c.**

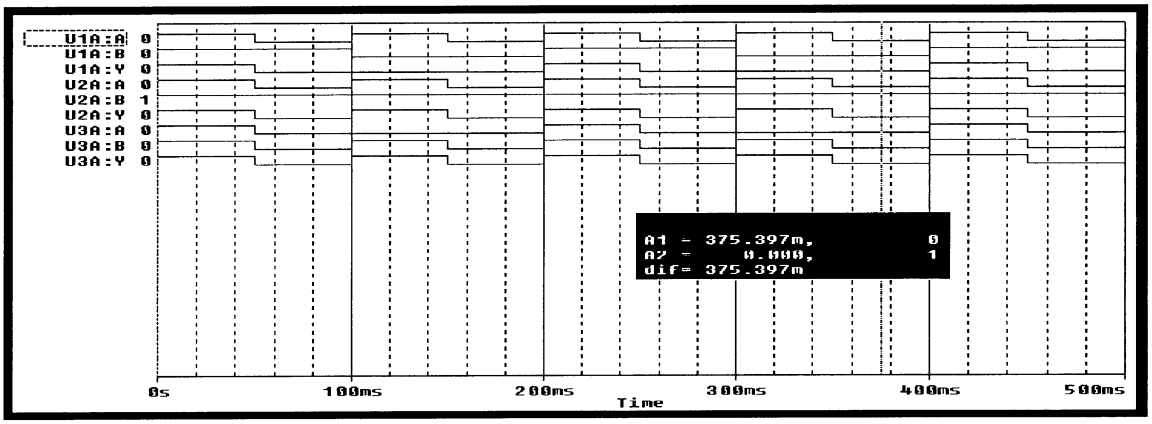
At t = 25 milliseconds




At t = 125 milliseconds



At t = 375 milliseconds




**d.** The output of the 7432 gate, U3A:Y, is evenly divided between the ON state and the OFF state during the simulation.

**B**. Experimental Determination of Logic States

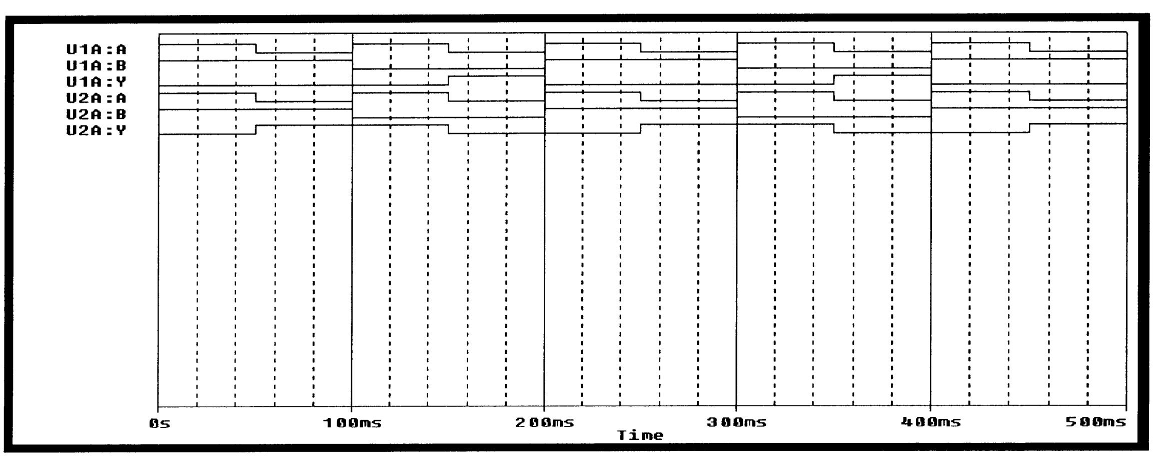
**a.** The logic states of the simulation and those experimentally determined are identical.

**b.** The logic state of the output terminal U3A:Y is identical to that of the **TTL** clock.

**c.** The logic state of the output terminal U3A:Y id identical to that of the output terminal U2A:Y of the U2A gate.

Part 5: **NOR** and **XOR** Logic combined

**a.**



**b**. The output trace of the 7402 **NOR** gate, U1A:Y and the output trace of the **XOR** gate, U2A:Y are both shown in the above plot.

**c.**

Table 34-3

| U1A:A | U1A:B | U1A:Y | U2A:A | U2A:B | U2A:Y |
|---|---|---|---|---|---|
| 1 | 1 | 0 | 1 | 1 | 0 |
| 0 | 1 | 0 | 0 | 1 | 1 |
| 1 | 0 | 0 | 1 | 0 | 1 |
| 0 | 0 | 1 | 0 | 0 | 0 |

**d.** The output of the 7402 gate, U1A:Y is **HIGH** if and only if both inputs are **LOW**, otherwise the output is **LOW**.

**e.** This is a logical inversion of the **OR** gate.

**e.** The output of the 7486 gate is **HIGH** if and only if the two inputs U2A:A and U2A:B are at opposite logic levels.

**g.** The logic state of the **OR** gate is **HIGH** if both inputs are at opposite logic levels and if both inputs are **HIGH.**

B. Experimental Determination of Logic States

**a.** The experimental data is identical to that obtained from the simulation.

**b.** Refer to the data in Table 34-3.

**c.** Refer to the data in Table 34-3.

**d.** Refer to the data in Table 34-3.

**e.** The output of the 7486 XOR gate is **HIGH** if and only if its input terminals have opposite logic levels, otherwise, its output is at a **LOW.**

**f.** For an **OR** gate, its output is **HIGH** if both, or at least one input terminal, is **HIGH**. Its output will be **LOW** if both inputs are **LOW**. For an **XOR** gate, its output is **HIGH** if and only if both input terminals are at opposite logic levels, otherwise, the output will be **LOW**.

**g.** The output of an **XOR** gate will be **HIGH** when both input terminals are at opposite logic levels. Otherwise, its output is at a logical **LOW.**

EXPERIMENT 35: Analysis of Integrated Circuits

**a.** The PROBE data shows the flip flap to be in the **SET** condition.

**b.** The flip flop goes to **RESET** at 200 milliseconds because the D input terminal goes negative. The flip flop goes to **SET** at 400 milliseconds because both the **CLOCK** input and the **D** input are positive.

c. The importance to note is that the **D** input can be negative and positive during the time that the **Q** output is low.

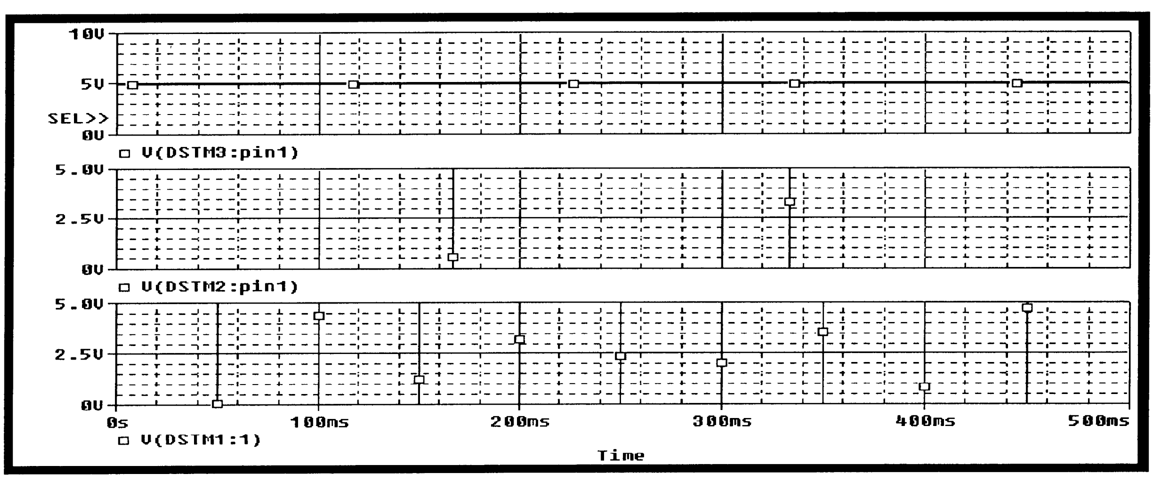
**d.** After the initial **SET** condition of the flip flap, and after a **RESET** state of 200 milliseconds, the flip flop returns to its **SET** condition because at 400 milliseconds, both the **CLOCK** and the **D** inputs are positive.

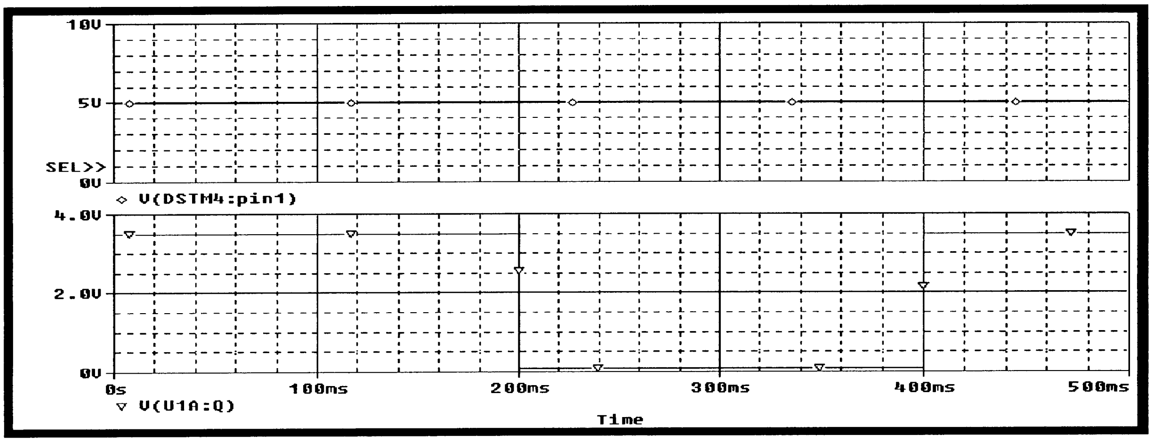
**e.** Starting from a **SET** condition, a transition to **RESET** will occur when the D input is negative and the **CLOCK** pulse goes positive. The flip flop will **SET** again when the **D** input is positive and the **CLOCK** goes positive.

**f.** The conditions stated in answer previous answer define a positive edge triggered flip flop as defined in the first paragraph of Part 1.

**g.** See above answers

**h.**






**i.** Let us assume that D is high when a positive a **CLOCK** pulse goes high. This will **SET** the flip flop. This **SET** will be stored, or remembered, until **D** is negative and the **CLOCK** triggers positive again. At that time, the flip flop will **RESET.** This **RESET** will be stored, or remembered, until **D** is positive and the **CLOCK** triggers positive again. At that time the flip flop will **SET**. Events repeat themselves after this.

B. Experimental Determination of Logic States

**a.** Both input terminals are held at 5 volts during the experiment.

**b.** The amplitude of the voltage of the **TTL** pulse is 5 volts.

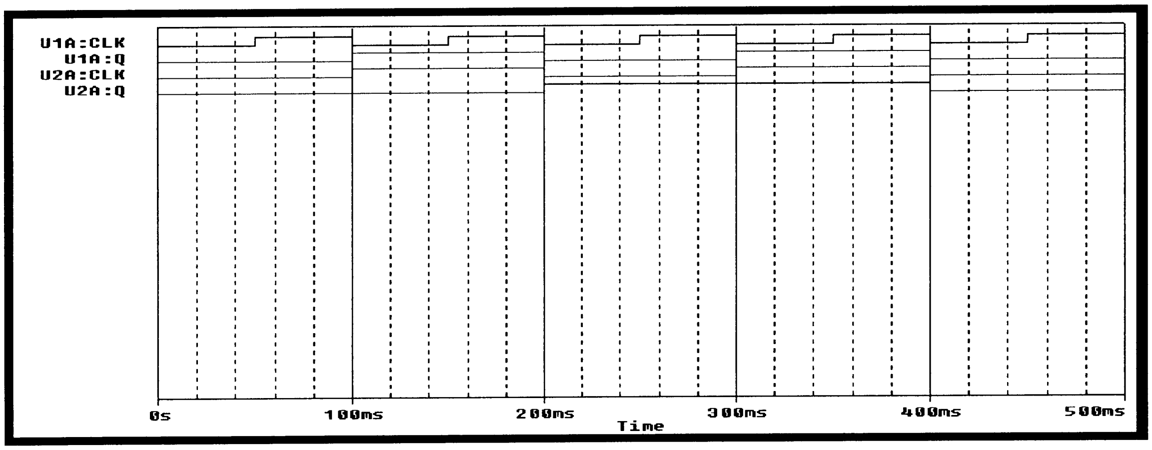
**c.** The amplitude of the output voltage at the **Q** terminal is 3.5 volts.

**d.** The difference between the input voltages and the output voltage is caused by the voltage drop through the flip flop

**e.** The experimental and the simulation transition states occur at the same times.

Part 2: Frequency Division

Answer all questions below with reference to the following **PROBE** plot.




**a.** The frequency at the **U1A:Q** terminal is 5 Hz.

**b.** The frequency **at** the **U1A:Q** terminal is one-half that of the **U1A:CLK** terminal.

**c.** The frequency at the **U2A:Q** terminal is 2.5 Hz

**d.** The frequency of the U2A:Q terminal is one-half that of the **U2A:CLK** terminal.

**e.** The overall frequency reduction of the output pulse **U2A:Q** relative to the input pulse **U1A:CLK** is one-fourth.

**f.** Each flip flop reduced its input frequency by a factor of two.

**g.** It would take four 74107 flip-flops.

B. Experimental Determination of Logic States.

**a.** The **J** and **CLR** terminals of both flip flops are kept at 5 volts during the experiment.

**b.** The voltage level of the **U1A:CLK** terminal is 5 volts. The voltage level of the **U2A:CLK** terminal is 3.5 volts. The voltage level of the **U2A:Q** terminal is 3 volts.

**c.** Refer to the above **PROBE** plot.

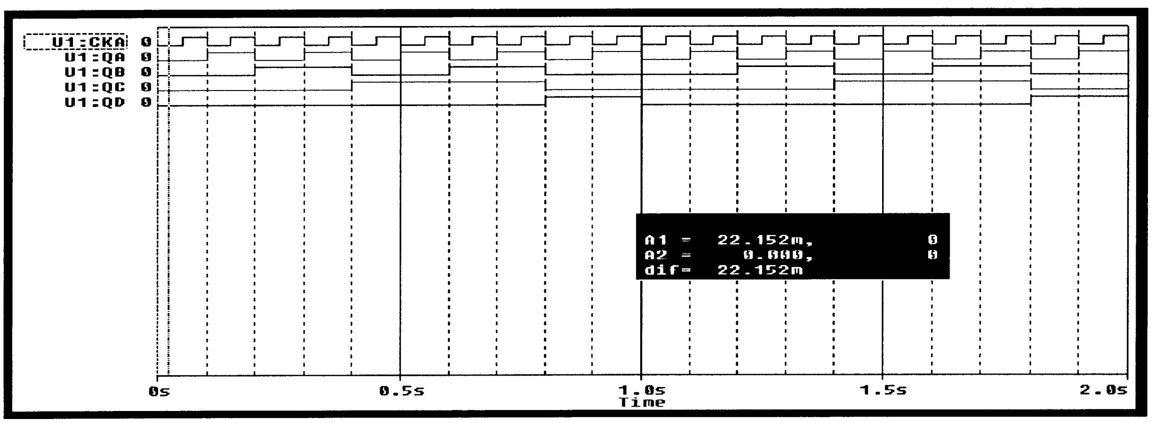
**d.**

| Pulse | Frequency |
|---|---|
| **U1A:CLK** | 10.0 Hz |
| **U1A:Q** | 5.0 Hz |
| **U2A:CLK** | 5.0 Hz |
| **U2A:Q** | 2.5 Hz |

**e.** They are identical.

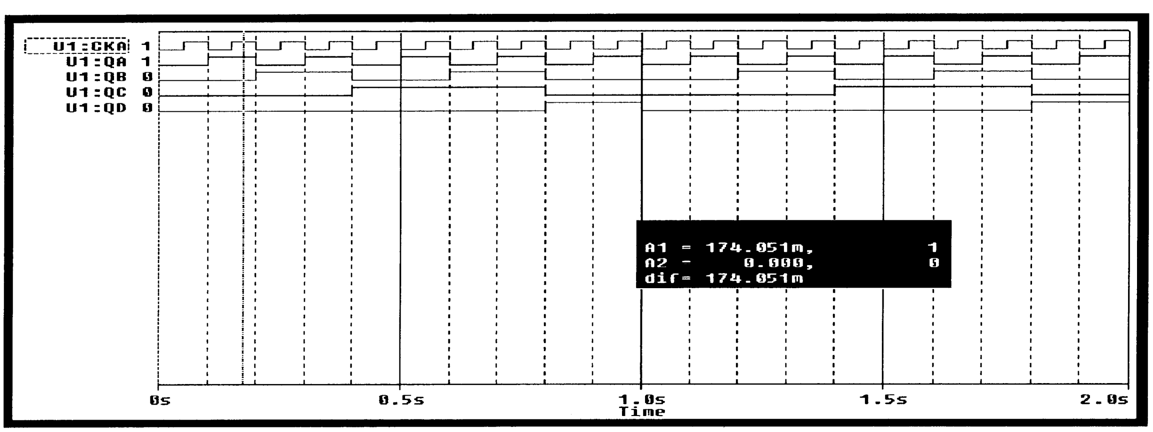
Part 3: An Asynchronous Counter: the 7493A Integrated Circuit

**a.**

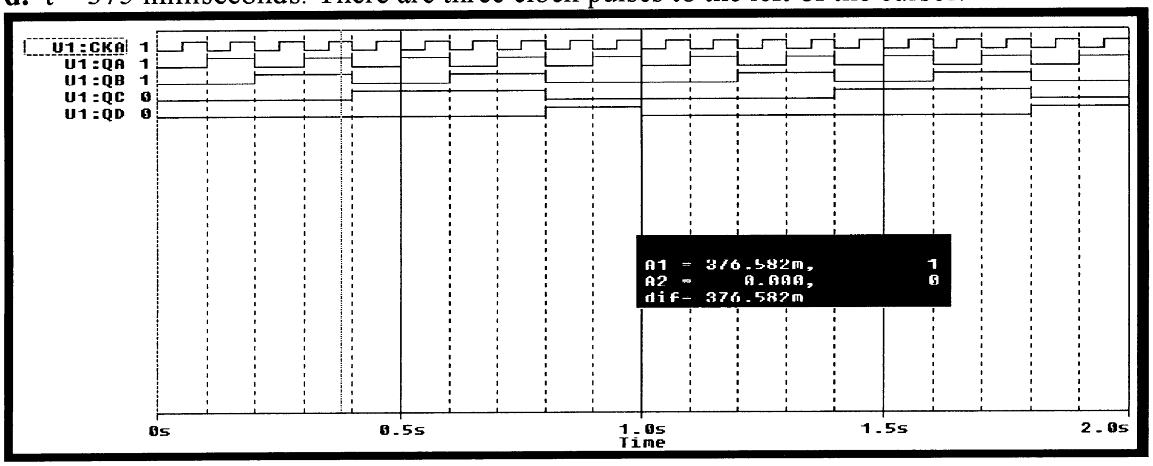



**b.** See **PROBE** plot above.

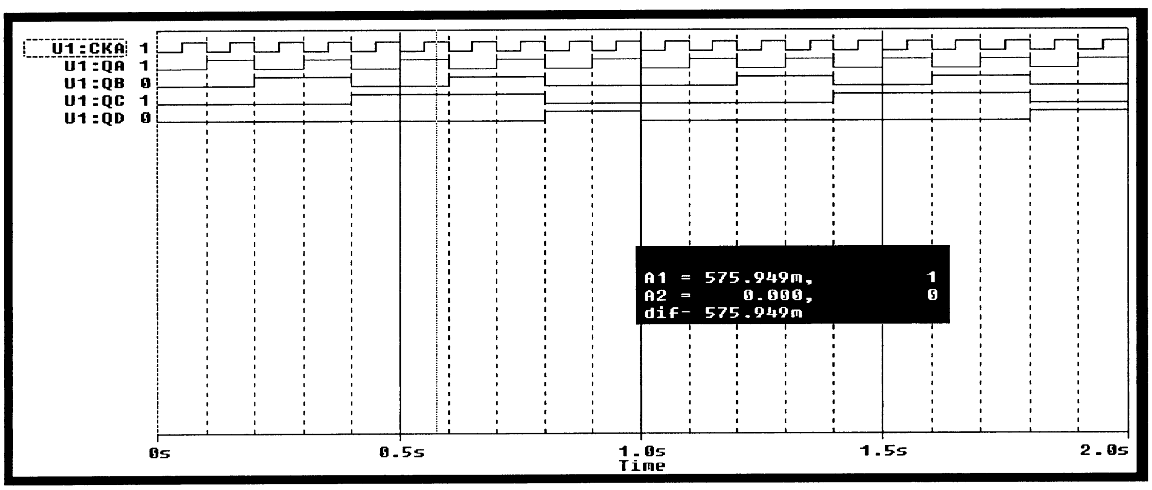
**c.** t = 175 milliseconds. There is one clock pulse to the left of the cursor.



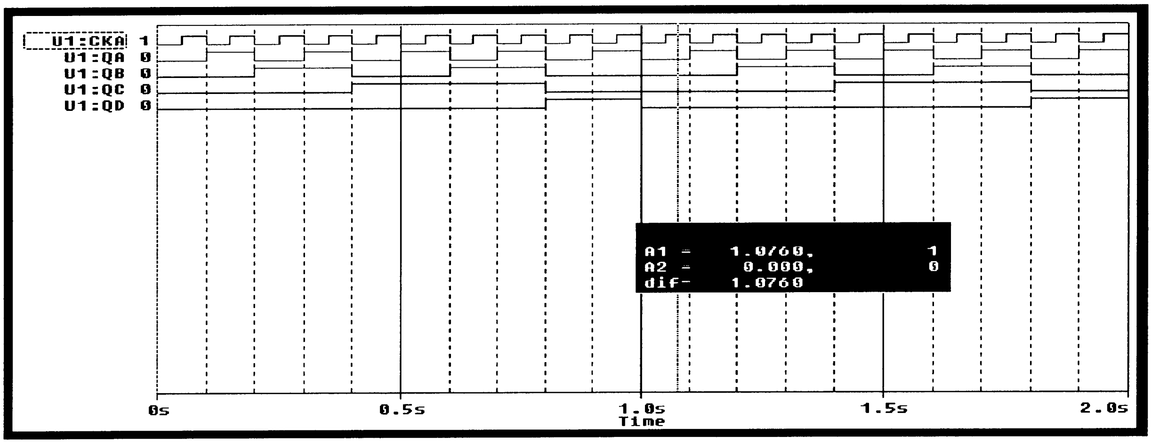
**d.** t = 375 milliseconds. There are three clock pulses to the left of the cursor.




**e.** t = 575 milliseconds. There are five clock pulses to the left of the cursor.



**f.** t = 1.075 seconds. There are ten clock pulses to the left of the cursor.

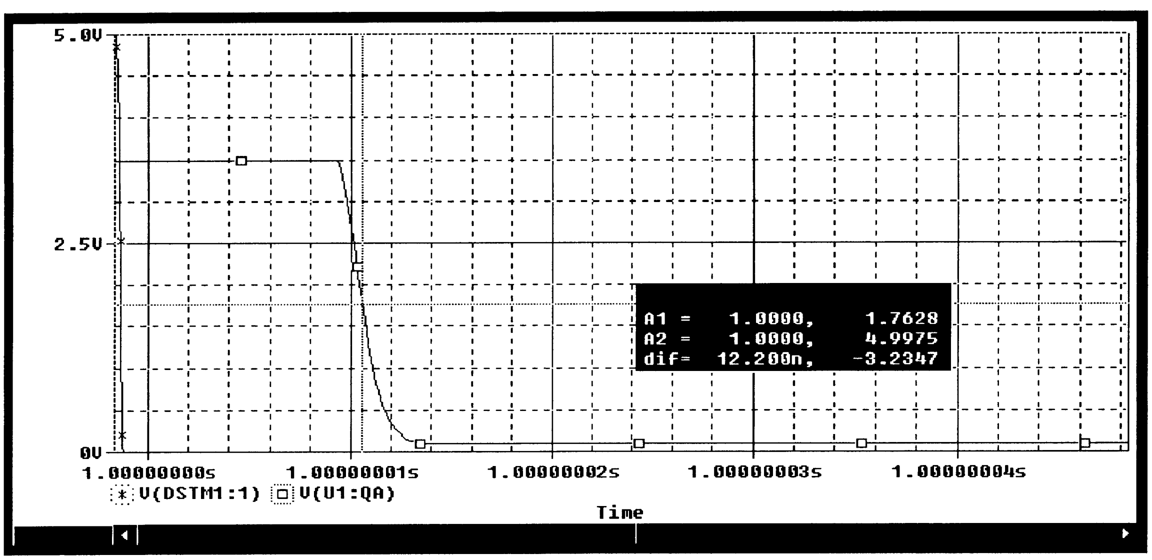



**g.** At t = 1.075 milliseconds, the output terminals, **QA**, **QB**, **QC** and **QD** have resumed their initial states.

**h.** **The MOD 10** counts to ten in binary code after which it recycles to its original condition.

**i.** The output terminal **QA** represents the most significant digit.

**j.** The indicated propagation delay is about 12.2 nanoseconds.



B. Experimental Determination of Logic States

**a.** The logic states of the output terminals were equal to the number of the **TTL** pulses.

**b.** The experimental data is equal to that obtained from the simulation.

**c.** The propagation delay measured was about 13 nanoseconds.

**d.** The difference in the experimentally determined propagation delay was 13 nanoseconds compared to a propagation delay of 12 nanoseconds as obtained from the simulation data.

# Test Item File

Prepared by Rajiv Kapadia

# Chapter 1: Semiconductor Diodes

## *MULTIPLE CHOICE*

1. The characteristic of an ideal diode are those of a switch that can conduct current:
   (a) in both directions
   (b) in one direction only
   (c) in both directions but in only one direction at a time
   (d) depends on the circuit it is used in

2. When a diode is doped with either a pentavalent or a trivalent impurity its resistance will __________.
   (a) increase
   (b) decrease
   (c) make the resistance stable against variation due to temperature
   (d) none of the above

3. To make a P-type of semiconductor material you need a doping material that is:
   (a) pentavalent
   (b) tetravalent
   (c) trivalent
   (d) hexavalent

## *SHORT ANSWER*

4. The majority carriers in the P-Type material are the _______ while in the N-Type material are the ________.

## *MULTIPLE CHOICE*

5. The direction of the arrow in the diode symbol points in the direction of:
   (a) positive terminal under forward bias
   (b) from N-type of semiconductor to P-type semiconductor material
   (c) from P-type of semiconductor to N-type semiconductor material
   (d) leakage current flow

6. The reverse saturation current of a diode will just about _________ for every 10° C rise in the diode temperature.
   (a) double
   (b) half
   (c) increase, proportionately with temperature
   (d) decrease, proportionately with temperature

7. With increase in temperature the current flowing through the forward biased diode will ________ while the voltage drop across the forward biased diode is __________.
   (a) increase; increased
   (b) decrease; held constant
   (c) increase; held constant
   (d) held constant; decreased

8. The DC or the static resistance of the diode is given by the expression:
   (a) $R_D = V_D / I_D$
   (b) $R_D = \nabla V_D / \nabla I_D$
   (c) $R_D = (V_{D1} - V_{D2})/(I_{D1} - I_{D2})$
   (d) all of the above can be used

9. The piecewise linear model, equivalent circuit of the diode consists of:
   (a) a junction capacitor, a battery, a small resistor and the ideal diode
   (b) a battery, a small resistor and the ideal diode
   (c) a battery and the ideal diode
   (d) the ideal diode

10. Some of the modern ohmmeters have a diode test setting. If you do not have one of these ohmmeters then to test the diode you need to check its resistance in the forward and the reverse direction. These resistances should be:
    (a) relatively high in the forward direction and relatively low in the reverse direction
    (b) relatively low in the forward direction and relatively low in the reverse direction
    (c) relatively low in the forward direction and relatively high in the reverse direction
    (d) relatively high in the forward direction and relatively high in the reverse direction

11. In the Zener region the current _________ and the voltage across the diode ___________.
    (a) is almost constant; can increase a lot
    (b) is almost constant; is almost constant
    (c) can increase a lot; is almost constant
    (d) can increase a lot; can increase a lot

12. Suppose that a particular Zener diode has a temperature coefficient of 0.00575. If the temperature of this Zener diode increases by 50° C, what is the change in $V_Z$?
    (a) 50 * 0.00575 = 0.2875
    (b) 5 * 0.00575 = 0.02875
    (c) 10 * 0.00575 = 0.0575
    (d) Cannot tell without looking at the circuit in which the Zener is used.

13. In an LED the visible light is produced when:
    (a) the electrons and the holes combine with each other
    (b) when an electron enters the diffusion region
    (c) when a hole enters the diffusion region
    (d) when the electrons and the holes combine in the diffusion region

14. The light emitting diodes emit light when the diode is _________.
    (a) forward biased
    (b) reversed biased
    (c) operating in the Zener region

15. As semiconductor devices have become _________ one of the primary purposes of the container is simply to provide some means of handling.
    (a) larger
    (b) widely used
    (c) miniaturized
    (d) more powerful
    (e) less powerful

16. The advantage of the miniaturization of electronic devices is that they:
    (a) improve reliability
    (b) reduce cost
    (c) increase speed
    (d) reduce system size and weight
    (e) all of the above

17. The characteristics of an ideal diode are those of a switch that can conduct current in:
    (a) both directions
    (b) only one direction
    (c) the reverse bias direction
    (d) the high voltage direction
    (e) none of the above

18. The _________ diode is a short circuit for the region of conduction and it is an open circuit in the region of nonconduction.
    (a) ideal
    (b) actual
    (c) power
    (d) small
    (e) large

19. The ideal diode symbol has an arrow that points in the direction of:
    (a) the leakage current flow
    (b) the forward current flow
    (c) positive terminal under forward bias
    (d) all of the above

20. The term _________ is applied to any material that will support a generous flow of charge when a voltage source of limited magnitude is applied across its terminals.
    (a) conductor
    (b) insulator
    (c) semiconductor
    (d) dielectric
    (e) none of the above

21. The term _________ is applied to a material that offers a very low level of conductivity under pressure from an applied voltage.
    (a) conductor
    (b) insulator
    (c) semiconductor
    (d) dielectric
    (e) none of the above

22. The term _________ is applied to a material that has a conductivity level somewhere between the extremes of conductivity.
    (a) conductor
    (b) insulator
    (c) semiconductor
    (d) dielectric
    (e) none of the above

23. Which of the following is not a commonly used semiconductor material?
    (a) carbon
    (b) lead
    (c) silicon
    (d) germaniun
    (e) none of the above

24. As temperature increases, semiconductor materials tend to have:
    (a) an increased number of free electrons
    (b) a decreased number of free electrons
    (c) reduced conduction
    (d) relatively unchanged conduction
    (e) none of the above

25. Pentavalent elements have _________ valence electrons.
    (a) 1
    (b) 3
    (c) 5
    (d) 8
    (e) none of the above

26. Doping is used to:
    (a) decrease the conductivity of an intrinsic semiconductor
    (b) increase the conductivity of an intrinsic semiconductor
    (c) stabilize the conductivity of an intrinsic semiconductor
    (d) increase the insulative quality of an intrinsic semiconductor
    (e) none of the above

27. When pentavalent elements are used in doping, the resulting material is called _________ material and has an excess of _________.
    (a) N-type; valence-band holes
    (b) N-type; conduction-band electrons
    (c) P-type; valence-band holes
    (d) P-type; conduction-band electrons
    (e) none of the above

28. When trivalent elements are used in doping, the resulting material is called _________ material and has an excess of _________.
    (a) N-type; valence-band holes
    (b) N-type; conduction-band electrons
    (c) P-type; valence-band holes
    (d) P-type; conduction-band electrons
    (e) none of the above

29. In an N-type material, the majority carriers are:
    (a) conduction-band electrons
    (b) conduction-band holes
    (c) valence-band electrons
    (d) valence-band holes
    (e) neutral atoms

30. In a P-type material, the minority carriers are:
    (a) conduction-band electrons
    (b) conduction-band electrons
    (c) valence-band electrons
    (d) valence-band holes
    (e) charged atoms

31. Pentavalent atoms are often referred to as:
    (a) donor atoms
    (b) minority carriers
    (c) acceptor atoms
    (d) majority carriers
    (e) none of the above

32. When a PN junction is reverse-biased, its junction resistance is:
    (a) high
    (b) low
    (c) determined by the components that are external to the device
    (d) constantly changing
    (e) none of the above

33. A PN junction is forward biased when:
    (a) the applied potential causes the N-type material to be more positive than the P-type material
    (b) the applied potential causes the N-type material to be more negative than the P-type material
    (c) both materials are at the same potential
    (d) all of the above
    (e) none of the above

34. A PN junction is reverse biased when:
    (a) the applied potential causes the N-type material to be more positive than the P-type material
    (b) the applied potential causes the N-type material to be more negative than the P-type material
    (c) both materials are at the same potential
    (d) the current flow across the junction is based on minority carrier transfer
    (e) all of the above

35. The isolated atomic energy structure associated with electron orbital shells is called a/an:
    (a) conduction band
    (b) energy band
    (c) valence band
    (d) energy gap
    (e) none of the above

36. The more distant the electron is from the nucleus:
    (a) the higher its energy
    (b) the lower its energy
    (c) the less likely it is to be invalued in conduction
    (d) all of the above
    (e) none of the above

37. The energy required to move an electron in silicon from the valence band to the conduction band is:
    (a) 0.67 EV
    (b) 10 EV
    (c) 1.8 EV
    (d) 1.1 EV
    (e) none of the above

38. Silicon diodes have been more significantly developed than germanium because:
    (a) it is cheaper
    (b) it is easier to produce
    (c) it is more tolerant of heat
    (d) it has a lower forward voltage drop

39. When a PN junction's depletion layer is narrowed and the device acts as a nearly perfect conductor it is:
    (a) forward biased
    (b) reverse biased
    (c) unbiased
    (d) none of the above

40. The maximum reverse bias potential that can be applied to a Zener diode before it enters the Zener region is called the:
    (a) threshold voltage
    (b) PIV
    (c) barrier voltage
    (d) depletion voltage
    (e) none of the above

41. When a PN junction is reverse biased, the depletion layer is __________ and the device acts as a near-perfect __________.
    (a) narrowed; conductor
    (b) narrowed; insulator
    (c) widened; conductor
    (d) widened; insulator
    (e) none of the above

42. The electrode with N-type material of a diode is called the:
    (a) anode
    (b) cathode
    (c) depletion region
    (d) Zener region
    (e) none of the above

43. The electrode with P-type material of a diode is called the:
    (a) anode
    (b) cathode
    (c) depletion region
    (d) Zener region
    (e) none of the above

44. When forward biased a PN junction diode will conduct when the arrow in the schematic symbol:
    (a) points to the more negative potential
    (b) points to the more positive potential
    (c) points to ground
    (d) points away from ground
    (e) none of the above

45. Determine the static resistance of a diode whose $V_D = 0.8$ V and $I_D = 4$ mA.
    (a) 4 ohms
    (b) 80 ohms
    (c) 200 ohms
    (d) 1000 ohms
    (e) none of the above

46. What is the static resistance of the diode at 25 degrees C and -30 Volts and $I_D = 0.5\ \mu A$?
    (a) 60 M ohms
    (b) 30 M ohms
    (c) 3 K ohms
    (d) 60 K ohms
    (e) 600 ohms

47. The steeper the slope of the diode characteristic curve:
    (a) the greater the ac resistance
    (b) the greater diode's capacitance
    (c) the less the diode's ac resistance
    (d) the less diode's breakdown voltage
    (e) all of the above

48. The average diode resistance $R_{av}$ is defined by __________ between the limits of operations.
    (a) the distance
    (b) a curved line
    (c) a straight line
    (d) a characteristic curve
    (e) none of the above

49. The model of the diode represents the device as:
    (a) an ideal diode
    (b) in series with a battery
    (c) in series with a battery and a resistor
    (d) an ideal diode and a switch
    (e) a switch and a battery

50. The diffusion capacitance of a diode is a shunt capacitance effect that occurs when the diode:
    (a) is large
    (b) is small
    (c) is forward biased
    (d) is reverse biased
    (e) none of the above

51. The transition capacitance of a diode is a shunt capacitive effect that occurs when the diode:
    (a) is large
    (b) is small
    (c) is forward biased
    (d) is reverse biased
    (e) none of the above

52. When tested with an ohmmeter, a diode should have a relatively high resistance for _________ condition.
    (a) the reverse-biased
    (b) the forward-biased
    (c) both reverse- and forward-bias
    (d) none-biased
    (e) none of the above

53. When tested with an ohmmeter, a diode should have a relatively small resistance for _________ conditions.
    (a) the reverse-biased
    (b) the forward-biased
    (c) both reverse- and forward-biased
    (d) none-biased
    (e) none of the above

54. The nominal voltage for a 1N961 Fairchild 10 V, Zener diode has a temperature coefficient of 0.072. If the temperature increases by 50 degrees C, what is the change in $V_Z$?
    (a) 0.54 V
    (b) 0.36 V
    (c) 0.72 V
    (d) 0.108 V
    (e) none of the above

55. The act of giving off light by applying an electrical source of energy is called:
    (a) light power
    (b) laser
    (c) photons
    (d) electroluminescence
    (e) all of the above

1. Answer: (b) Difficulty: 2 Section: 2 Objective: 1
2. Answer: (b) Difficulty: 2 Section: 3 Objective: 1
3. Answer: (c) Difficulty: 2 Section: 5 Objective: 1
4. Answer: holes, electrons Difficulty: 2 Section: 5 Objective: 1
5. Answer: (c) Difficulty: 2 Section: 6 Objective: 1
6. Answer: (a) Difficulty: 2 Section: 7 Objective: 1
7. Answer: {c;d} Difficulty: 2 Section: 7 Objective: 1
8. Answer: (a) Difficulty: 2 Section: 8 Objective: 1
9. Answer: (b) Difficulty: 2 Section: 9 Objective: 1
10. Answer: (c) Difficulty: 2 Section: 14 Objective: 1
11. Answer: (c) Difficulty: 2 Section: 15 Objective: 1
12. Answer: (a) Difficulty: 2 Section: 15 Objective: 1
13. Answer: (a) Difficulty: 2 Section: 16 Objective: 1
14. Answer: (a) Difficulty: 2 Section: 16 Objective: 1
15. Answer: (c) Difficulty: 1 Section: 1 Objective: 1
16. Answer: (e) Difficulty: 2 Section: 2 Objective: 1
17. Answer: (b) Difficulty: 1 Section: 1 Objective: 2
18. Answer: (a) Difficulty: 1 Section: 2 Objective: 2
19. Answer: (b) Difficulty: 2 Section: 3 Objective: 2
20. Answer: (a) Difficulty: 1 Section: 1 Objective: 3
21. Answer: (b) Difficulty: 1 Section: 2 Objective: 3
22. Answer: (c) Difficulty: 1 Section: 3 Objective: 3
23. Answer: (b) Difficulty: 2 Section: 4 Objective: 3
24. Answer: (a) Difficulty: 2 Section: 5 Objective: 3
25. Answer: (c) Difficulty: 2 Section: 1 Objective: 5

26. Answer: (b) Difficulty: 2 Section: 2 Objective: 5

27. Answer: (b) Difficulty: 2 Section: 3 Objective: 5

28. Answer: (c) Difficulty: 2 Section: 4 Objective: 5

29. Answer: (a) Difficulty: 2 Section: 5 Objective: 5

30. Answer: (a) Difficulty: 2 Section: 6 Objective: 5

31. Answer: (a) Difficulty: 2 Section: 7 Objective: 5

32. Answer: (a) Difficulty: 2 Section: 1 Objective: 6

33. Answer: (b) Difficulty: 2 Section: 2 Objective: 6

34. Answer: (e) Difficulty: 2 Section: 3 Objective: 6

35. Answer: (b) Difficulty: 2 Section: 1 Objective: 4

36. Answer: (a) Difficulty: 2 Section: 2 Objective: 4

37. Answer: (d) Difficulty: 2 Section: 3 Objective: 4

38. Answer: (c) Difficulty: 2 Section: 4 Objective: 6

39. Answer: (a) Difficulty: 2 Section: 5 Objective: 6

40. Answer: (b) Difficulty: 2 Section: 6 Objective: 6

41. Answer: (d) Difficulty: 2 Section: 7 Objective: 6

42. Answer: (b) Difficulty: 2 Section: 8 Objective: 6

43. Answer: (a) Difficulty: 2 Section: 9 Objective: 6

44. Answer: (a) Difficulty: 2 Section: 10 Objective: 6

45. Answer: (c) Difficulty: 2 Section: 1 Objective: 8

46. Answer: (a) Difficulty: 2 Section: 2 Objective: 8

47. Answer: (c) Difficulty: 2 Section: 3 Objective: 8

48. Answer: (c) Difficulty: 2 Section: 4 Objective: 8

49. Answer: (c) Difficulty: 2 Section: 1 Objective: 9

50. Answer: (c) Difficulty: 2 Section: 1 Objective: 11

51. Answer: (d) Difficulty: 2 Section: 2 Objective: 11

52. Answer: (a) Difficulty: 2 Section: 1 Objective: 14

53. Answer: (b) Difficulty: 2 Section: 2 Objective: 14

54. Answer: (b) Difficulty: 2 Section: 1 Objective: 15

55. Answer: (d) Difficulty: 2 Section: 1 Objective: 16

# Chapter 2: Diode Applications

*MULTIPLE CHOICE*

1. For the circuit shown in Figure 2.1.1 determine the load line intersection with the two axis:
   (a) $V_D$ = 10 Volts and $I_D$ = 1m Amp.
   (b) $V_D$ = 1 Volts and $I_D$ = 1m Amp.
   (c) $V_D$ = 1 Volts and $I_D$ = 10m Amp.
   (d) $V_D$ = 10 Volts and $I_D$ = 10m Amp.

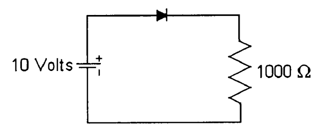


Figure 2.1.1

*SHORT ANSWER*

2. The operating point of the diode is where the _________ intersects the diode _________ curve.

*MULTIPLE CHOICE*

3. If one silicon diode and one germanium diode are connected in series, the voltage drop across the combination of the two diodes will be equal to:
   (a) the forward drop equal to that of the silicon diode
   (b) the forward drop equal to that of the germanium diode
   (c) the forward drop equal to that of the sum of the voltage drops across the two diodes
   (d) the forward drop equal to that of the difference of the voltage drops across the two diodes

*SHORT ANSWER*

4. If the current flowing in the diode due to the applied voltage source is in the direction of the diode symbol's arrow then the diode is operating in the _____ state.

*MULTIPLE CHOICE*

5. Name the logic gate that is formed by the circuit shown in Figure 2.1.5.
   (a) positive logic OR gate
   (b) positive logic AND gate
   (c) negative logic OR gate
   (d) negative logic AND gate

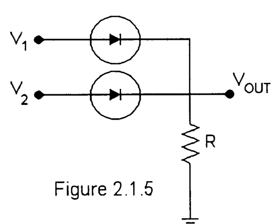


Figure 2.1.5

6. Name the logic gate that is formed by the circuit shown in Figure 2.1.6.
   (a) positive logic OR gate
   (b) positive logic AND gate
   (c) negative logic OR gate
   (d) negative logic AND gate

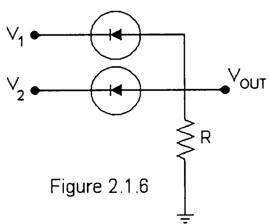


Figure 2.1.6

7. For the circuit shown in Figure 2.1.7 the current will flow through the load resistor during the ________.
   (a) positive half cycle of the input waveform
   (b) negative half cycle of the input waveform
   (c) during the entire input waveform
   (d) the diode will block all current and there will be no current flowing through the load

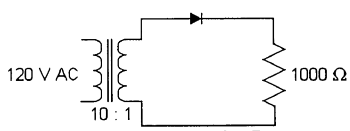


Figure 2.1.7

8. Calculate the peak current that will flow through the circuit of Figure 2.1.8 assuming an ideal diode.
   (a) 12 m Amps during the positive half cycle
   (b) 12 m Amps during the negative half cycle
   (c) 16.97 m Amps during the positive half cycle
   (d) 16.97 m Amps during the negative half cycle

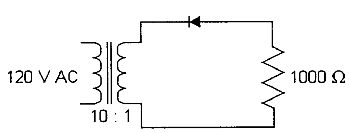


Figure 2.1.8

9. For the clipping circuit shown in Figure 2.1.9 what will be the maximum output voltage when the diode is conducting?
   (a) + 16.97 Volts
   (b) - 16.97 Volts
   (c) + 2.5 Volts
   (d) + 19.47 Volts

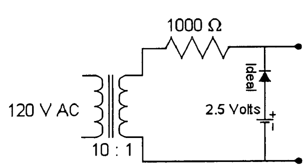


Figure 2.1.9

10. For the clipping circuit shown in Figure 2.1.9 what will be the maximum output voltage when the diode is not conducting?
(a) + 16.97 Volts
(b) - 16.97 Volts
(c) + 2.5 Volts
(d) + 19.47 Volts

11. For the clipping circuit shown in Figure 2.1.11 what will be the minimum output voltage when the diode is conducting?
(a) - 16.97 Volts
(b) + 16.97 Volts
(c) - 1.0 Volts
(d) - 17.97 Volts

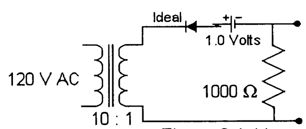


Figure 2.1.11

12. For the clipping circuit shown in Figure 2.1.11 what will be the minimum output voltage when the diode is not conducting?
(a) - 16.97 Volts
(b) + 16.97 Volts
(c) zero Volts
(d) - 17.97 Volts

13. For the clamping circuit shown in Figure 2.1.13 what will be the maximum output voltage?
(a) + 11 Volts
(b) + 21 Volts
(c) - 11 Volts
(d) - 21 Volts

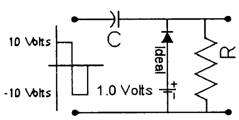


Figure 2.1.13

14. For the clamping circuit shown in Figure 2.1.13 what will be the minimum output voltage?
(a) + 1 Volts
(b) + 21 Volts
(c) - 11 Volts
(d) - 1 Volts

15. The maximum and minimum value of the current flowing load resistor in the circuit of Figure 2.1.15 while the diode is operating in the Zener region is:
    (a) 8 mA and 40 mA
    (b) need to know the load resistor value before we can determine the value
    (c) 8 mA and 35 mA
    (d) 12.5 mA to 40 mA

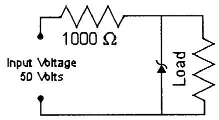



Figure 2.1.15

***SHORT ANSWER***

16. For the voltage multiplier circuit shown in Figure 2.1.16 the voltage across capacitors $C_1$ is _____ and the voltage across capacitor $C_2$ is _____.

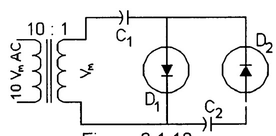



Figure 2.1.16

17. In general **Capacitors** in parallel with inductive elements or across switches are there as ___________ elements and do not act as typical network capacitive elements.

***MULTIPLE CHOICE***

18. The point of intersection between the characteristic curve of the diode and the resistor's loadline is known as:
    (a) the point of operation
    (b) the Q-point
    (c) the quescent point
    (d) none of the above
    (e) all of the above

19. Given a series silicon diode circuit with the resistor R = 2 K ohms and an applied voltage of 10 Volts, what is $I_{DQ}$?
    (a) 4.65 mA
    (b) 1.0 mA
    (c) 10 mA
    (d) 0.5 mA
    (e) none of the above

20. A series silicon diode circuit has a resistor R of 2 K ohms and a 10 Volt source. Determine $V_{DQ}$ if $I_{DQ}$ is 4.5 mA.
(a) 2 V
(b) 0.7 V
(c) 11.5 V
(d) 1 V
(e) none of the above

21. For the series diode configuration of Fig. 2.3(a) change the resistor R to 2 K ohms, and use the diode characteristic of Fig 2.3(b) to determine $V_R$.
(a) 0.92 V
(b) 92 mV
(c) 9.2 V
(d) 10
(e) none of the above

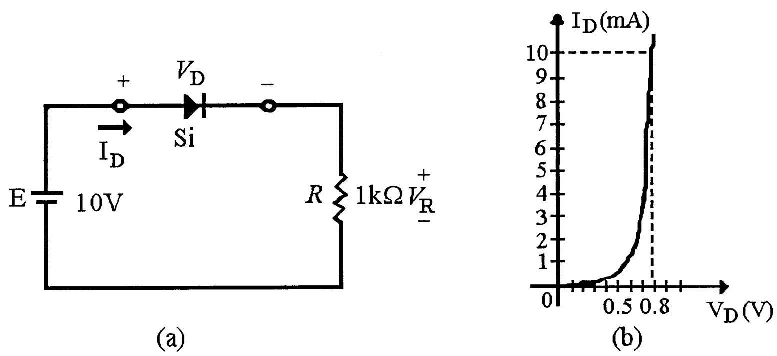



Figure 2.3

22. Generally a silicon diode is in the _________ state if the current established by the applied voltage source is in the direction of the diode symbol's arrow and $V_D$ is greater than or equal to 0.7 Volts.
(a) off
(b) on
(c) saturated
(d) reverse-biased
(e) none of the above

23. Generally a germanium diode is in the _________ state when the current established by the applied voltage source is in the direction of the diode symbol's arrow and $V_D$ is greater than or equal to 0.3 Volts.
(a) off
(b) on
(c) saturated
(d) reverse-biased
(e) none of the above

24. The practical value of the current $I_R$ for the circuit in Figure 2.18 in the textbook is _________ if the applied voltage is dropped to 0.5 Volts and R to 1 K.
(a) 0 A
(b) 0.5 mA
(c) 0.5 A
(d) 5 mA
(e) none of the above

25. Given a diode circuit with two forward-biased diodes, silicon and a germanium diode in series with each other and a 1000 ohm resistor and an applied voltage source of 12 Volts the voltage and current associated with the resistor are:
(a) 10 Volts and 5 mA
(b) 11 Volts and 2 mA
(c) 11 Volts and 11 mA
(d) 2 Volts and 11 mA
(e) 5 Volts and 10 mA

26. What is the value of the voltage dropped across forward-biased silicon diodes that are connected in parallel with each other?
(a) 11.3 V
(b) 10.6 V
(c) 0.7 V
(d) 0.3 V
(e) 1.4 V

27. The value of the voltage dropped across two diodes one silicon and one germanium, connected in their forward-biased direction in parallel with each other and in series with a 12 Volt source and a 1 K ohm resistor is:
(a) 11.3 V
(b) 10.6 V
(c) 0.7 V
(d) 0.3 V
(e) 1.0 V

28. When the diode in a half-wave rectifier points toward the load, the output from the rectifier will be:
(a) positive
(b) negative
(c) either positive or negative, depending on the polarity of the transformer secondary voltage
(d) full-wave
(e) none of the above

29. A half-wave rectifier with the diode arrow pointing away from the load has a dc output voltage of _________ for an ac input voltage of 20 Watts maximum.
(a) 19.3
(b) 13.65
(c) 6.14
(d) 12.49
(e) none of the above

30. A half-wave rectifier is connected to an ac source with a voltage of 20 $V_{max}$. The dc output voltage is:
(a) 19.3 Vdc
(b) 13.65 Vdc
(c) 6.14 Vdc
(d) 12.29 Vdc
(e) none of the above

31. Why are bridge rectifiers preferred over full-wave center-tapped rectifiers?
(a) They do not require the use of a center-tapped transformer.
(b) They provide higher dc output voltages.
(c) They require a lower PIV rating.
(d) They require less space.
(e) All of the above.

32. A bridge rectifier has values of V = 177 $V_{max}$, turns ratio = 5 : 1, and $R_L$ = 500 ohms. What is the dc output voltage?
(a) 13.75 Vdc
(b) 9.91 Vdc
(c) 19.82 Vdc
(d) 6.88 Vdc

33. A positive full-wave center-tapped rectifier has a secondary voltage of 20 $V_{max}$. The peak load voltage for the circuit is _________ if the diode drop is included.
(a) 20 Vp
(b) 9.3 Vp
(c) 19.3 Vp
(d) 10 Vp
(e) none of the above

34. A full-wave center-tapped rectifier has a secondary maximum voltage of 20 Vm, and a 4.7 kn load resistance. What is the dc load current for the circuit?
(a) 1.26 mA
(b) 2.61 mA
(c) 629.8 mA
(d) 1.4 mA
(e) none of the above

35. Which of the following circuits is used to eliminate a portion of a signal?
(a) a clipper
(b) a clamper
(c) a voltage multiplier
(d) a voltage divider
(e) all of the above

36. There are two general categories of clippers, which are:
(a) dc restorer and dc eliminator
(b) half-wave and full-wave
(c) series and parallel
(d) regenerator and eliminator

37. The simplest diode performs the same basic function as a _________.
 (a) half-wave rectifier
 (b) full-wave rectifier
 (c) bridge rectifier
 (d) clamper
 (e) none of the above

38. The circuit in Figure 2.8.5 is a:
 (a) series clipper
 (b) shunt clipper
 (c) series clamper
 (d) shunt clamper

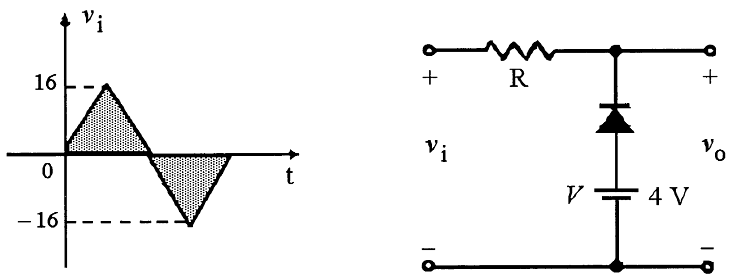



Figure 2.8.5

39. Which of the following circuits is commonly used to provide transient protection?
 (a) a clamper
 (b) a multiplier
 (c) an eliminator
 (d) a clipper

40. Which of the following circuits is used to change the dc reference of a signal without changing the shape of the signal?
 (a) a clipper
 (b) a clamper
 (c) a voltage multiplier
 (d) a voltage divider

41. A clamper must have a/an _________ that is large enough to maintain the capacitor's charge during diode conduction.
 (a) dc restorer
 (b) RC time constant
 (c) diode voltage
 (d) applied voltage
 (e) none of the above

42. The circuit in Figure 2.98 uses a:
    (a) positive clipper
    (b) negative clipper
    (c) positive clamper
    (d) negative clamper

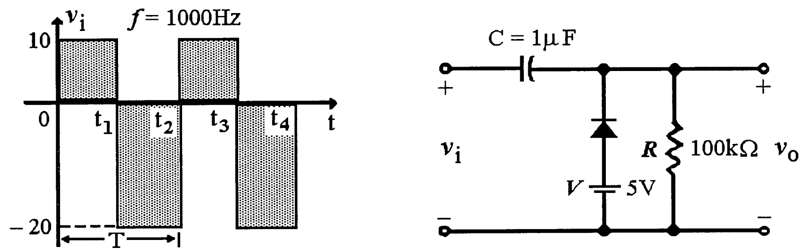



Figure 2.98

43. The output voltage of the circuit in Figure 2.98 will be clamped to _________ if the diode is silicon.
    (a) 10.7 V
    (b) 5.7 V
    (c) 4.3 V
    (d) 9.3 V
    (e) 5.3V

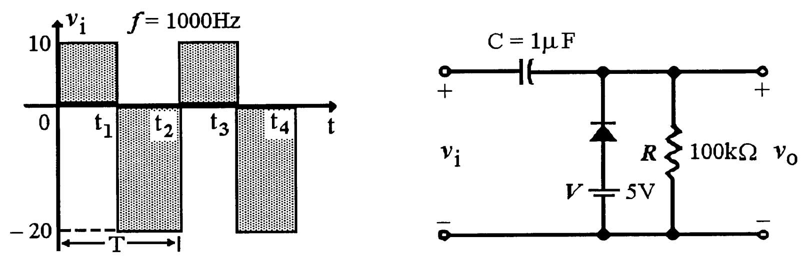



Figure 2.98

44. The clamper works on the principle of:
    (a) charging alternate capacitors to increase $V_{out}$
    (b) creating an input open circuit to disconnect the load
    (c) switching time constants
    (d) alternating dc reference voltages
    (e) all of the above

45. Which of the following determines whether a given clamper is a positive clamper or a negative clamper?
    (a) the type of diode used
    (b) the direction of the diode
    (c) diode placement (i.e., in series or shunt with the load)
    (d) all of the above
    (e) none of the above

46. The biased clamper has a dc reference voltage that is:
    (a) approximately equal to the dc voltage that is applied to the diode
    (b) approximately equal to zero Volts
    (c) dependent on the peak-to-peak value of the ac input
    (d) equal to the dc average of the circuit's output signal
    (e) none of the above

47. Given that a 1000 Hz signal is applied to a clamper with a resistor R of 10,000 ohms. What is the minimum value of capacitor needed to maintain safe clamping action?
    (a) .25 pF
    (b) 10 pF
    (c) 5 pF
    (d) 250 pF
    (e) none of the above

48. When the output signal is clamped to zero the total swing of the output is equal to:
    (a) total diode voltage drop
    (b) 1/2 the total voltage drop
    (c) the total input voltage swing
    (d) 1/2 the total input voltage swing
    (e) none of the above

49. The Zener diode is on if the applied voltage V is:
    (a) $V < V_Z$
    (b) V is greater than or equal to $V_Z$
    (c) $V > 2\ V_Z$
    (d) $V < 1/2\ V_Z$

50. When it is in the "on" state, the voltage across a Zener diode, $V_Z$
    (a) gets larger with an increase in applied voltage
    (b) gets smaller with an increase in applied voltage
    (c) increases sharply with a decrease in applied voltage
    (d) goes to zero with an increase in applied voltage
    (e) none of the above

51. The Zener diode must be operated such that:
    (a) $I_Z \times V_Z = P_Z$
    (b) $P_Z$ is less than the specified $P_{Zmax}$
    (c) the applied voltage is greater than $V_Z$
    (d) behaves as a standard diode when not in the "on" state
    (e) all of the above

52. The most frequent applications for a _________ _________ are in regulator networks and as a reference voltage.
    (a) half-wave rectifier
    (b) full-wave rectifier
    (c) Zener diode
    (d) ideal diode
    (e) clipper circuit

53. A typical Zener diode regulator circuit uses a:
    (a) dropping resistor in series with the load
    (b) resistor in parallel with the load
    (c) Zener diode in parallel with the series resistor
    (d) Zener diode in series with the load
    (e) all of the above

54. When the Zener regulator is used to stabilize the output voltage given a fixed input voltage and a variable load resistance, a too small load resistor will result in:
    (a) $V_l$ is greater than $V_z$
    (b) $V_l$ is less than $V_z$
    (c) $V_l$ is equal to $V_z$
    (d) $V_z$ is equal to $V_{in}$
    (e) none of the above

55. When a Zener diode circuit is used to stabilize the output voltage given a fixed load resistor and a variable input voltage, the input voltage must be:
    (a) small enough to turn-off the Zener diode
    (b) large enough to turn-off the Zener diode
    (c) small enough to turn-on the Zener diode
    (d) large enough to turn-on the Zener diode
    (e) none of the above

56. Two Zener diodes connected _________ can be used as an ac regulator.
    (a) in parallel with each other
    (b) in series with the load
    (c) back-to-back
    (d) in series with the input voltage
    (e) none of the above

57. A Zener diode is designed to operate in the _________ region of its characteristic curve.
    (a) forward operating
    (b) reverse bias
    (c) reverse breakdown
    (d) zero voltage

58. If the maximum Zener current is exceeded the Zener diode is:
    (a) turned off
    (b) turned on
    (c) destroyed
    (d) none of the above

1. Answer: (d) Difficulty: 2 Section: 2 Objective: 1
2. Answer: load line; characteristic
   Difficulty: 2 Section: 2 Objective: 1
3. Answer: (c) Difficulty: 2 Section: 5 Objective: 1
4. Answer: on Difficulty: 2 Section: 5 Objective: 1
5. Answer: (a) Difficulty: 2 Section: 6 Objective: 1
6. Answer: (a) Difficulty: 2 Section: 6 Objective: 1
7. Answer: (a) Difficulty: 2 Section: 7 Objective: 1
8. Answer: (d) Difficulty: 2 Section: 7 Objective: 1
9. Answer: (c) Difficulty: 2 Section: 9 Objective: 1
10. Answer: (c) Difficulty: 2 Section: 9 Objective: 1
11. Answer: (c) Difficulty: 2 Section: 9 Objective: 1
12. Answer: (c) Difficulty: 2 Section: 9 Objective: 1
13. Answer: (b) Difficulty: 2 Section: 10 Objective: 1
14. Answer: (d) Difficulty: 2 Section: 10 Objective: 1
15. Answer: (a) Difficulty: 2 Section: 11 Objective: 1
16. Answer: $V_m$; $2V_m$ Difficulty: 2 Section: 11 Objective: 1
17. Answer: protective Difficulty: 2 Section: 13 Objective: 1
18. Answer: (e) Difficulty: 2 Section: 1 Objective: 2
19. Answer: (a) Difficulty: 2 Section: 2 Objective: 2
20. Answer: (d) Difficulty: 2 Section: 3 Objective: 2
21. Answer: (c) Difficulty: 2 Section: 4 Objective: 2
22. Answer: (b) Difficulty: 2 Section: 1 Objective: 4
23. Answer: (b) Difficulty: 2 Section: 2 Objective: 4
24. Answer: (a) Difficulty: 2 Section: 3 Objective: 4

25. Answer: (c) Difficulty: 2 Section: 4 Objective: 4

26. Answer: (c) Difficulty: 2 Section: 1 Objective: 5

27. Answer: (d) Difficulty: 2 Section: 2 Objective: 5

28. Answer: (a) Difficulty: 2 Section: 1 Objective: 7

29. Answer: (c) Difficulty: 2 Section: 2 Objective: 7

30. Answer: (c) Difficulty: 2 Section: 3 Objective: 7

31. Answer: (e) Difficulty: 2 Section: 1 Objective: 8

32. Answer: (c) Difficulty: 2 Section: 2 Objective: 8

33. Answer: (b) Difficulty: 2 Section: 3 Objective: 8

34. Answer: (a) Difficulty: 2 Section: 4 Objective: 8

35. Answer: (a) Difficulty: 2 Section: 1 Objective: 9

36. Answer: (c) Difficulty: 2 Section: 2 Objective: 9

37. Answer: (a) Difficulty: 2 Section: 3 Objective: 9

38. Answer: (b) Difficulty: 2 Section: 4 Objective: 9

39. Answer: (d) Difficulty: 2 Section: 5 Objective: 9

40. Answer: (b) Difficulty: 2 Section: 1 Objective: 10

41. Answer: (b) Difficulty: 2 Section: 2 Objective: 10

42. Answer: (d) Difficulty: 2 Section: 3 Objective: 10

43. Answer: (c) Difficulty: 2 Section: 4 Objective: 10

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52. Answer: (c) Difficulty: 2 Section: 4 Objective: 11

53. Answer: (a) Difficulty: 2 Section: 5 Objective: 11

54. Answer: (b) Difficulty: 2 Section: 6 Objective: 11

55. Answer: (d) Difficulty: 2 Section: 7 Objective: 11

56. Answer: (c) Difficulty: 2 Section: 8 Objective: 11

57. Answer: (c) Difficulty: 2 Section: 9 Objective: 11

58. Answer: (c) Difficulty: 2 Section: 10 Objective: 11

# Chapter 3: Bipolar Junction Transistors

## *SHORT ANSWER*

1. The three terminals of a bipolar junction transistor are known as _____, _____, and _____.

## *MULTIPLE CHOICE*

2. For basic operation of a transistor the base-emitter junction is ______ biased.
   (a) forward
   (b) reverse
   (c) not
   (d) semi

3. For basic operation of a transistor the base-collector junction is ______ biased.
   (a) forward
   (b) reverse
   (c) not
   (d) semi

4. The output or the collector characteristics for a common base transistor amplifier shows that as a first approximation the relation between $I_E$ and $I_C$ in the active region is given by:
   (a) $I_E = I_C$
   (b) $I_E \gg I_C$
   (c) $I_E \ll I_C$
   (d) $I_E \cong I_C$

5. In the **cut-off** region the base-emitter junction and the base-collector junctions of the transistor are:
   (a) both forward biased
   (b) both reversed biased
   (c) base-emitter junction is forward biased while the base-collector junction is reversed biased
   (d) base-emitter junction is reversed biased while the base-collector junction is forward biased

6. In the **saturation** region the base-emitter junction and the base-collector junctions of the transistor are:
   (a) both forward biased
   (b) both reversed biased
   (c) base-emitter junction is forward biased while the base-collector junction is reversed biased
   (d) Base-emitter junction is reversed biased while the base-collector junction is forward biased

7. In the **active** region the base-emitter junction and the base-collector junctions of the transistor are:
   (a) both forward biased
   (b) both reversed biased
   (c) base-emitter junction is forward biased while the base-collector junction is reversed biased
   (d) base-emitter junction is reversed biased while the base-collector junction is forward biased

## *SHORT ANSWER*

8. The transistor parameter $\alpha$ is defined as ______.

9. The transistor parameter $\beta$ is defined as ______.

## *MULTIPLE CHOICE*

10. In a small signal transistor the typical range of the parameter $\alpha$ is _____.
    (a) greater than 1
    (b) between 0 and 1
    (c) almost equal to 1 but always less than 1 (0.9 to 1.0)
    (d) almost equal to 1 but always greater than 1 (1.0 to 1.1)

11. In a small signal transistor the typical range of the parameter $\beta$ is _____.
    (a) greater than 100
    (b) between 0 and 100
    (c) almost equal to 100 but always less than 100 (90 to 100)
    (d) large and in the range of about 50 to 400

12. A BJT has measured dc current values of $I_B = 0.1$ mA and $I_C = 8.0$ mA. When $I_b$ is varied by 100 μA, $I_c$ changes by 10 mA. What is the value of the ac beta for this device?
    (a) 80
    (b) 10
    (c) 100
    (d) 800

13. A BJT has measured dc current values of $I_B = 0.1$ mA and $I_C = 8.0$ mA. When $I_b$ is varied by 100 μA, $I_c$ changes by 10 mA. What is the value of the dc beta for this device?
    (a) 80
    (b) 10
    (c) 100
    (d) 800

14. When a BJT is operating in the **saturation** region the voltage drop from the collector to the emitter $V_{CE}$ is approximately equal to:
    (a) collector supply voltage
    (b) collector current times the collector resistor
    (c) almost equal to zero (about 0.3 Volts)
    (d) equal to the emitter voltage

15. When a BJT is operating in the **active** region the voltage drop from the base to the emitter $V_{BE}$ is approximately equal to:
    (a) base bias voltage
    (b) base current times the base resistor
    (c) almost equal to the one diode drop (about 0.7 Volts)
    (d) equal to the emitter voltage

16. Bipolar junction transistors (BJTs) are commonly used as:
    (a) the primary components in amplifiers
    (b) shunt clipper circuits
    (c) the primary components in rectifiers
    (d) series clamper circuits
    (e) all of the above

17. $V_{CE}$ is measured:
    (a) from the collector terminal to ground
    (b) from the collector terminal to the emitter terminal
    (c) from the emitter terminal to ground
    (d) from the collector-emitter junction to ground
    (e) none of the above

18. Why is the arrow on the BJT schematic symbol important?
    (a) It identifies the emitter terminal and the type of BJT.
    (b) It identifies the collector terminal and the type of BJT.
    (c) It identifies the base terminal and the type of BJT.
    (d) It identifies the direction of the emitter current.
    (e) None of the above.

19. In most cases, which two of the three BJT terminal currents are approximately equal in value?
    (a) collector current and base current
    (b) collector current and emitter current
    (c) emitter current and base current
    (d) all currents are approximately equal
    (e) no two are ever approximately equal in value

20. Which of the following biasing combinations is not normally associated with one of the three transistor operating regions?
    (a) E-B junction = forward, C-B junction = reverse
    (b) E-B junction = reverse, C-B junction = reverse
    (c) E-B junction = reverse, C-B junction = forward
    (d) E-B junction = forward, C-B junction = forward
    (e) All of the above

21. The condition where increase in bias current will not cause further increases in collector current is called:
    (a) cutoff
    (b) saturation
    (c) active operation
    (d) limit operation
    (e) none of the above

22. Beta is the ratio of:
    (a) collector current to emitter current
    (b) base current to collector current
    (c) collector current to base current
    (d) emitter current to collector current
    (e) none of the above

23. A given BJT has an emitter current of 12 mA and a base current of 600 μA. What is the value of the dc beta?
    (a) 20
    (b) 21
    (c) 19
    (d) 200
    (e) none of the above

24. A given BJT has an emitter current of 15 mA and a collector current of 14.95 mA. What is the exact value of beta?
    (a) 300
    (b) 299
    (c) 1.003
    (d) 250
    (e) none of the above

25. A given BJT has a beta rating of 400. What is the value of alpha for the device?
    (a) 1.0025
    (b) 0.0025
    (c) 0.9975
    (d) 1.00
    (e) none of the above

26. A given BJT has an alpha of 0.9985 and a collector current of 15 mA. What is the value of base current?
    (a) 151.5 μA
    (b) 15.15 mA
    (c) 14.85 mA
    (d) 15 mA
    (e) none of the above

27. Which transistor amplifier configuration is the most commonly used?
    (a) common-emitter
    (b) common-collector
    (c) common-base
    (d) none of them are used more often than the others

28. A given transistor has ratings of maximum collector current equal to 200 mA maximum and a beta that varies between 150 and 200. What is the maximum allowable value of base current for the device?
    (a) 1 mA
    (b) 4 mA
    (c) 1.33 mA
    (d) none of the above

29. A BJT has measured dc current values of $I_B$ = 1 mA and $I_C$ = 80 mA. When $I_B$ is varied by 100 μA, $I_C$ changes by 10 mA. What is the value of dc beta for the device?
(a) 80
(b) 10
(c) 100
(d) 800

30. A BJT has measured dc current values of $I_B$ = 1 mA and $I_C$ = 80 mA. When $I_B$ is varied by 100 μA, $I_C$ changes by 10 mA. What is the value of the ac beta for the device?
(a) 80
(b) 10
(c) 100
(d) 800

31. When a transistor is in saturation $V_{ce}$ is approximately equal to:
(a) collector supply voltage
(b) collector current times collector resistor
(c) 0.3 Volts
(d) emitter voltage
(e) none of the above

32. A transistor has a rating of Beta = 50 to 450. What value of Beta should be used for circuit analysis purposes?
(a) 50
(b) 250
(c) 450
(d) 150

1. Answer: emitter; base; collector

   Difficulty: 1 Section: 2 Objective: 1

2. Answer: (a) Difficulty: 1 Section: 3 Objective: 1

3. Answer: (b) Difficulty: 1 Section: 3 Objective: 1

4. Answer: (d) Difficulty: 1 Section: 3 Objective: 1

5. Answer: (b) Difficulty: 1 Section: 4 Objective: 1

6. Answer: (a) Difficulty: 1 Section: 4 Objective: 1

7. Answer: (c) Difficulty: 1 Section: 4 Objective: 1

8. Answer: $I_C/I_E$ Difficulty: 1 Section: 4 Objective: 1

9. Answer: $I_B/I_C$ Difficulty: 1 Section: 6 Objective: 1

10. Answer: (c) Difficulty: 1 Section: 12 Objective: 1

11. Answer: (d) Difficulty: 1 Section: 12 Objective: 1

12. Answer: (c) Difficulty: 2 Section: 10 Objective: 1

13. Answer: (a) Difficulty: 2 Section: 10 Objective: 1

14. Answer: (c) Difficulty: 2 Section: 10 Objective: 1

15. Answer: (c) Difficulty: 2 Section: 10 Objective: 1

16. Answer: (a) Difficulty: 2 Section: 1 Objective: 1

17. Answer: (b) Difficulty: 2 Section: 1 Objective: 2

18. Answer: (d) Difficulty: 2 Section: 1 Objective: 4

19. Answer: (b) Difficulty: 2 Section: 2 Objective: 4

20. Answer: (c) Difficulty: 2 Section: 1 Objective: 6

21. Answer: (b) Difficulty: 2 Section: 2 Objective: 6

22. Answer: (c) Difficulty: 2 Section: 3 Objective: 6

23. Answer: (a) Difficulty: 2 Section: 4 Objective: 6

24. Answer: (b) Difficulty: 2 Section: 5 Objective: 6

25. Answer: (c) Difficulty: 2 Section: 6 Objective: 6

26. Answer: (e) Difficulty: 2 Section: 7 Objective: 6

27. Answer: (a) Difficulty: 2 Section: 8 Objective: 6

28. Answer: (a) Difficulty: 2 Section: 9 Objective: 6

29. Answer: (a) Difficulty: 2 Section: 10 Objective: 6

30. Answer: (c) Difficulty: 2 Section: 11 Objective: 6

31. Answer: (c) Difficulty: 2 Section: 1 Objective: 8

32. Answer: (d) Difficulty: 2 Section: 1 Objective: 9

# Chapter 4: DC Biasing--BJTs

*MULTIPLE CHOICE*

1. When a BJT is biased in the **Active Region** its base-emitter junction and its base-collector junctions are _______ and _______.
   (a) forward biased; reversed biased
   (b) reversed biased; forward biased
   (c) forward biased; forward biased
   (d) reversed biased; reversed biased

2. When a BJT is biased in the **Cut-off Region** its base-emitter junction and its base-collector junctions are _______ and _______.
   (a) forward biased; reversed biased
   (b) reversed biased; forward biased
   (c) forward biased; forward biased
   (d) reversed biased; reversed biased

3. When a BJT is biased in the **Saturation Region** its base-emitter junction and its base-collector junctions are _______ and _______.
   (a) forward biased; reversed biased
   (b) reversed biased; forward biased
   (c) forward biased; forward biased
   (d) reversed biased; reversed biased

4. The fixed bias circuit shown in Figure 4.1.4 uses a silicon transistor, a 12.5 KΩ base bias resistor and a 2 KΩ collector resistor. The supply voltage $V_{CC}$ is 12 Volts. Calculate the base current:
   (a) 0.904 mA
   (b) 0.96 mA
   (c) 0.056 mA
   (d) 6.0 mA

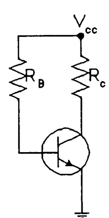

Figure 4.1.4 Fixed bias circuit

5. The fixed bias circuit shown in Figure 4.1.4 uses a silicon transistor, a 12.5 KΩ base bias resistor and a 2 KΩ collector resistor. The supply voltage $V_{CC}$ is 12 Volts. Calculate the maximum collector current:
   (a) 0.904 mA
   (b) 0.96 mA
   (c) 0.056 mA
   (d) 6.0 mA

6. When a BJT is biased in the Cut-off Region the collector to emitter voltage is typically equal to:
   (a) the emitter voltage
   (b) 0.03 Volts
   (c) collector current times the collector resistor
   (d) collector supply voltage

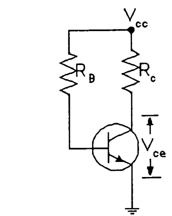

Figure 4.1.6 Fixed bias circuit

7. The emitter stabilized bias circuit shown in Figure 4.1.7 uses a silicon transistor, a 120.0 KΩ base bias resistor and a 2 KΩ collector resistor and a 500 Ω emitter resistor. The supply voltage $V_{CC}$ is 15 Volts. Which region is the transistor biased in?
   (a) saturation Region
   (b) cut-off region
   (c) active region
   (d) the transistor is not properly biased

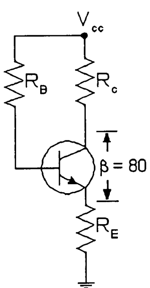

Figure 4.1.7 Emitter Stabilized bias circuit

8. The emitter stabilized bias circuit shown in Figure 4.1.7 uses a silicon transistor, a 120.0 KΩ base bias resistor and a 1 KΩ collector resistor and a 500 Ω emitter resistor. The supply voltage $V_{CC}$ is 15 Volts. Calculate the base current.
   (a) 89.0 mA
   (b) 89.0 μA
   (c) 0.119 mA
   (d) none of the above

9. The emitter stabilized bias circuit shown in Figure 4.1.7 uses a silicon transistor, a 90.0 Ω base bias resistor and a 1 KΩ collector resistor and a 500 Ω emitter resistor. The supply voltage $V_{CC}$ is 15 Volts. Calculate the collector-emitter voltage. (The base current is 0.089 mA)
   (a) 4.32 Volts
   (b) 10.68 Volts
   (c) 0.1335 Volts
   (d) 14.24 Volts

10. The voltage divider bias circuit shown in Figure 4.1.10 uses a silicon transistor. The values of the various resistors are shown on the diagram. The supply voltage $V_{CC}$ is 18 Volts. Calculate the base current.
(a) 233.78 μA
(b) 34.62 μA
(c) 596.55 μA
(d) 76.8 μA

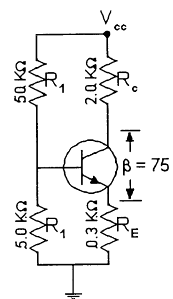


Figure 4.1.10 Voltage Divider bias circuit

11. When voltage divider bias is used it is considered appropriate to use the approximate analysis to determine the bias condition when the resistance $R_2$ ____ $(1+\beta)R_E$.
(a) is greater than
(b) is less than
(c) is very much greater than
(d) is very much less than

12. The voltage feedback bias circuit shown in Figure 4.1.12 uses a silicon transistor. The values of the various resistors are shown on the diagram. The supply voltage $V_{CC}$ is 20 Volts. Calculate the base current.
(a) 28.4 μA
(b) 20.2 μA
(c) 28.3 μA
(d) need more information to calculate the base current

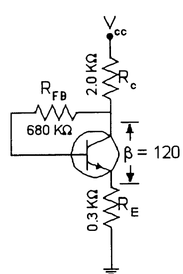


Figure 4.1.12 Voltage Feedback bias circuit

13. When designing a current-gain-stabilized voltage divider bias circuit (Figure 4.1.13) the rule of thumb used for the emitter voltage is:
    (a) $V_E = V_{CC}/10$
    (b) $V_{CE} = V_{CC}/10$
    (c) $V_B = V_{CC}/10$
    (d) $V_C = V_{CC}/10$

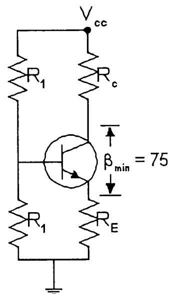


Figure 4.1.13 Design of Voltage Divider bias circuit

14. When a BJT transistor is used in a switching circuit it operates in the ______ region and the ______ region.
    (a) saturation; active
    (b) active; cut-off
    (c) saturation; cut-off
    (d) active region only

15. The only difference between the resulting equations for a network in which an NPN transistor has been replaced by a PNP transistor is:
    (a) the size of the resistors
    (b) the value of β
    (c) the sign associates with the particular quantities
    (d) all of the above

16. When a BJT has its base-emitter junction forward biased and its base-collector junction reverse biased, it is biased in the _________ _________.
    (a) saturation region
    (b) active region
    (c) cut-off region
    (d) passive region
    (e) none of the above

17. When a BJT has its base-emitter junction reverse biased and its base-collector junction forward biased, it is in the _________ _________.
    (a) saturation region
    (b) active region
    (c) cut-off region
    (d) passive region
    (e) none of the above

18. When a BJT has its base-emitter junction forward biased and its base-collector junction also forward biased it is in the ____________________.
   (a) saturation region
   (b) active region
   (c) cut-off region
   (d) passive region
   (e) none of the above

19. When a BJT has its base-emitter junction reverse biased and its base-collector junction reverse biased it is in the ____________________.
   (a) saturation region
   (b) active region
   (c) cut-off region
   (d) passive region
   (e) none of the above

20. The term quiescent means:
   (a) midpoint biased
   (b) at rest
   (c) active
   (d) inactive

21. The fixed-bias circuit of Figure 4.2 uses a silicon transistor, a 10 K ohms base-bias resistor, a 2 K ohm collector resistor and a collector supply of 12 Volts. Find the base current.
   (a) 6 mA
   (b) 1.37 mA
   (c) 1.13 mA
   (d) 12 mA
   (e) none of the above

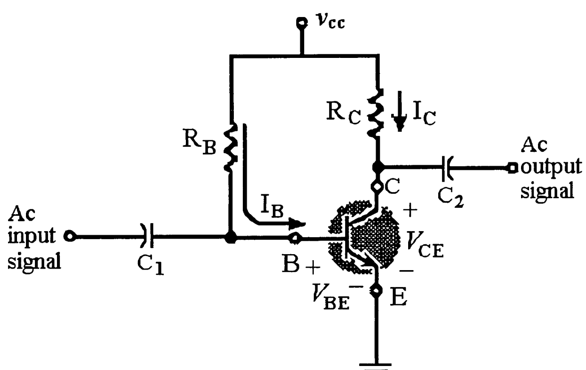


Figure 4.2

22. The fixed-biased circuit of Figure 4.2 uses a silicon transistor, a 12 K ohms base-bias resistor, a 2 K ohm collector resistor and a collector supply of 12 Volts. Find the maximum collector current.
(a) 1.13 mA
(b) 12 mA
(c) 6 mA
(d) 1.0 mA
(e) none of the above

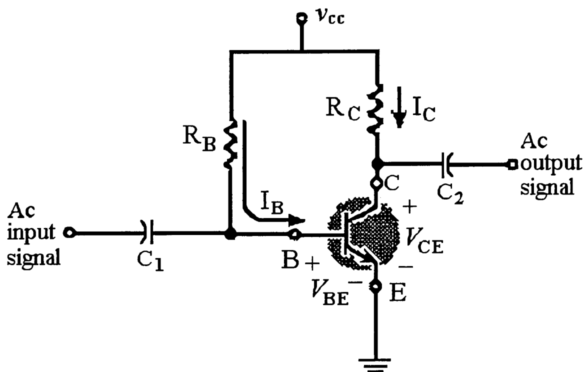


Figure 4.2

23. When a BJT is in cut-off collector to emitter, voltage is typically equal to:
(a) collector supply voltage
(b) collector current times collector resistor
(c) 0.3 Volts
(d) emitter voltage
(e) none of these

24. The change in $I_c$ and $V_{ce}$ that can occur when the temperature changes is known as:
(a) midpoint bias
(b) midpoint movement
(c) output movement
(d) Q-point movement

25. A/An __________ __________ is added to the fixed-bias configuration to improve bias stability.
(a) base voltage
(b) emitter resistor
(c) collector resistor
(d) all of the above

26. The input resistance of the stabilized fixed-bias circuit configuration is:
(a) inversely related to the emitter resistor
(b) inversely related to beta
(c) directly related to the collector resistor
(d) directly related to the emitter resistor
(e) none of the above

27. Two of the factors associated with bias stability are:
    (a) voltage and current
    (b) the beta and the junction temperature
    (c) age and amount of use
    (d) none of the above

28. When a transistor is in saturation, the total collector current is limited by:
    (a) collector supply voltage and the total resistance in the collector and emitter circuits
    (b) collector to emitter and collector supply voltage
    (c) collector supply, collector to emitter voltage, and the total collector circuit resistance
    (d) the transistor
    (e) none of the above

29. Voltage-divider bias stability is:
    (a) dependent on alpha
    (b) dependent of beta
    (c) dependent on the collector resistor
    (d) independent of beta
    (e) none of the above

30. Collector-feedback bias:
    (a) provides a feedback path from collector to base
    (b) provides an improved level of stability
    (c) is not totally independent of beta
    (d) all of the above

31. The collector-feedback bias configuration's input resistance is related to:
    (a) the emitter resistor
    (b) the collector resistor
    (c) the device beta
    (d) the base feedback resistor
    (e) all of the above

32. The emitter follower configuration has:
    (a) a 180 degree phase shift
    (b) an output voltage slightly greater than the input voltage
    (c) the emitter connected to dc ground potential
    (d) the dc supply applied to the base
    (e) none of the above

33. A collector-feedback bias circuit is found to be in saturation. Which of the following could cause this condition?
    (a) The base resistor is open.
    (b) The collector resistor is open.
    (c) The transistor is shorted base-to-emitter.
    (d) A solder bridge across the base resistor.

34. In the design of an emitter-bias stabilized circuit engineering judgment must be used because:
    (a) the collector resistor is usually unknown
    (b) the emitter resistor is usually unknown
    (c) the relative voltage levels have not been defined
    (d) all of the above

35. When designing for best bias stability the _________ configuration should be chosen.
    (a) voltage-divider bias
    (b) collector-feedback bias
    (c) fixed-bias
    (d) emitter-feedback bias
    (e) none of the above

36. When designing a voltage-divider bias circuit, the divider resistors:
    (a) should carry approximately equal current
    (b) should carry currents that are 10 times the base current
    (c) determine the base voltage as the drop across R2
    (d) all of the above

37. Why is design for a specific bias point desirable for most amplifiers?
    (a) To meet manufacturer suggested opening point.
    (b) It allows optimum ac operation of the circuit.
    (c) It allows optimum dc operation of the circuit.
    (d) All of the above.

38. There are transistors that are called switching transistors because:
    (a) they have a built in switch
    (b) of the speed at which they can be changed from on to off
    (c) of the power they can transfer from input to output
    (d) of the voltage they can transfer from input to output
    (e) all of the above

39. The only difference between the resulting equations for a network in which an NPN transistor has been replaced by a PNP transistor is:
    (a) the size of the resistors
    (b) the value of beta
    (c) the sign associated with the particular quantities
    (d) all of the above

40. Transistor circuits that are quite stable and relatively insensitive to temperature variations have:
    (a) a large input voltage
    (b) a large stability factor
    (c) a small stability factor
    (d) a large beta
    (e) a small beta

41. To design a transistor circuit for maximum stability one must consider:
    (a) the collector leakage current stability factor
    (b) the base-emitter junction voltage stability factor
    (c) the transistor's beta stability factor
    (d) all of the above

42. Variation in hfe is influenced by:
    (a) junction temperature and collector current
    (b) temperature and base current
    (c) bias type and device size
    (d) device size amd base current

1. Answer: (a) Difficulty: 2 Section: 2 Objective: 1
2. Answer: (d) Difficulty: 2 Section: 2 Objective: 1
3. Answer: (c) Difficulty: 2 Section: 2 Objective: 1
4. Answer: (a) Difficulty: 2 Section: 3 Objective: 1
5. Answer: (d) Difficulty: 2 Section: 3 Objective: 1
6. Answer: (d) Difficulty: 2 Section: 3 Objective: 1
7. Answer: (a) Difficulty: 3 Section: 4 Objective: 1
8. Answer: (c) Difficulty: 2 Section: 4 Objective: 1
9. Answer: (a) Difficulty: 2 Section: 4 Objective: 1
10. Answer: (c) Difficulty: 2 Section: 5 Objective: 1
11. Answer: (c) Difficulty: 2 Section: 5 Objective: 1
12. Answer: (b) Difficulty: 2 Section: 7 Objective: 1
13. Answer: (a) Difficulty: 2 Section: 8 Objective: 1
14. Answer: (c) Difficulty: 2 Section: 9 Objective: 1
15. Answer: (c) Difficulty: 2 Section: 11 Objective: 1
16. Answer: (b) Difficulty: 2 Section: 1 Objective: 2
17. Answer: (c) Difficulty: 2 Section: 2 Objective: 2
18. Answer: (a) Difficulty: 2 Section: 3 Objective: 2
19. Answer: (c) Difficulty: 2 Section: 4 Objective: 2
20. Answer: (d) Difficulty: 2 Section: 5 Objective: 2
21. Answer: (c) Difficulty: 2 Section: 1 Objective: 3
22. Answer: (c) Difficulty: 2 Section: 2 Objective: 3
23. Answer: (a) Difficulty: 2 Section: 3 Objective: 3
24. Answer: (d) Difficulty: 2 Section: 4 Objective: 3
25. Answer: (b) Difficulty: 2 Section: 1 Objective: 4

26. Answer: (d) Difficulty: 2 Section: 2 Objective: 4

27. Answer: (b) Difficulty: 2 Section: 3 Objective: 4

28. Answer: (a) Difficulty: 2 Section: 4 Objective: 4

29. Answer: (d) Difficulty: 2 Section: 1 Objective: 5

30. Answer: (d) Difficulty: 2 Section: 1 Objective: 6

31. Answer: (e) Difficulty: 2 Section: 2 Objective: 6

32. Answer: (e) Difficulty: 2 Section: 3 Objective: 6

33. Answer: (c) Difficulty: 2 Section: 4 Objective: 6

34. Answer: (d) Difficulty: 4 Section: 1 Objective: 8

35. Answer: (a) Difficulty: 2 Section: 2 Objective: 8

36. Answer: (d) Difficulty: 2 Section: 3 Objective: 8

37. Answer: (d) Difficulty: 2 Section: 4 Objective: 8

38. Answer: (b) Difficulty: 2 Section: 1 Objective: 9

39. Answer: (c) Difficulty: 2 Section: 1 Objective: 11

40. Answer: (c) Difficulty: 2 Section: 1 Objective: 12

41. Answer: (d) Difficulty: 2 Section: 2 Objective: 12

42. Answer: (a) Difficulty: 2 Section: 3 Objective: 12

# Chapter 5: Field-Effect Transistors

## *SHORT ANSWER*

1. A BJT is a _______ controlled device while the FET is a ______ controlled device.

2. The three regions of operations for the FET are ______; ______; and ________.

3. In the ohmic region the channel behaves like a ________.

## *MULTIPLE CHOICE*

4. The maximum current in a JFET is defined as $I_{DSS}$ and occurs when $V_{GS}$ is equal to _______.
   (a) zero Volts
   (b) pinch-off voltage
   (c) a small positive voltage
   (d) a voltage greater than the pinch-off voltage

5. Schokley's equation defines the _______ _______ of the FET and are unaffected by the network in which the device is employed.
   (a) $V_{GS}$ characteristics
   (b) drain characteristics
   (c) input output characteristics
   (d) transfer characteristics

6. For an N-channel JFET $I_{DSS}$ = 8 mA and $V_P$ = -6 Volts. If $V_{GS}$ = -2 Volts then what is the value of the drain current $I_D$?
   (a) 2.666 mA
   (b) 3.5 μA
   (c) 3.55 mA
   (d) 5.33 mA

7. For an N-channel JFET $I_{DSS}$ = 8 mA and $V_P$ = -6 Volts. If $I_D$ = 6 mAmps then what is the value of the gate-to-source voltage $V_{GS}$?
   (a) -0.8 Volts
   (b) -1.5 Volts
   (c) 0.1335 Volts
   (d) -4.5 Volts

8. The drain characteristics for a FET that you see on a curve tracer are drawn for equal step increases in the $V_{GS}$ values, yet they are spaced further apart as $V_{GS}$ gets closer to zero. Why?
   (a) This is true for only some FET devices, not all.
   (b) The curve depends on the FET device used.
   (c) Due to the square relation between $I_D$ and $V_{GS}$, as $V_{GS}$ gets closer to zero $I_D$ increases faster so the curves are spaced apart further.
   (d) None of the above.

9. The depletion type of MOSFET can operate in the:
   (a) depletion mode only
   (b) enhancement mode only
   (c) in the depletion mode and the enhancement mode
   (d) none of the above

10. For an N-channel depletion type of MOSFET if $V_{GS} > 0$ then $I_{DSS}$ will be ________ $I_D$.
   (a) less than
   (b) more than
   (c) equal to
   (d) $V_{GS}$ is not allowed to be greater than zero

11. For an N-channel depletion MOSFET $I_{DSS} = 8$ mA and $V_P = -6$ Volts. If $V_{GS} = 0.8$ Volts then what is the value of the drain current $I_D$?
   (a) 8 mA
   (b) 10.25 μA
   (c) 10.28 mA
   (d) 6 mA

12. For an N-channel depletion MOSFET $I_{DSS} = 8$ mA and $V_P = -6$ Volts. If $I_D = 0.0095$ Amps then what is the value of the gate-to-source voltage $V_{GS}$?
   (a) 0.54 Volts
   (b) -0.54 Volts
   (c) 0.1335 Volts
   (d) 6.54 Volts

13. For $V_{GS} < V_{TH}$ in an enhancement MOSFET the drain current will be:
   (a) 10.0 μA
   (b) 1.0 μA
   (c) zero μA
   (d) -1.0 μA

14. The enhancement type of MOSFETs operate in the:
   (a) depletion mode only
   (b) depletion mode and the enhancement mode
   (c) enhancement mode only
   (d) none of the above

15. Many MOSFET devices now contain internal _______ that protect these devices from static electricity.
   (a) BJT transistors to bypass the static charge
   (b) back to back zener diodes
   (c) capacitors to collect and store the static charge
   (d) nothing can be done to protect these devices from accidental static discharge except very careful handling

16. The FET that has the best switching speed performance is:
   (a) CMOS
   (b) PMOS
   (c) NMOS
   (d) VMOS

17. A CMOS inverter is biased with a +10 Volt $V_{SS}$ supply. The input to the inverter varies between zero Volts and +10 Volts. When the input to the inverter is +10 Volts the output from the circuit will be:
    (a) +10 Volts
    (b) -10 Volts
    (c) zero Volts
    (d) circuit cannot have an input voltage that is equal to the supply voltage

18. The primary difference between BJT and FET types of transistors is:
    (a) BJTs are voltage controlled and FETs are current controlled
    (b) BJTs are current controlled and FETs are voltage controlled
    (c) BJTs amplify better than FETs
    (d) none of the above

19. The Field Effect Transistor has:
    (a) an N-channel type
    (b) a P-channel type
    (c) unipolar structure
    (d) all of the above

20. FETs usually:
    (a) are smaller in construction than BJT's
    (b) are less sensitive to temperature change than BJTs
    (c) have a higher input impudence than BJTs
    (d) are less sensitivity to applied signals than BJTs
    (e) all of the above

21. The level of drain to source voltage where it appears that the two depletions regions touch is known as:
    (a) the depletion zone
    (b) channel establishment
    (c) pinch-off
    (d) channel saturation

22. The JFET is a:
    (a) voltage-controlled device
    (b) current-controlled device
    (c) frequency-controlled device
    (d) power-controlled device

23. The _________ terminal of the JFET is the equivalent of the collector terminal of a BJT.
    (a) gate
    (b) drain
    (c) source
    (d) anode

24. The _________ terminal of the JFET is the equivalent of the base terminal of a BJT.
    (a) gate
    (b) drain
    (c) source
    (d) anode

25. The _________ terminal of the JFET is the equivalent of the emitter terminal of a BJT.
(a) gate
(b) drain
(c) source
(d) anode

26. The _________ JFET uses a positive drain supply voltage.
(a) N-channel
(b) P-channel
(c) MDS
(d) CMOS

27. The region of the characteristic curve family for the junction FET that is normally used for linear amplification is:
(a) the constant-current region
(b) the saturation region
(c) the linear amplification region
(d) all of the above
(e) none of the above

28. The collector current $I_c$ of a BJT flows through two junctions. The drain current of an FET $I_d$ flows through _________ junctions.
(a) 0
(b) 1
(c) 2
(d) 3
(e) none of the above

29. As the channel width of a JFET decreases, the source-to-drain resistance of the device:
(a) increases
(b) decreases
(c) remains constant
(d) is not affected

30. Which of the following is usually used to control the channel width of a given JFET?
(a) the source voltage
(b) the gate-to-source voltage
(c) the operating frequency
(d) the drain current

31. The region of the JFET drain curve that lies between pinch-off and breakdown is called:
(a) the constant-voltage region
(b) the ohmic region
(c) the saturation region
(d) none of the above

32. The value of gate-to-source voltage that causes the drain current to reach its maximum value at a given value of drain voltage is called:
(a) $VD_{MAX}$
(b) pinch-off voltage
(c) $V_{DSS}$
(d) none of the above

33. The FET transfer characteristic curve is defined by Shockley's equation and is:
(a) unaffected by the network it is used in
(b) directly related to the drain resistor
(c) inversely related to the drain resistor
(d) inversely related to the sum of the drain and source resistors
(e) none of the above

34. What two parameters represent the FET transfer characteristic?
(a) drain-to-source voltage and gate-to-source voltage
(b) drain-to-source voltage and drain current
(c) gate-to-source voltage and drain current
(d) gate current and drain current
(e) none of the above

35. The value of drain current is always _________ the value of the short circuit drain current $I_{DSS}$ for a given JFET.
(a) less than
(b) equal to
(c) less than or equal to
(d) greater than

36. A JFET has values of $I_{DSS}$ = mA and $V_{GS\ OFF}$ = -5 V. What is the value of $I_D$ at $V_{GS}$ = -3 V?
(a) 1.6 mA
(b) 3.6 mA
(c) 25.6 mA
(d) 4 mA

37. A given JFET has values of $V_P$ = 10 V and $I_{DSS}$ = 8 mA. What is the value of $V_{GS\ OFF}$ for the device?
(a) +10
(b) -10
(c) -5
(d) cannot be determined from the information given

38. The enhancement-type and the depletion-type FETs are subclasses of:
(a) junction FET
(b) metal-oxide-semiconductor FETs
(c) BJTs
(d) bipolar FETs

39. The depletion-type MOSFET has specifications and many characteristics that are similar to:
    (a) the PNP BJT
    (b) the NPN BJT
    (c) the JFET
    (d) none of the above

40. Which of the following FETs is the best choice when the gate-to-source voltage has both positive and native swings?
    (a) JFET
    (b) enhancement MOSFET
    (c) depletion MOSFET
    (d) CMOS
    (e) VMOS

41. MOSFETs typically have an input impedance value that is:
    (a) higher than the JFET
    (b) lower than the JFET
    (c) equal to the JFET
    (d) randomly defined relative to the JFET

42. D-MOSFETs can operate in:
    (a) the depletion mode only
    (b) the enhancement mode only
    (c) the depletion mode and the enhancement mode
    (d) all of the above

43. MOSFETs are also referred to as:
    (a) substrates
    (b) IGFETs
    (c) DEFETs
    (d) SiO-FETS

44. Which of the following is true for an N-channel D-MOSFET that is being operated in the depletion mode?
    (a) $I_D > I_{DSS}$ and $V_{GS}$ is positive
    (b) $I_D < I_{DSS}$ and $V_{GS}$ is negative
    (c) $I_D > I_{DSS}$ and $V_{GS}$ is negative
    (d) $I_D < I_{DSS}$ and $V_{GS}$ is positive

45. A D-MOSFET has values of $I_D = 15.63$ mA and $V_{GS} = +1$ V. What is the value of $I_{DSS}$?
    (a) 0 mA
    (b) 5 mA
    (c) 10 mA
    (d) none of the above

46. For levels of gate-to-source voltage greater than the threshold voltage, the drain current is directly related to the:
    (a) square of the difference between the gate-to-source voltage and the threshold voltage
    (b) gate-to-drain voltage
    (c) square of the gate current
    (d) none of the above

47. For a gate-to-drain voltage less than the threshold level the drain current of an enhancement-type MOSFET is:
    (a) 100 mA
    (b) 10 mA
    (c) 1.0 mA
    (d) 0.0 mA

48. The E-MOSFET can operate in:
    (a) the depletion mode only
    (b) the enhancement mode only
    (c) the depletion mode and the enhancement mode
    (d) all of the above

49. A major disadvantage of MOSFETs is:
    (a) its high input impedance
    (b) that it is a voltage operated device
    (c) that it is sensitive to electrostatic discharges
    (d) none of the above

50. Many MOSFET devices now contain internal _________ that protect them from static electricity.
    (a) BJTs
    (b) Zener diodes
    (c) PN junction diodes
    (d) capacitors

51. The power-handling levels of a MOSFET:
    (a) is usually less than one Watt
    (b) is about 10 Watts
    (c) is similar to that of a vacuum tube
    (d) is usually about 100 Watts

52. When compared with commercially available planar MOSFETs, VMOS FETs have:
    (a) reduced channel resistance
    (b) higher current capability
    (c) higher power ratings
    (d) a positive temperature coefficient
    (e) all of the above

53. The VMOS FET typically has switching times that are:
    (a) very slow
    (b) 1/2 that of the typical BJT
    (c) 2 times that of the typical BJT
    (d) 20 times that of the typical BJT

54. VMOS is a special-purpose type of:
    (a) D-MOSFET
    (b) E-MOSFET
    (c) JFET
    (d) BJT

55. A relatively high input impedance, fast switching speeds, and low operating power describe the characteristics of the _________ family.
(a) BJT
(b) enhancement-type MOSFET
(c) depletion-type MOSFET
(d) CMOS FET
(e) VMOS FET

56. The FET that typically has the best switching speed performance is:
(a) CMOS
(b) JFET
(c) NMOS
(d) PMOS
(e) VMOS

57. CMOS stands for:
(a) complementary MOS
(b) current MOS
(c) capacitive MOS
(d) conductive MOS

58. A CMOS inverter has a +10 V $V_{SS}$ supply and an input that varies between 0 V and +10 V. When the input to the circuit is +10 V, the output from the circuit is:
(a) -10 V
(b) 0 V
(c) +10 V
(d) cannot be determined from the information given

1. Answer: current; voltage Difficulty: 2 Section: 1 Objective: 1
2. Answer: ohmic; saturation; breakdown

   Difficulty: 2 Section: 2 Objective: 1
3. Answer: voltage controlled resistor

   Difficulty: 2 Section: 2 Objective: 1
4. Answer: (a) Difficulty: 2 Section: 2 Objective: 1
5. Answer: (d) Difficulty: 2 Section: 3 Objective: 1
6. Answer: (c) Difficulty: 2 Section: 3 Objective: 1
7. Answer: (a) Difficulty: 2 Section: 3 Objective: 1
8. Answer: (c) Difficulty: 2 Section: 5 Objective: 1
9. Answer: (c) Difficulty: 2 Section: 7 Objective: 1
10. Answer: (a) Difficulty: 2 Section: 7 Objective: 1
11. Answer: (c) Difficulty: 2 Section: 7 Objective: 1
12. Answer: (a) Difficulty: 2 Section: 7 Objective: 1
13. Answer: (c) Difficulty: 2 Section: 8 Objective: 1
14. Answer: (c) Difficulty: 2 Section: 8 Objective: 1
15. Answer: (b) Difficulty: 2 Section: 9 Objective: 1
16. Answer: (a) Difficulty: 2 Section: 9 Objective: 1
17. Answer: (c) Difficulty: 2 Section: 11 Objective: 1
18. Answer: (b) Difficulty: 2 Section: 1 Objective: 1
19. Answer: (d) Difficulty: 2 Section: 2 Objective: 1
20. Answer: (e) Difficulty: 2 Section: 1 Objective: 2
21. Answer: (c) Difficulty: 2 Section: 2 Objective: 2
22. Answer: (a) Difficulty: 2 Section: 3 Objective: 1
23. Answer: (b) Difficulty: 2 Section: 4 Objective: 1

24. Answer: (a) Difficulty: 2 Section: 5 Objective: 1

25. Answer: (c) Difficulty: 2 Section: 6 Objective: 1

26. Answer: (a) Difficulty: 2 Section: 3 Objective: 2

27. Answer: (d) Difficulty: 2 Section: 4 Objective: 2

28. Answer: (a) Difficulty: 2 Section: 5 Objective: 2

29. Answer: (a) Difficulty: 2 Section: 6 Objective: 2

30. Answer: (b) Difficulty: 2 Section: 7 Objective: 2

31. Answer: (c) Difficulty: 2 Section: 8 Objective: 2

32. Answer: (a) Difficulty: 2 Section: 9 Objective: 2

33. Answer: (a) Difficulty: 2 Section: 1 Objective: 3

34. Answer: (c) Difficulty: 2 Section: 2 Objective: 3

35. Answer: (c) Difficulty: 2 Section: 3 Objective: 3

36. Answer: (a) Difficulty: 2 Section: 4 Objective: 3

37. Answer: (a) Difficulty: 2 Section: 1 Objective: 4

38. Answer: (b) Difficulty: 2 Section: 1 Objective: 7

39. Answer: (c) Difficulty: 2 Section: 2 Objective: 7

40. Answer: (c) Difficulty: 2 Section: 3 Objective: 7

41. Answer: (a) Difficulty: 2 Section: 4 Objective: 7

42. Answer: (d) Difficulty: 2 Section: 5 Objective: 7

43. Answer: (b) Difficulty: 2 Section: 6 Objective: 7

44. Answer: (b) Difficulty: 2 Section: 7 Objective: 7

45. Answer: (c) Difficulty: 2 Section: 8 Objective: 7

46. Answer: (a) Difficulty: 2 Section: 1 Objective: 8

47. Answer: (d) Difficulty: 2 Section: 2 Objective: 8

48. Answer: (b) Difficulty: 2 Section: 3 Objective: 8

49. Answer: (c) Difficulty: 2 Section: 1 Objective: 9

50. Answer: (b) Difficulty: 2 Section: 2 Objective: 9

51. Answer: (a) Difficulty: 2 Section: 1 Objective: 10

52. Answer: (e) Difficulty: 2 Section: 2 Objective: 10

53. Answer: (b) Difficulty: 2 Section: 3 Objective: 10

54. Answer: (b) Difficulty: 2 Section: 4 Objective: 10

55. Answer: (d) Difficulty: 2 Section: 1 Objective: 11

56. Answer: (a) Difficulty: 2 Section: 2 Objective: 11

57. Answer: (a) Difficulty: 2 Section: 3 Objective: 11

58. Answer: (b) Difficulty: 2 Section: 4 Objective: 11

# Chapter 6: FET Biasing

## *MULTIPLE CHOICE*

1. A JFET can be biased in several different ways. The common method(s) of biasing an N-Channel JFET is(are) ________.
   (a) self-bias configuration
   (b) voltage divider bias configuration
   (c) fixed-bias configuration
   (d) all of the above

## *SHORT ANSWER*

2. In a self-bias circuit for an N-channel JFET transistor the bias voltage $V_{GS}$ is developed across the resistor connected to the __________.

## *MULTIPLE CHOICE*

3. In a self-bias circuit for an N-channel JFET transistor the self-bias line ____________.
   (a) is straight up and down parallel to the $I_D$ axis
   (b) is straight left and right parallel to the $V_{GS}$ axis
   (c) is slanted and passing through the $I_D$ and the $V_{GS}$ axis on the positive side
   (d) is slanted and passes through origin

4. In a voltage divider-bias circuit for an N-channel JFET transistor the bias line ____________.
   (a) is straight up and down parallel to the $I_D$ axis
   (b) is straight left and right parallel to the $V_{GS}$ axis
   (c) is slanted and passing through the $I_D$ and the $V_{GS}$ axis on the positive side
   (d) is slanted and passes through origin

5. In the voltage divider-bias circuit for an N-channel JFET transistor, shown in Figure 6.1.5 calculate the quiescent drain current $I_D$ and the gate-to-source voltage $V_{GS}$.
   (a) $I_{DQ}$ = 2.4 mA and $V_{GSQ}$ = 1.8 Volts
   (b) $I_{DQ}$ = 2.4 mA and $V_{GSQ}$ = -1.8 Volts
   (c) $I_{DQ}$ = 1.2 mA and $V_{GSQ}$ = -3.6 Volts
   (d) $I_{DQ}$ = 1.2 mA and $V_{GSQ}$ = 3.6 Volts

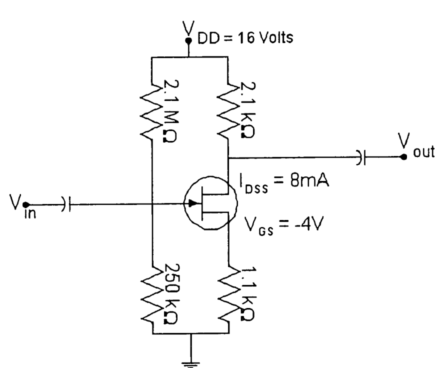


Figure 6.1.5 Voltage Divider-Bias Circuit

6. In the voltage divider-bias circuit for an N-channel JFET transistor, shown in Figure 6.1.5 calculate the drain gate voltage $V_{DG}$.
(a) $V_{DG}$ = 8.42 Volts
(b) $V_{DG}$ = 7.42 Volts
(c) $V_{DG}$ = 6.42 Volts
(d) $V_{DG}$ = 5.42 Volts

7. There are many similarities between the transfer curves of JFETs and the depletion type MOSFETs so they permit similar analysis of each in the dc domain. The primary difference, for an N-channel device, between the two is the fact that depletion-type MOSFETs permit operating points with _______ values of $V_{GS}$ and levels of $I_D$ that ______ $I_{DSS}$.
(a) positive; exceed
(b) negative; exceed
(c) positive; do not exceed
(d) negative; do not exceed

8. In the self-bias circuit for an N-channel depletion mode MOSFET transistor, shown in Figure 6.1.8 calculate the quiescent drain current $I_D$ and the gate-to-source voltage $V_{GS}$.
(a) $I_{DQ}$ = 1.9 mA
(b) $I_{DQ}$ = 1.7 mA
(c) $I_{DQ}$ = 1.5 mA
(d) $I_{DQ}$ = 1.3 mA

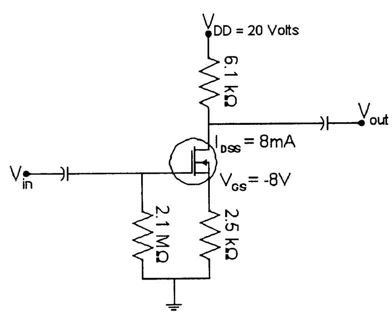

Figure 6.1.8 Self-Bias Circuit

9. In the enhancement type of MOSFET the channel is formed when the gate-to-source voltage _______ the ________ voltage.
(a) exceeds; pinch-off
(b) is less than; pinch-off
(c) is less than; threshold
(d) exceeds; threshold

10. In the feedback-bias circuit for an N-channel enhancement mode MOSFET transistor, shown in Figure 6.1.10 calculate the quiescent drain current $I_D$.
(a) $I_{DQ}$ = 2.5 mA
(b) $I_{DQ}$ = 2.9 mA
(c) $I_{DQ}$ = 3.3 mA
(d) $I_{DQ}$ = 3.7 mA

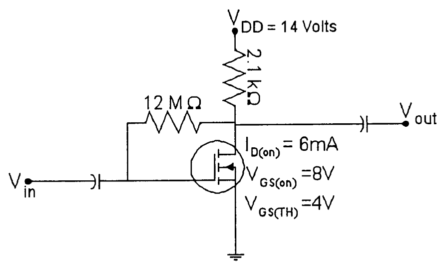

Figure 6.1.10 Feedback-Bias Circuit

11. In the combination network, shown in Figure 6.1.11 calculate the quiescent collector current $I_C$.
(a) $I_C$ = 1.7 mA
(b) $I_C$ = 1.9 mA
(c) $I_C$ = 2.1 mA
(d) $I_C$ = 2.3 mA

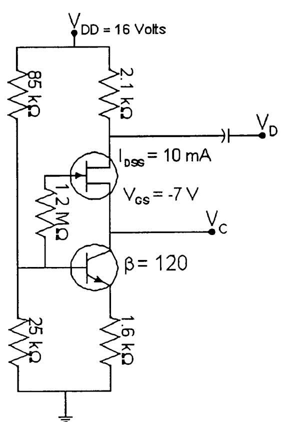

Figure 6.1.11 Combination Network

12. In the combination network, shown in Figure 6.1.11 calculate the quiescent voltage collector to emitter voltage $V_{CE}$ for the BJT transistor.
(a) $V_{CE}$ = 3.63 Volts
(b) $V_{CE}$ = 7.78 Volts
(c) $V_{CE}$ = -4.14 Volts
(d) $V_{CE}$ = 5.11 Volts

13. In the combination network, shown in Figure 6.1.11 calculate the voltage at the drain of the JFET.
(a) $V_D$ = 8.22 Volts
(b) $V_D$ = 4.14 Volts
(c) $V_D$ = 12.5 Volts
(d) $V_D$ = 3.5 Volts

14. Generally, it is a good design practice for linear amplifiers to choose the operating point that is approximately ________.
    (a) near the saturation region
    (b) near the cut-off region
    (c) in the center of the active region
    (d) near the origin

15. The analysis that we mostly work with is that of the N-channel device. For P-channel devices the transfer curve employed is the ______ image and the defined current directions are ______.
    (a) identical; the same
    (b) mirror; the same
    (c) mirror; reversed
    (d) identical; reversed

16. It is important to remember that when the JFET is used as a voltage variable resistor, which is one of its practical applications, the voltage $V_{DS}$ is ____ $V_{DS(max)}$ and $|V_{GS}|$ is ___ $|V_P|$.
    (a) very much greater than; very much greater than
    (b) very much less than; very much greater than
    (c) very much greater than; very much less than
    (d) very much less than; very much less than

### *SHORT ANSWER*

17. One of the most important factors that affect the stability of a system is temperature variation. As the system heats up the usual tendency is for the gain of the system to _____.

### *MULTIPLE CHOICE*

18. The simplest biasing arrangement for the N-channel JFET is:
    (a) voltage divider-bias
    (b) variable-bias
    (c) drain feedback-bias
    (d) fixed-bias

19. The fixed-bias technique requires _________ power supplies.
    (a) 1
    (b) 2
    (c) 3
    (d) 4

20. A JFET has the following ratings: $V_P$ = -2 V to -5 V and an $I_{DSS}$ = 4 mA. The device is being used in a fixed-bias circuit with a gate supply voltage of $V_{GG}$ = 1 V. What is the difference between the minimum and maximum values of $I_D$ values for the circuit?
    (a) 7.6 mA
    (b) 9.6 mA
    (c) 6.68 mA
    (d) 8.6 mA

21. The self-bias configuration develops the controlling gate-to-source voltage across a resistor introduced:
    (a) in the drain leg
    (b) in the gate leg
    (c) in the source leg
    (d) none of the above

22. A characteristic of voltage divider-bias in FET circuits is:
    (a) the current in both $R_1$ and $R_2$ is the same
    (b) the voltage drop across $R_2$ is $V_{GS}$
    (c) the gate current is zero
    (d) all of the above

23. When using voltage divider-bias in FET amplifiers, increasing the size of the source resistor results in:
    (a) lower quiescent values
    (b) more positive of $V_{GS}$
    (c) a larger value of drain current
    (d) all of the above

24. The primary difference between JFETs and depletion-type MOSFETs is:
    (a) JFETs can have positive values of $V_{GS}$ and levels of drain current that exceed $I_{DSS}$
    (b) depletion-type MOSFETs can have positive values of $V_{GS}$ and levels of $I_D$ that exceed $I_{DSS}$
    (c) depletion-type MOSFETs can have only positive of $V_{GS}$
    (d) JFETs can have only positive values of $V_{GS}$

25. __________ biasing may be used with D-MOSFETs but not with JFETs.
    (a) Gate drain
    (b) Zero
    (c) Gate cutoff
    (d) Current source

26. A popular arrangement for enhancement type MOSFET biasing is:
    (a) drain feedback biasing
    (b) fixed-bias
    (c) source resistor-bias
    (d) all of the above

27. An E-MOSFET has values of $V_{GS\ th} = 2$ V and $I_{D\ ON} = 8$ mA when $V_{FS} = 10$ V. What is the value of k for the device?
    (a) 0.0001
    (b) 0.000125
    (c) 80
    (d) cannot be determined from the information given

28. An E-MOSFET has values of $V_{GS\ th} = 4$ V and $I_{D\ ON} = 12$ mA when $V_{GS} = 10$ V. The device is being used in a circuit that has a value of $V_{GS} = 6$ V. What is the value of $I_D$ for the circuit?
    (a) 13.33 mA
    (b) 1 mA
    (c) 1.33 mA
    (d) 0 mA

29. Which of the following biasing circuits can be used with E-MOSFETs?
    (a) self-bias
    (b) zero-bias
    (c) drain feedback-bias
    (d) current source-bias

30. Generally, it is good design practice for linear amplifiers to have operating points that:
    (a) are close to saturation level
    (b) are close to the cut-off region
    (c) are close to midpoint of the load line
    (d) none of the above

1. Answer: (d) Difficulty: 1 Section: 2 Objective: 1

2. Answer: source Difficulty: 1 Section: 3 Objective: 1

3. Answer: (d) Difficulty: 2 Section: 3 Objective: 1

4. Answer: (c) Difficulty: 2 Section: 4 Objective: 1

5. Answer: (b) Difficulty: 2 Section: 4 Objective: 1

6. Answer: (a) Difficulty: 3 Section: 4 Objective: 1

7. Answer: (a) Difficulty: 1 Section: 5 Objective: 1

8. Answer: (b) Difficulty: 2 Section: 5 Objective: 1

9. Answer: (d) Difficulty: 1 Section: 6 Objective: 1

10. Answer: (c) Difficulty: 2 Section: 6 Objective: 1

11. Answer: (a) Difficulty: 3 Section: 8 Objective: 1

12. Answer: (d) Difficulty: 3 Section: 8 Objective: 1

13. Answer: (c) Difficulty: 3 Section: 8 Objective: 1

14. Answer: (c) Difficulty: 3 Section: 9 Objective: 1

15. Answer: (c) Difficulty: 2 Section: 11 Objective: 1

16. Answer: (d) Difficulty: 2 Section: 13 Objective: 1

17. Answer: increase Difficulty: 3 Section: 13 Objective: 1

18. Answer: (d) Difficulty: 2 Section: 1 Objective: 2

19. Answer: (b) Difficulty: 2 Section: 2 Objective: 2

20. Answer: (c) Difficulty: 4 Section: 3 Objective: 2

21. Answer: (c) Difficulty: 2 Section: 1 Objective: 3

22. Answer: (d) Difficulty: 2 Section: 1 Objective: 4

23. Answer: (a) Difficulty: 2 Section: 2 Objective: 4

24. Answer: (b) Difficulty: 2 Section: 1 Objective: 5

25. Answer: (b) Difficulty: 2 Section: 2 Objective: 5

26. Answer: (a) Difficulty: 2 Section: 1 Objective: 6

27. Answer: (b) Difficulty: 2 Section: 2 Objective: 6

28. Answer: (c) Difficulty: 2 Section: 3 Objective: 6

29. Answer: (c) Difficulty: 2 Section: 4 Objective: 6

30. Answer: (c) Difficulty: 2 Section: 1 Objective: 9

# Chapter 7: BJT Transistor Modeling

### *SHORT ANSWER*

1. A model is a combination of ______ ______ properly chosen that best approximates the actual behavior of ______ devices under specific operating conditions.

2. An ac equivalent circuit of a network is obtained by replacing the dc sources by ________ equivalent; replacing all the capacitors by ________ equivalent; and removing all the elements bypassed by the ________ equivalents.

3. The important two port parameters for analysis and design are ______; ______; ______; and ______.

### *MULTIPLE CHOICE*

4. The input impedance of a BJT is:
   (a) resistive
   (b) capacitive
   (c) inductive
   (d) a combination of resistive, capacitive, and inductive

5. The output impedance of a BJT is:
   (a) resistive
   (b) capacitive
   (c) inductive
   (d) a combination of resistive, capacitive, and inductive

6. To calculate the output impedance the applied signal must be set:
   (a) equal to the smallest value of the input signal
   (b) equal to the largest value of the input signal
   (c) equal to zero
   (d) equal to a value that is half way between the largest and the smallest

7. For a two-port system, like a BJT amplifier, the no-load voltage gain:
   (a) is always greater than the loaded voltage gain
   (b) is always less than the loaded voltage gain
   (c) is always equal to the loaded voltage gain
   (d) can be less than or equal to the loaded voltage gain

8. Depending on the configuration of the amplifier, the magnitude of the no-load voltage gain for a single BJT transistor amplifier typically ranges from:
   (a) 10 to about 10,000
   (b) a hundred to about a million
   (c) just a little less than 1 to a few hundred
   (d) none of the above

9. Depending on the configuration of the amplifier, the magnitude of the no-load current gain for a single BJT transistor amplifier typically ranges from:
   (a) 10 to about 10,000
   (b) one to about a thousand
   (c) just a little less than 1 to a level that may exceed one hundred
   (d) none of the above

10. Given the configuration of Figure 7.1.10 determine the input impedance. $V_S$ = 50 mVolts, $I_{In}$ = 20 μAmps, and $R_{Sence}$ = 500 Ω.
    (a) 2000 Ω
    (b) 20.0 KΩ
    (c) 200.0 KΩ
    (d) 2.0 MΩ

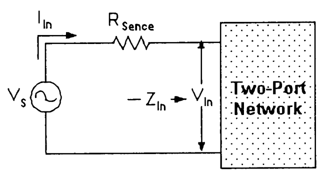


Figure 7.1.10

11. The '$r_e$' transistor model replaces the base-emitter junction by:
    (a) a constant voltage
    (b) an open circuit
    (c) the AC resistance of the forward-biased diode at the operating point
    (d) a diode

12. The typical value of the transistors input impedance, when used as a common emitter amplifier is:
    (a) $\beta r_e$ which ranges from a few hundred ohms to a few kilo ohms
    (b) $g_m I_B$. $g_m$ ranges from about $0.1 \times 10^{-3}$ to about $8 \times 10^{-3}$
    (c) depends on the transistor and the manufacturer
    (d) could be any one of the above. They all describe the input impedance in different ways

13. The H-parameter model uses ____ parameters to describe the equivalent circuit of the BJT transistor.
    (a) two
    (b) three
    (c) four
    (d) five

14. The H-parameter model and the '$r_e$' parameter models are almost identical if the parameter _____ in the H-parameter model is ignored.
    (a) $h_f$
    (b) $h_o$
    (c) $h_r$
    (d) $h_i$

15. Given the following H-parameter model values for a common emitter amplifier, what value would be equivalent for $\beta$ and $r_e$?
$h_{ie} = 1.450$ k; $h_{oe} = 17.5\ \mu S$ k; $h_{fe} = 125$; $h_{re} = 0.4 \times 10^{-3}$
(a) 17.5 $\mu$S and $0.4 \times 10^{-3}$
(b) 125 and 1.450 k
(c) 1.450 k and 17.5 $\mu$S
(d) $0.4 \times 10^{-3}$ and 125

16. The approximation that allows superposition to be used to isolate the ac analysis and the dc analysis of small-signal amplifiers is:
(a) that the circuit response is non-linear
(b) that the circuit response is linear
(c) that the circuit response is dc linear and ac non-linear
(d) that the circuit response is dc non-linear and ac linear
(e) none of the above

17. A _________ is a combination of circuit elements, properly chosen, that best approximate the actual behavior of a semiconductor device under specific operating conditions.
(a) circuit
(b) schematic
(c) model
(d) monolithic IC

18. The input impedance of a BJT is:
(a) inductive
(b) capacitive
(c) resistive
(d) resistive and capacitive
(e) resistive and inductive

19. The output impedance of a BJT is:
(a) inductive
(b) capacitive
(c) resistive
(d) resistive and capacitive
(e) resistive and inductive

20. For BJT amplifiers, the no-load voltage gain is:
(a) less than the loaded voltage gain
(b) equal to the loaded voltage gain
(c) greater than the loaded voltage gain
(d) equal to zero

21. Depending on configuration, the magnitude of the voltage gain for a loaded BJT amplifier ranges from:
(a) just less than 1 to a few hundred
(b) zero to 10,000
(c) 1 to 10,000
(d) 10 to 1000
(e) none of the above

22. BJT amplifiers current gain will typically range from:
    (a) just less than 1 to just exceeding 100
    (b) zero to 10,000
    (c) 1 to 10,000
    (d) 10 to 1000
    (e) none of the above

23. Given the configuration of Fig. 7.7, determine the input impedance if $V_s$ = 40 mV, $R_{sense}$ = 0.5 K ohms, and the input current is 20 μA.
    (a) 1.5 M ohms
    (b) 5.822 M ohms
    (c) 1,500 ohms
    (d) 582 K ohms
    (e) 100 K ohms

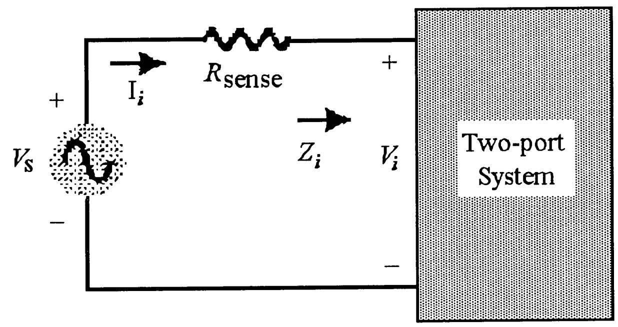


Figure 7.7

24. Given the configuration of Fig. 7.7, determine the input voltage if $V_s$ = 40 mV, $R_{sense}$ = 0.5 K ohms, and the input current is 20 μA.
    (a) 55 mV
    (b) 40 mV
    (c) 35 mV
    (d) 30 mV
    (e) none of the above

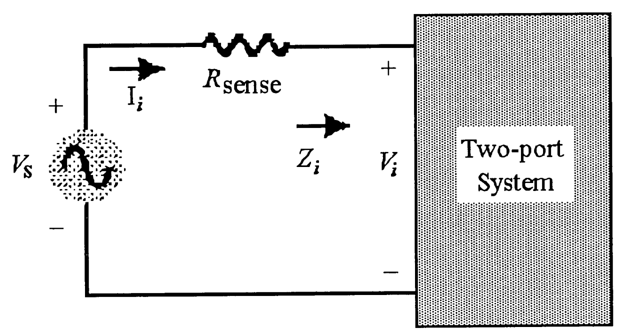


Figure 7.7

25. Given the two-port configuration of a BJT amplifier, determine the input voltage if $V_s$ = 18 mV, $R_{sense}$ = 600 ohms, $V_o$ = 3.6 Volts and the input current is 10 μA.
(a) 12 mV
(b) 16 mV
(c) 17.994 mV
(d) 21.6 mV
(e) none of the above

26. Given the two-port configuration of a BJT amplifier, determine the input impedance if $V_s$ = 18 mV, $R_{sense}$ = 600 ohms, $V_o$ = 3.6 Volts and the input current is 20 μA.
(a) 120 ohms
(b) 1,200 ohms
(c) 23 K ohms
(d) 27 K ohms
(e) none of the above

27. Given a two-port configuration of a BJT amplifier, determine the no-load voltage gain if $V_s$ = 18 mV, $R_{sense}$ = 600 ohms, $V_o$ = 3.6 Volts and the input current is 10 μA.
(a) 100
(b) 200
(c) 300
(d) 400
(e) none of the above

28. Given a two-port BJT amplifier configuration, determine the loaded voltage gain if $V_s$ = 18 mV, $R_{sense}$ = 600 ohms, $V_o$ = 3.6 Volts and the input current is 10 μA.
(a) 96.66
(b) 112.33
(c) 133.33
(d) 150
(e) 166.66

29. The '$r_e$' transistor model replaces the ____________ __________ with the junction diode's ac resistance.
(a) collector-base junction
(b) collector-emitter junction
(c) emitter-base junction
(d) all of the above

30. For the common-base configuration, the typical value of the input impedance range is:
(a) 2 to 50 ohms
(b) 50 to 1000 ohms
(c) 100 to 10,000 ohms
(d) 1 M ohms to 2 M ohms
(e) none of the above

31. For the common-base configuration, typical values of the output impedance range is:
    (a) 2 to 50 ohms
    (b) 50 to 1000 ohms
    (c) 100 to 10,000 ohms
    (d) 1 M ohm to 2 M ohms

32. The input impedance of the common-emitter configuration is:
    (a) inversely related to the transistor beta
    (b) directly related to the transistor beta
    (c) equal to the transistor beta
    (d) none of the above

33. The common-emitter configuration has a current gain that is equal to:
    (a) 1/2 beta
    (b) beta
    (c) 2 beta
    (d) 20 beta
    (e) none of the above

34. The equation that correctly defines one of the hybrid parameters is:
    (a) $V_o = h_{11} \times I_i + h_{21} \times V_i$
    (b) $V_i = h_{11} \times I_i + h_1 \times 2V_o$
    (c) $I_o = h_{12} \times V_o + h_{22} \times V_o$
    (d) $I_i = h_{21} \times I_o + h_{22} \times V_o$

35. The $h_{12}$ hybrid parameter is defined as the:
    (a) open-circuit output admittance
    (b) open-circuit reverse voltage ratio
    (c) short-circuit forward current ratio
    (d) short-circuit input impedance

36. The $h_{22}$ hybrid parameter is defined as the:
    (a) open-circuit output admittance
    (b) open-circuit reverse voltage ratio
    (c) short-circuit forward current ratio
    (d) short-circuit input impedance

37. The hybrid parameter that is represented by the name hf_ is:
    (a) $h_{11}$
    (b) $h_{12}$
    (c) $h_{21}$
    (d) $h_{22}$

38. The H-parameter that is the equivalent of the common-emitter circuit's beta is:
    (a) $h_{fe}$
    (b) $h_{ie}$
    (c) $h_{oe}$
    (d) $h_{re}$

39. The base input impedance of a BJT is listed on its spec sheet as:
   (a) $h_{je}$
   (b) $h_{re}$
   (c) $h_{ie}$
   (d) $h_{oe}$

40. A given transistor has the following values: $h_{FE} = 200$, $h_{fe} = 120$, $h_{ie} = 5$ K ohms, $h_{re} = 40$, and $h_{oe} = 2500$ µS. What is the value of $r_e$ for the device?
   (a) 44 ohms
   (b) 41.7 ohms
   (c) 400 ohms
   (d) 25 ohms

41. The hybrid model is used in analysis and design:
   (a) much more than the $r_e$ model
   (b) more than the $r_e$ model
   (c) equal to the $r_e$ model
   (d) less than the $r_e$ model
   (e) much less than the $r_e$ model

1. Answer: circuit elements; semiconductor

   Difficulty: 2 Section: 3 Objective: 1

2. Answer: short-circuit; short-circuit; short-circuit

   Difficulty: 2 Section: 2 Objective: 1

3. Answer: input impedance; output impedance; voltage gain; current gain

   Difficulty: 2 Section: 4 Objective: 1

4. Answer: (a) Difficulty: 2 Section: 4 Objective: 1

5. Answer: (a) Difficulty: 2 Section: 4 Objective: 1

6. Answer: (c) Difficulty: 2 Section: 4 Objective: 1

7. Answer: (a) Difficulty: 2 Section: 4 Objective: 1

8. Answer: (c) Difficulty: 2 Section: 4 Objective: 1

9. Answer: (c) Difficulty: 2 Section: 4 Objective: 1

10. Answer: (a) Difficulty: 2 Section: 4 Objective: 1

11. Answer: (c) Difficulty: 2 Section: 5 Objective: 1

12. Answer: (a) Difficulty: 2 Section: 5 Objective: 1

13. Answer: (c) Difficulty: 2 Section: 6 Objective: 1

14. Answer: (c) Difficulty: 2 Section: 6 Objective: 1

15. Answer: (b) Difficulty: 2 Section: 6 Objective: 1

16. Answer: (b) Difficulty: 4 Section: 1 Objective: 2

17. Answer: (c) Difficulty: 2 Section: 1 Objective: 3

18. Answer: (c) Difficulty: 2 Section: 1 Objective: 4

19. Answer: (c) Difficulty: 2 Section: 2 Objective: 4

20. Answer: (c) Difficulty: 2 Section: 3 Objective: 4

21. Answer: (a) Difficulty: 2 Section: 4 Objective: 4

22. Answer: (a) Difficulty: 2 Section: 5 Objective: 4

23. Answer: (c) Difficulty: 2 Section: 6 Objective: 4

24. Answer: (d) Difficulty: 2 Section: 7 Objective: 4

25. Answer: (a) Difficulty: 2 Section: 8 Objective: 4

26. Answer: (b) Difficulty: 2 Section: 9 Objective: 4

27. Answer: (b) Difficulty: 2 Section: 10 Objective: 4

28. Answer: (c) Difficulty: 4 Section: 11 Objective: 4

29. Answer: (c) Difficulty: 2 Section: 1 Objective: 5

30. Answer: (a) Difficulty: 1 Section: 2 Objective: 5

31. Answer: (d) Difficulty: 1 Section: 3 Objective: 5

32. Answer: (b) Difficulty: 2 Section: 4 Objective: 5

33. Answer: (b) Difficulty: 2 Section: 5 Objective: 5

34. Answer: (b) Difficulty: 2 Section: 1 Objective: 6

35. Answer: (b) Difficulty: 2 Section: 2 Objective: 6

36. Answer: (a) Difficulty: 2 Section: 3 Objective: 6

37. Answer: (c) Difficulty: 2 Section: 4 Objective: 6

38. Answer: (a) Difficulty: 2 Section: 5 Objective: 6

39. Answer: (c) Difficulty: 2 Section: 6 Objective: 6

40. Answer: (b) Difficulty: 2 Section: 7 Objective: 6

41. Answer: (d) Difficulty: 2 Section: 8 Objective: 6

## Chapter 8: BJT Small-Signal Analysis

### *SHORT ANSWER*

1. The negative sign in the resulting equation for $A_V$, in a BJT small signal analysis, reveals that there is _____________ between the input and the output signal.

### *MULTIPLE CHOICE*

2. If the resistor in the emitter leg is not bypassed by a capacitor then the input impedance of the small signal amplifier will _______.
   (a) increase
   (b) decrease
   (c) stay the same
   (d) increase in some cases and decrease in other cases

3. If the resistor in the emitter leg is not bypassed by a capacitor then the voltage gain of the small signal amplifier will _______.
   (a) increase
   (b) decrease
   (c) stay the same
   (d) increase in some cases and decrease in other cases

4. Calculate the voltage gain for the circuit shown in Figure 8.1.4 assuming that the capacitor of 10 μF is **not** connected in the circuit. (Assume the value of the resistor $r_e$ = 15.3Ω)
   (a) -137.25
   (b) -8.4
   (c) -7.91
   (d) -16.34

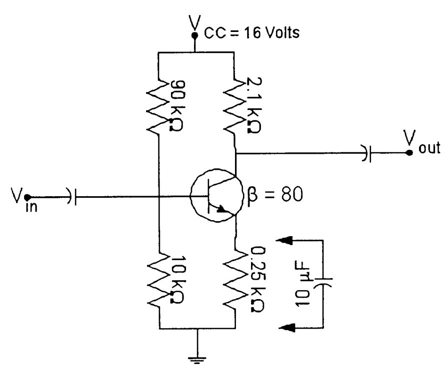


Figure 8.1.4 Voltage Divider-Bias Circuit

5. Calculate the voltage gain for the circuit shown in Figure 8.1.4; assuming that the resistor in the emitter leg (0.25 kΩ) has a capacitor of 10 μF connected in parallel. (Assume the value of the resistor $r_e$ = 15.3 Ω)
   (a) -137.25
   (b) -8.4
   (c) -7.91
   (d) -16.34

6. The voltage gain of a very well-designed common collector amplifier configuration, using a PNP transistor, is:
   (a) about -0.9
   (b) about 0.9
   (c) in the range 0.95 to 0.99
   (d) in the range -0.95 to -0.99

7. When comparing the common emitter and the common collector amplifiers, the input impedance of the common _______ is much larger and the output impedance of the common _______ is much smaller.
   (a) collector; emitter
   (b) collector; collector
   (c) emitter; collector
   (d) emitter; emitter

8. The common base amplifier is characterized as having a relatively _____ input impedance and relatively _____ output impedance.
   (a) low; high
   (b) low; low
   (c) high; low
   (d) high; high

***SHORT ANSWER***

9. For the common base amplifier configuration the input voltage $V_{in}$ and the amplified output voltage $V_{out}$ are ________ phase with each other.

10. Match the H-parameters to their proper names in the table given below:

| | |
|---|---|
| 1. $h_{fb}$ | a. input impedance - common emitter |
| 2. $h_{re}$ | b. forward gain - common base |
| 3. $h_{oc}$ | c. output impedance - common base |
| 4. $h_{ib}$ | d. reverse - common base |
| 5. $h_{fe}$ | e. output impedance - common collector |
| 6. $h_{ic}$ | f. output impedance - common emitter |
| 7. $h_{rb}$ | g. forward gain - common emitter |
| 8. $h_{ob}$ | h. input impedance - common base |
| 9. $h_{oe}$ | i. input impedance - common collector |
| 10. $h_{ie}$ | j. reverse - common emitter |

11. For the three amplifier configurations of the BJT transistor studied fill in the following table:

| Parameter | Common Emitter | Common Collector | Common Base |
|---|---|---|---|
| Input Impedance | | | |
| Output Impedance | | | |
| Voltage Gain | | | |
| Current gain | | | |

Fill in all the entries using the relative terms
Highest; In between; Lowest
for each parameter.

**Figure 8.1.11** Table comparing the three amplifier configurations.

## *MULTIPLE CHOICE*

12. For the circuit shown in Figure 8.1.12, determine the input impedance for the amplifier:
(a) $R_1 || R_2 || (\beta r_e)$
(b) $R_1 || R_2$
(c) $(\beta r_e)$
(d) cannot determine from the information given

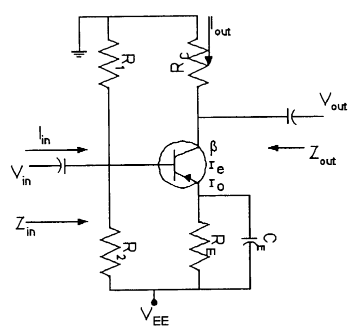


Figure 8.1.12 Voltage Divider Bias PNP transistor

13. For the circuit shown in Figure 8.1.12, determine the output impedance for the amplifier:
(a) $R_C || (\beta r_o)$
(b) $R_C || r_o$
(c) $R_C$
(d) cannot determine from the information given

14. For the circuit shown in Figure 8.1.12, determine the voltage gain for the amplifier:
    (a) $(R_C) \div (\beta r_e)$
    (b) $(R_C) \div (r_e)$
    (c) $(R_C || r_o) \div (r_e)$
    (d) cannot determine from the information given

15. For the circuit shown in Figure 8.1.12, determine the current gain for the amplifier:
    (a) $-(\beta(R_1 || R_2)) \div ((R_1 || R_2)+\beta r_e)$
    (b) $\beta$
    (c) $\beta * (R_C) \div (R_C + r_o)$
    (d) cannot determine from the information given

16. The common-emitter amplifier has:
    (a) voltage gain, current gain, and power gain
    (b) voltage gain and power gain, but no current gain
    (c) current gain and power gain, but no voltage gain
    (d) current gain and voltage gain, but no power gain

17. A fixed-bias BJT circuit has values of $h_{FE} = 200$ and $h_{fe} = 120$. The ac current gain for the device is:
    (a) 200
    (b) 120
    (c) 24,000
    (d) 320

18. Coupling capacitors are chosen to ensure that the values of $X_C$ are _________ at the amplifier's operating frequency.
    (a) very small
    (b) small
    (c) large
    (d) very large

19. A CE amplifier has values of $V_E = 1.1$ V, $r_e = 1$ K ohms and $R_C = 10$ k ohms. What is the value of the voltage gain for the circuit?
    (a) 10
    (b) 110
    (c) 484
    (d) cannot be determined with the information given

20. Bypass capacitors are chosen to ensure that the values of $X_C$ are _________ at the amplifier's operating frequency.
    (a) very small
    (b) small
    (c) large
    (d) very large

21. A CE amplifier with voltage divider bias and a bypassed $R_E$ has values of $R_C$ = 10 K ohms, $r_e$ = 25 ohms, and $h_{FE}$ = 150. What is the value of the voltage gain for the circuit?
(a) 3750
(b) 60,000
(c) 400
(d) cannot be determined with the information given

22. If a bypass capacitor opens, the value of $r_e$ will:
(a) increase
(b) decrease
(c) remain the same
(d) go to zero

23. Which of the following circuit conditions would indicate that a bypass capacitor is open?
(a) The presence of a dc voltage at the BJT's emitter terminal.
(b) The voltage gain increases significantly.
(c) The loss of the ac signal at the base terminal of the BJT.
(d) None of the above.

24. A fixed-bias CE amplifier has an unbypassed emitter resistor $R_E$ = 1.2K ohms and a base resistor $R_B$ = 270 K ohms. If the value of $r_e$ = 5 ohms and beta is 200, what is the voltage gain?
(a) 4.64
(b) 10.3
(c) 24.64
(d) 103.3

25. A fixed-bias CE amplifier has an unbypassed emitter resistor $R_E$ = 1.2 K ohms, a collector resistor $R_C$ = 5.6 K ohms and a base resistor $R_B$ = 270 K ohms. If the value of $r_e$ = 5 ohms and beta is 200 the current gain is:
(a) 1.05
(b) 20.55
(c) 105.55
(d) 565.5

26. A fixed-bias CE amplifier with an unbypassed emitter resistor $R_E$ = 12 K ohms, a collector resistor $R_C$ = 5.6 K ohms, a load resistor $R_L$ = 10 K ohms and a base resistor $R_B$ = 270 K ohms If the value of $r_e$ is 5 ohms and the beta is 200, what is the loaded voltage gain?
(a) 400
(b) 150
(c) 200
(d) 33.33

27. Which of the following would indicate that a CE amplifier load resistor has opened and indicates the effect of $Z_o$?
(a) the emitter voltage
(b) the collector voltage
(c) the loaded voltage gain
(d) current gain

28. A CE amplifier with emitter-bias has values of $r_e$ = 25 ohms, $h_{fe}$ = 150, $h_{FE}$ = 200, and $R_E$ = 2 K ohms. What is the value of $Z_b$ for the circuit?
    (a) 3750 ohms
    (b) 303.75 K ohms
    (c) 5 K ohms
    (d) 430 K ohms

29. The common-collector amplifier (emitter-follower) has:
    (a) voltage gain, current gain, and power gain
    (b) voltage gain and power gain, but no current gain
    (c) current gain and power gain, but no voltage gain
    (d) current gain and voltage gain, but no power gain

30. The common-base amplifier has:
    (a) voltage gain, current gain, and power gain
    (b) voltage gain and power gain, but no current gain
    (c) current gain and power gain, but no voltage gain
    (d) current gain and voltage gain, but no power gain

31. A transistor amplifier has an input signal applied to its emitter terminal and an output signal taken from its collector terminal. The amplifier is a/an:
    (a) common-emitter amplifier
    (b) common-base amplifier
    (c) common-collector amplifier
    (d) emitter follower

32. An emitter follower has the following values: $h_{ie}$ = 3 K ohms $h_{fe}$ = 150, and $R_E$ = 1.5 K ohms. What is the value of the voltage gain for the circuit?
    (a) 0.5
    (b) 0.9925
    (c) 0.9868
    (d) cannot be determined with the information given

33. Which transistor amplifier configuration has a 180 degree voltage phase shift from input to output?
    (a) common-emitter
    (b) common-collector
    (c) common-base
    (d) none of the above

34. Which transistor amplifier configuration has a 180 degree current phase shift from input to output?
    (a) common-emitter
    (b) common-collector
    (c) common-base
    (d) none of the above

35. Amplifier ac input and output currents are:
    (a) always 180 degrees out of phase
    (b) 180 degrees phase shift in all but one amplifier configuration
    (c) in phase in all but one amplifier configuration
    (d) always in phase

36. Amplifier ac input and output voltages are:
    (a) always 180 degrees out of phase
    (b) 180 degrees phase shift in all but one amplifier configuration
    (c) in phase in all but one amplifier configuration
    (d) always in phase

1. Answer: 180 degree phase shift Difficulty: 2 Section: 2 Objective: 1

2. Answer: (a) Difficulty: 2 Section: 3 Objective: 1

3. Answer: (b) Difficulty: 2 Section: 4 Objective: 1

4. Answer: (c) Difficulty: 2 Section: 4 Objective: 1

5. Answer: (a) Difficulty: 2 Section: 4 Objective: 1

6. Answer: (c) Difficulty: 2 Section: 5 Objective: 1

7. Answer: (b) Difficulty: 2 Section: 5 Objective: 1

8. Answer: (a) Difficulty: 2 Section: 6 Objective: 1

9. Answer: in Difficulty: 2 Section: 6 Objective: 1

10. Answer: 1 - b; 2 - j; 3 - e; 4 - h; 5 - g; 6 - i; 7 - d; 8 - c; 9 - f; 10 - a

    Difficulty: 2 Section: 6 Objective: 1

11. Answer:

| | | | |
|---|---|---|---|
| Input Impedance | In Between; | Highest; | Lowest |
| Output Impedance | In Between; | Lowest; | Highest |
| Voltage Gain | Highest; | Lowest; | In Between |
| Current gain | Highest; | In Between; | Lowest |

    Difficulty: 2 Section: 6 Objective: 1

12. Answer: (a) Difficulty: 2 Section: 9 Objective: 1

13. Answer: (b) Difficulty: 3 Section: 9 Objective: 1

14. Answer: (c) Difficulty: 3 Section: 9 Objective: 1

15. Answer: (a) Difficulty: 3 Section: 9 Objective: 1

16. Answer: (a) Difficulty: 2 Section: 1 Objective: 2

17. Answer: (b) Difficulty: 2 Section: 2 Objective: 2

18. Answer: (a) Difficulty: 2 Section: 3 Objective: 2

19. Answer: (d) Difficulty: 2 Section: 4 Objective: 2

20. Answer: (a) Difficulty: 2 Section: 1 Objective: 3

21. Answer: (c) Difficulty: 2 Section: 2 Objective: 3

22. Answer: (c) Difficulty: 2 Section: 1 Objective: 4

23. Answer: (b) Difficulty: 2 Section: 2 Objective: 4

24. Answer: (a) Difficulty: 4 Section: 3 Objective: 4

25. Answer: (c) Difficulty: 2 Section: 4 Objective: 4

26. Answer: (c) Difficulty: 2 Section: 5 Objective: 4

27. Answer: (c) Difficulty: 2 Section: 6 Objective: 4

28. Answer: (b) Difficulty: 2 Section: 7 Objective: 4

29. Answer: (c) Difficulty: 2 Section: 1 Objective: 5

30. Answer: (b) Difficulty: 2 Section: 1 Objective: 6

31. Answer: (b) Difficulty: 2 Section: 1 Objective: 7

32. Answer: (c) Difficulty: 2 Section: 2 Objective: 9

33. Answer: (a) Difficulty: 2 Section: 1 Objective: 11

34. Answer: (d) Difficulty: 2 Section: 2 Objective: 11

35. Answer: (d) Difficulty: 2 Section: 3 Objective: 11

36. Answer: (c) Difficulty: 2 Section: 4 Objective: 11

# Chapter 9: FET Small-Signal Analysis

### *SHORT ANSWER*

1. The *change* in the drain current that will result from a *change* in the gate-to-source voltage can be determined by using the ________ factor $g_m$ in the following manner: $\Delta I_D = g_m \Delta V_{GS}$.

2. The negative sign in the resulting equation for $A_v$, in any FET small signal analysis, reveals that there is ______________ between the input and the output signal.

### *MULTIPLE CHOICE*

3. If the resistor in the source leg is not bypassed by a capacitor then the voltage gain of the small signal FET amplifier will ________.
(a) increase
(b) decrease
(c) stay the same
(d) may increase in some cases and decrease in other cases

4. The input impedance $Z_i$ is many magnitudes (100's of times) greater than the input impedance $Z_i$ of a BJT. This _______ effect on the overall gain of the system.
(a) has a very negative
(b) has a very positive
(c) has no
(d) may be positive or negative and depends on the rest of the circuit

5. Calculate the input impedance $Z_{in}$ for the FET transistor amplifier shown in Figure 9.1.5 assuming that the 10 μF capacitor is connected in parallel with the 250 Ω resistor in the Source leg.
(a) $Z_i = R_1 || R_2 = 9$ MΩ
(b) $Z_i = R_2 = 10$ MΩ
(c) $Z_i = R_1 = 90$ MΩ
(d) $Z_i$ = would depend on the drain current $I_D$

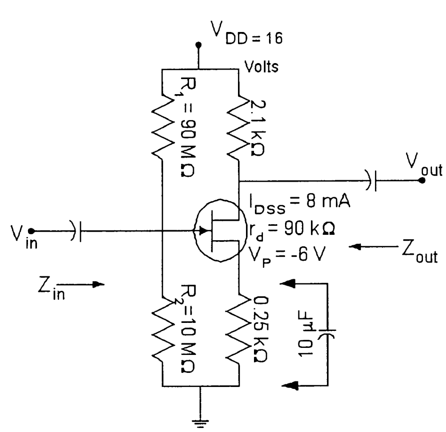


Figure 9.1.5 Voltage Divider-Bias Circuit

6. Calculate the output impedance $Z_{out}$ for the FET transistor amplifier shown in Figure 9.1.5 assuming that the 10 µF capacitor is connected in parallel with the 250 Ω resistor in the Source leg.
   (a) $Z_{out} = R_D = 2.1$ kΩ
   (b) $Z_{out} = r_d = 90$ kΩ
   (c) $Z_{out} = R_D || r_d = 2052Ω$
   (d) $Z_{out}$ = would depend on the drain current $I_D$

7. Calculate the Voltage Gain $A_v$ for the FET transistor amplifier shown in Figure 9.1.5 assuming that the 10 µF capacitor is connected in parallel with the 250 Ω resistor in the Source leg. You are given that the trans-conductance $g_m$ for this circuit is 0.00185 Amps/Volt.
   (a) $A_v = -g_m R_D = -3.885$
   (b) $A_v = -g_m(R_D || r_d) = -3.7962$
   (c) $A_v = -g_m r_d = -166.5$
   (d) $A_v$ = would depend on the drain current $I_D$

8. Calculate the Voltage Gain $A_v$ for the source follower FET transistor amplifier shown in Figure 9.1.8. You are given that the trans-conductance $g_m$ for this circuit is 0.00185 Amps/Volt.
   (a) $A_v = g_m(r_d || R_1 || R_2) \div \{1 + g_m(r_d || R_1 || R_2)\} = 0.9939$
   (b) $A_v = g_m r_d = 166.5$
   (c) $A_v = g_m R_S = 0.4625$
   (d) $A_v$ = would depend on the drain current $I_D$

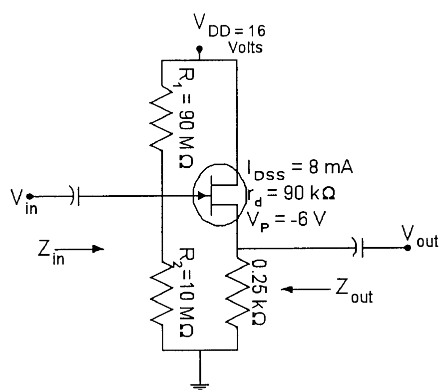

Figure 9.1.8 JFET Source Follower Circuit

9. Calculate the input impedance $Z_{in}$ for the source follower FET transistor amplifier shown in Figure 9.1.8. You are given that the trans-conductance $g_m$ for this circuit is 0.00185 Amps/Volt.
   (a) $Z_i = R_1 || R_2 = 9$ MΩ
   (b) $Z_i = R_2 = 10$ MΩ
   (c) $Z_i = R_1 = 90$ MΩ
   (d) $Z_i$ = would depend on the drain current $I_D$

10. Calculate the output impedance $Z_{out}$ for the FET transistor amplifier shown in Figure 9.1.8 You are given that the trans-conductance $g_m$ for this circuit is 0.00185 Amps/Volt.
   (a) $Z_{out} = R_S = 250$ Ω
   (b) $Z_{out} = r_d = 90$ kΩ
   (c) $Z_{out} = R_S || r_d || (1/g_m) = 170.6$ Ω
   (d) $Z_{out}$ = would depend on the drain current $I_D$

## *SHORT ANSWER*

11. For the three amplifier configurations of the JFET transistor studied fill in the following table:

| Parameter | Common Source | Common Gate | Common Drain |
|---|---|---|---|
| Input Impedance | | | |
| Output Impedance | | | |
| Voltage Gain | | | |

Fill in all the entries using the relative terms
Highest; In between; Lowest
for each parameter.

**Figure 9.1.11** Table comparing the three amplifier configurations.

## *MULTIPLE CHOICE*

12. For an E-MOSFET you are given $V_{GS(ON)} = 8$ Volts, $V_{TH} = 5$ Volts and $I_{D(ON)} = 5$ mAmps. Calculate the 'k' parameter for this transistor.
(a) $k = 1.555 \times 10^{-3}$
(b) $k = 1.000 \times 10^{-3}$
(c) $k = 0.555 \times 10^{-3}$
(d) $k = 5.550 \times 10^{-3}$

13. For an E-MOSFET shown in Figure 9.1.13 calculate the input impedance.
(a) $Z_i = R_F \div \{1 + (r_d \| R_D)\} = 5.130$ kΩ
(b) $Z_i = R_F \div \{1 + g_m r_d\} = 53.05$ kΩ
(c) $Z_i = R_F = 10.0$ MΩ
(d) $Z_i = R_F \div \{1 + g_m(r_d \| R_D)\} = 1.7035$ MΩ

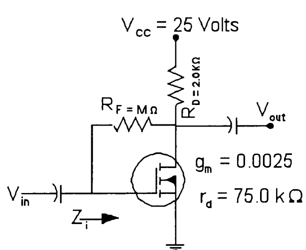

Figure 9.1.13 Calculate the input impedance.

14. Design the transistor amplifier shown in Figure 9.1.14 for a gain of 8. You have to calculate the value of resistor $R_D$.
   (a) $R_D$ = 9.0 kΩ
   (b) $R_D$ = 10.0 kΩ
   (c) $R_D$ = 3103.44 Ω
   (d) $R_D$ = 3.0 kΩ

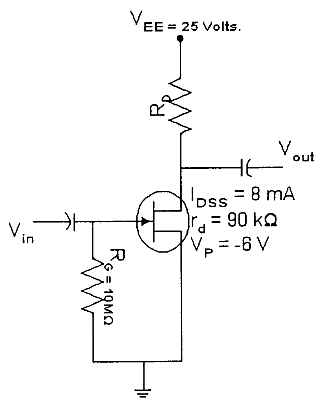


Figure 9.1.14 Design a transistor amplifier for specific gain.

15. Design the transistor amplifier shown in Figure 9.1.15 for a gain of 10. You have to calculate the value of resistor $R_D$ and $R_S$. It is desired that the transistor operate with a relatively high value of $g_m$. For this device a high value of $g_m$ is defined as $V_{GS} = 0.2V_p$.
   (a) $R_D$ = 9.0 kΩ; $R_S$ = 1.0 kΩ
   (b) $R_D$ = 5.555 kΩ; $R_S$ = 250 Ω
   (c) $R_D$ = 5.555 kΩ; $R_S$ = 1.0 kΩ
   (d) $R_D$ = 9.0 kΩ; $R_S$ = 250 Ω

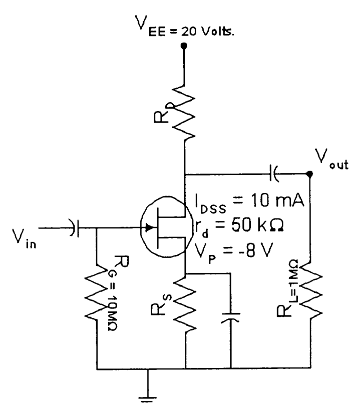


Figure 9.1.15 Design a transistor amplifier for specific gain.

16. The operating value of $g_m$ is always __________ the value of $g_{m0}$ for a given JFET.
   (a) less than
   (b) equal to
   (c) less than or equal to
   (d) greater than

17. A given JFET has values of $g_{m0}$ = 1200 μS and $V_{GS\ OFF}$ = -4 V. What is the value of $q_m$ for the device at $V_{GS}$ = -2 V?
(a) 500 μS
(b) 1200 μS
(c) 300 μS
(d) cannot be determined from the information given

18. A JFET has values of $g_{m0}$ = 1200 μS and $V_{GS\ OFF}$ = -4 V. What is the approximate value of $I_{DSS}$?
(a) 4.8 mA
(b) 9.6 mA
(c) 2.4 mA
(d) cannot be determined from the information given

19. The _________ amplifier has high input impedance, low output impedance, and low voltage gain.
(a) common-gate
(b) common-drain
(c) common-source
(d) none of the above

20. The _________ amplifier has low input impedance, high output impedance, and high voltage gain.
(a) common-gate
(b) common-drain
(c) common-source
(d) none of the above

1. Answer: transconductance Difficulty: 1 Section: 2 Objective: 1
2. Answer: 180 degree phase shift Difficulty: 2 Section: 3 Objective: 1
3. Answer: (b) Difficulty: 2 Section: 4 Objective: 1
4. Answer: (b) Difficulty: 2 Section: 4 Objective: 1
5. Answer: (a) Difficulty: 2 Section: 4 Objective: 1
6. Answer: (c) Difficulty: 2 Section: 5 Objective: 1
7. Answer: (b) Difficulty: 2 Section: 5 Objective: 1
8. Answer: (a) Difficulty: 2 Section: 6 Objective: 1
9. Answer: (a) Difficulty: 2 Section: 6 Objective: 1
10. Answer: (c) Difficulty: 2 Section: 6 Objective: 1
11. Answer:

| | | | |
|---|---|---|---|
| Input Impedance | In Between; | Lowest; | In Between |
| Output Impedance | In Between; | In Between; | Lowest |
| Voltage Gain | In Between; | In Between; | Lowest |

Difficulty: 2 Section: 7 Objective: 1

12. Answer: (c) Difficulty: 2 Section: 9 Objective: 1
13. Answer: (d) Difficulty: 2 Section: 10 Objective: 1
14. Answer: (c) Difficulty: 3 Section: 12 Objective: 1
15. Answer: (b) Difficulty: 3 Section: 12 Objective: 1
16. Answer: (c) Difficulty: 2 Section: 1 Objective: 2
17. Answer: (a) Difficulty: 2 Section: 2 Objective: 2
18. Answer: (c) Difficulty: 2 Section: 3 Objective: 2
19. Answer: (b) Difficulty: 2 Section: 1 Objective: 5
20. Answer: (a) Difficulty: 2 Section: 1 Objective: 6

# Chapter 10: Systems Approach--Effects of Rs and RL

## *SHORT ANSWER*

1. The load impedance, when added to the no-load two-port equivalent circuit, will always _______ the overall voltage gain.

## *MULTIPLE CHOICE*

2. For the circuit shown in Figure 10.1.2, the input impedance is 1.071 kΩ (with $r_e$ = 10.71Ω and β = 100) and the output impedance is 3.0 kΩ Determine the loaded voltage gain if the no-load voltage gain is 250.
   (a) Loaded voltage gain = 100
   (b) Loaded voltage gain = 250
   (c) Loaded voltage gain = 150
   (d) Loaded voltage gain = 416.666

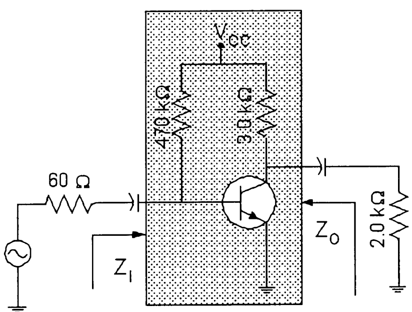

Figure 10.1.2

3. For the circuit shown in Figure 10.1.2, the input impedance is 1.071 kΩ (with $r_e$ = 10.71 Ω and β = 100) and the output impedance is 3.0 kΩ Determine the loaded output impedance for the circuit.
   (a) Equal to the sum of the load resistor and the output impedance = 5 kΩ.
   (b) Equal to the load resistor which is 2 kΩ.
   (c) 3 kΩ parallel with 2 kΩ = 1.2 kΩ.
   (d) The output impedance does not change, it is still 3 kΩ.

4. For the circuit shown in Figure 10.1.2, the input impedance is 1.071 kΩ (with $r_e$ = 10.71Ω and β = 100) and the output impedance is 3.0 kΩ Determine the voltage gain after taking the source resistance into account, if the no-load voltage gain is 250.
   (a) Equal to 236.73 considering both the source and the load resistors.
   (b) Equal to 94.69 considering both the source and the load resistors.
   (c) The source resistor does not alter the voltage gain so it is still 100.
   (d) The source resistor does not alter the voltage gain so it is still 250.

## *SHORT ANSWER*

5. For a particular design, the smaller the level of the load resistance, the _______ the level of ac voltage gain.

*MULTIPLE CHOICE*

6. With a change in the source resistance $R_S$ the two-port parameter affected will be:
   (a) $Z_I$
   (b) $Z_O$
   (c) $A_V$
   (d) none of the above

*SHORT ANSWER*

7. For a particular design, the larger the level of the source resistance, the _______ the overall gain of the amplifier.

*MULTIPLE CHOICE*

8. For the circuit shown in Figure 10.1.8, and the two-port parameters given, determine the voltage gain from the source to the load.
   (a) required voltage gain is 111.43
   (b) required voltage gain = 416.666
   (c) required voltage gain is 160.45
   (d) required voltage gain = 117.65

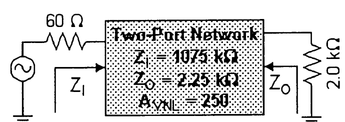

Figure 10.1.8

*SHORT ANSWER*

9. The common collector amplifier is also known as the *voltage follower* because the ________ voltage follows the _______ voltage.

*MULTIPLE CHOICE*

10. For the common collector amplifier the output impedance is ______ and the input impedance is ________ when compared to the common emitter amplifier.
    (a) small; small
    (b) large; small
    (c) large; large
    (d) small; large

*SHORT ANSWER*

11. The no-load two-port network for a JFET or for a depletion mode MOSFET or for an enhancement mode MOSFET amplifier are ______ by an applied load or the source.

## *MULTIPLE CHOICE*

12. The two-port parameters may be different but the two-port equivalent circuit for the shaded portion of the circuit in Figure 10.1.2 and for the shaded portion of the circuit in Figure 10.1.12 are ______.
   (a) entirely different two-port networks
   (b) different two-port networks but not entirely different
   (c) sort of same two-port networks but not exactly so
   (d) exactly the same two-port network

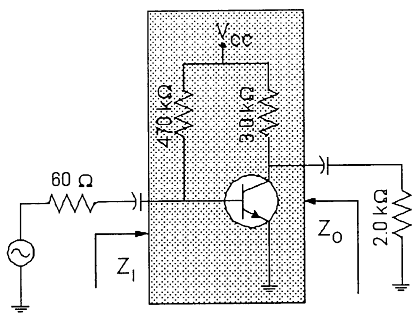

Figure 10.1.2

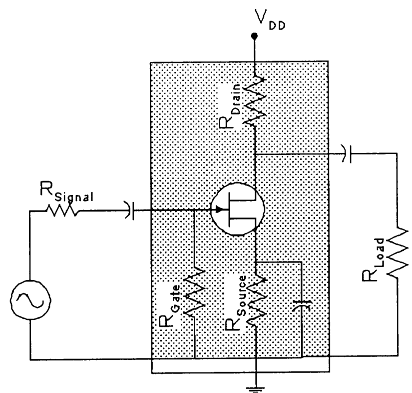

Figure 10.1.12

13. In a cascaded amplifier as shown in figure 10.1.13 the input impedance $Z_{i2}$ is ______ the load resistance for Amplifier 1.
   (a) less than
   (b) large than
   (c) not equal to
   (d) exactly equal to

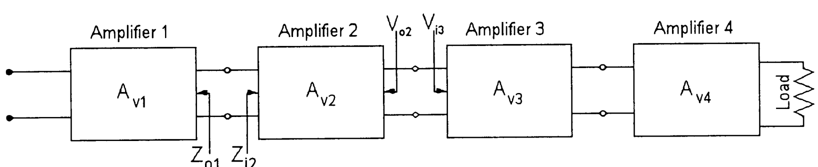

Figure 10.1.13 Cascaded Amplifiers

14. In a cascaded amplifier as shown in figure 10.1.13 the output impedance $Z_{o1}$ is ______ the source resistance seen by Amplifier 2.
   (a) less than
   (b) larger than
   (c) not equal to
   (d) exactly equal to

15. In a cascaded amplifier as shown in figure 10.1.13 the output voltage $V_{o2}$ is ______ the input voltage $V_{i3}$.
   (a) less than
   (b) larger than
   (c) not equal to
   (d) exactly equal to

16. The basic two-port system is evaluated under _________ conditions.
    (a) full-load
    (b) applied-source
    (c) no-load and no-source
    (d) none of the above

17. The basic two-port system has _________ as a primary factor.
    (a) the full-load voltage gain
    (b) the no-load voltage gain
    (c) the full-load current gain
    (d) none of the above

18. The loaded voltage gain is _________ the no-load level.
    (a) always less than
    (b) always greater than
    (c) usually equal to
    (d) none of the above

19. The load-voltage gain of a BJT amplifier with two-port parameters $Z_i$ = 1.1 K ohms, $Z_o$ = 5.3 K ohms, and $V_{NL}$ = -260. What is the loaded-voltage gain if $R_L$ = 4.7 K ohms?
    (a) -100
    (b) -122.2
    (c) -234.82
    (d) none of the above

20. For a particular design the _________ the value of $R_L$, the _________ the value of the small-signal voltage gain.
    (a) larger; smaller
    (b) smaller; smaller
    (c) smaller; larger
    (d) none of the above

21. The parameters _________ and _________ of a two-part system are not affected by $R_S$.
    (a) $Z_i$ $A_{VNL}$
    (b) $Z_o$ $A_{iNL}$
    (c) $Z_i$ $Z_o$
    (d) none of the above

22. Given the circuit of Figure 10.11 determine the value of $r_e$ that has a major influence of the voltage gain.
    (a) 1.066 K ohms
    (b) 106.6 ohms
    (c) 87.43 ohms
    (d) 10.66 ohms

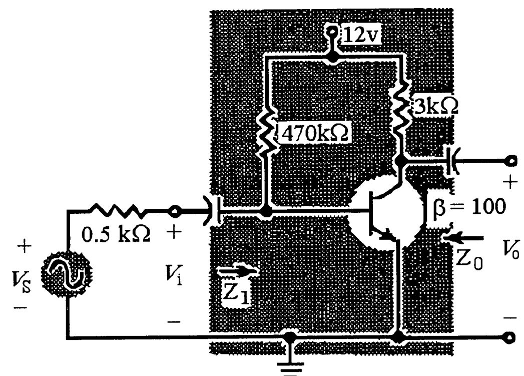


Figure 10.11

23. For a particular base-bias amplifier design the __________ the value of $R_L$ the __________ the small-signal voltage gain.
    (a) smaller; smaller
    (b) smaller; larger
    (c) larger; smaller
    (d) all of the above
    (e) none of the above

24. The larger the values of both $R_S$ and $R_L$, the less __________.
    (a) the voltage gain
    (b) the current gain
    (c) both the voltage and current gains
    (d) none of the above

25. Emitter followers are generally used to match a __________ impedance source to a __________ impedance load.
    (a) high; high
    (b) low; high
    (c) high; low
    (d) low; low

26. A common-base amplifier has values of $r_e$ = 15 ohms and $R_E$ = 3 K ohms. What is the approximate input impedance of the circuit?
    (a) 3 K ohms
    (b) 3015 ohms
    (c) 15 ohms
    (d) 5 ohms

27. The common-base amplifier does not provide __________ gain.
    (a) voltage
    (b) current
    (c) power
    (d) current and power

28. A common-base amplifier may be used to match a _________ impedance source to a _________ impedance load.
(a) high; high
(b) low; high
(c) high; low
(d) low; low

29. For the common source amplifier the input and output impedances are equal to the _________ and _________ values.
(a) $R_S$; $R_D$
(b) $R_G$; $R_L$
(c) $R_G$; $R_D$
(d) none of the above

30. A common source amplifier with an unbypassed source resistor has a two-port model with parameters $A_{VNL}$ = -4.2 $Z_i$ = 240 K ohms, $Z_o$ = 2.7 K ohms and $g_m$ = 2.5 mS. If $R_L$ = 5 K ohms what is the loaded voltage gain?
(a) -2.727
(b) -21
(c) -7.78
(d) none of the above

31. The determination of the total gain of a cascaded system requires that the _________ be calculated first.
(a) no-load voltage gain for each stage
(b) input impedance for each stage
(c) the individual loaded voltage gain
(d) all of the above

32. A cascade amplifier has a total loaded-voltage gain of -100 and the stage input inpedances are $Z_{i1}$ = $Z_{i2}$ = 10 K ohms, $Z_{i3}$ = 2 K ohms. If the load resistor $R_L$ = 12 K ohms what is the system current gain?
(a) 100
(b) -101.2
(c) 83.53
(d) 57.92

1. Answer: decrease Difficulty: 2 Section: 3 Objective: 1
2. Answer: (a) Difficulty: 2 Section: 3 Objective: 1
3. Answer: (c) Difficulty: 2 Section: 3 Objective: 1
4. Answer: (b) Difficulty: 2 Section: 4 Objective: 1
5. Answer: lower Difficulty: 2 Section: 4 Objective: 1
6. Answer: (d) Difficulty: 2 Section: 5 Objective: 1
7. Answer: lower Difficulty: 2 Section: 5 Objective: 1
8. Answer: (a) Difficulty: 2 Section: 6 Objective: 1
9. Answer: output; input Difficulty: 2 Section: 7 Objective: 1
10. Answer: (d) Difficulty: 2 Section: 7 Objective: 1
11. Answer: unaffected Difficulty: 2 Section: 7 Objective: 1
12. Answer: (d) Difficulty: 2 Section: 9 Objective: 1
13. Answer: (d) Difficulty: 2 Section: 11 Objective: 1
14. Answer: (d) Difficulty: 2 Section: 11 Objective: 1
15. Answer: (d) Difficulty: 2 Section: 11 Objective: 1
16. Answer: (c) Difficulty: 2 Section: 1 Objective: 2
17. Answer: (b) Difficulty: 2 Section: 2 Objective: 2
18. Answer: (a) Difficulty: 2 Section: 1 Objective: 3
19. Answer: (b) Difficulty: 2 Section: 2 Objective: 3
20. Answer: (b) Difficulty: 2 Section: 3 Objective: 3
21. Answer: (a) Difficulty: 2 Section: 1 Objective: 4
22. Answer: (d) Difficulty: 2 Section: 2 Objective: 4
23. Answer: (a) Difficulty: 2 Section: 3 Objective: 4
24. Answer: (c) Difficulty: 2 Section: 1 Objective: 5
25. Answer: (c) Difficulty: 2 Section: 1 Objective: 7

26. Answer: (c) Difficulty: 2 Section: 1 Objective: 8

27. Answer: (b) Difficulty: 2 Section: 2 Objective: 8

28. Answer: (b) Difficulty: 2 Section: 3 Objective: 8

29. Answer: (c) Difficulty: 2 Section: 1 Objective: 9

30. Answer: (a) Difficulty: 2 Section: 2 Objective: 9

31. Answer: (d) Difficulty: 2 Section: 1 Objective: 11

32. Answer: (c) Difficulty: 2 Section: 2 Objective: 11

# Chapter 11: BJT and JFET Frequency Response

***SHORT ANSWER***

1. The common and the natural logarithm are related to each other by the following equation ___________.

2. Using a calculator match up the two columns below.

| | |
|---|---|
| 1. $\log_{10}$ (4675) | a. 8.4499 |
| 2. $\ln_e$ (4675) | b. -0.5621 |
| 3. $\log_{10}$ (0.59) | c. 3.3064 |
| 4. $\ln_e$ (0.57) | d. 3.6698 |
| 5. $\log_{10}$ $(45)^2$ | e. -0.2291 |

3. The name of the graph paper generally used to draw the frequency response of either a BJT amplifier or a FET amplifier is ______ graph paper.

***MULTIPLE CHOICE***

4. The input power to a device is 5000 Watts at a voltage level of 400 Volts. The output power of the device is 750 Watts and the output impedance is 25 Ω. Calculate the power gain in decibels.
(a) -8.239
(b) 8.239
(c) -16.478
(d) -16.478

5. For the conditions given in the previous question calculate the voltage gain in decibels.
(a) -4.6556
(b) 4.6556
(c) -9.311
(d) 9.311

6. To fix the frequency boundaries of relatively high gain 0.7 $A_{mid}$ was chosen to be the at the cutoff levels. The corresponding frequencies $f_1$ and $f_2$ are generally called:
(a) corner frequencies
(b) cutoff frequencies
(c) half-power frequencies
(d) break frequencies
(e) all of the above

***SHORT ANSWER***

7. One very important parameter defined by the two corner frequencies is given by $\{f_1 - f_2\}$, and is known as ________.

***MULTIPLE CHOICE***

8. The capacitor(s) in a BJT amplifier that have their break points in the low frequency region are:
(a) the coupling capacitor $C_C$
(b) the emitter by pass capacitor $C_E$
(c) the source capacitor $C_s$
(d) all of the above

***SHORT ANSWER***

9. A change in frequency by a factor of 2, equivalent to 1 octave, results in a ______ dB change in the ration as noted by the change in gain from $f_1/2$ to $f_1$.

***MULTIPLE CHOICE***

10. Calculate the low frequency break point due to the capacitor $C_s$ for the BJT amplifier in Figure 11.1.11.
(a) $f_{Ls} = 1/\{2\pi(R_s + R_i)C_s\} = 280.25$ Hz.
(b) $f_{Ls} = 1/\{2\pi(R_s + R_1 || R_2)C_s\} = 30.6$ Hz.
(c) $f_{Ls} = 1/\{2\pi(R_s || R_i)C_s\} = 5585.4$ Hz.
(d) $f_{Ls} = 1/\{2\pi(R_s + R_1 + R_2)C_s\} = 4.269$ Hz.

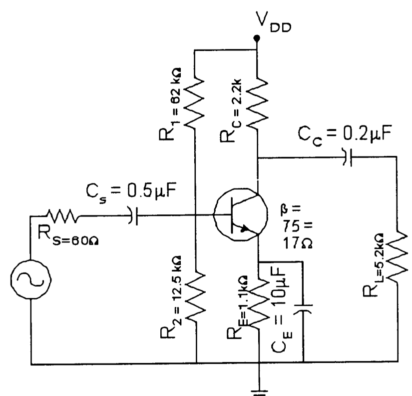


Figure 11.1.11

11. Calculate the low frequency break point due to the capacitor $C_C$ for the BJT amplifier in Figure 11.1.11.
(a) $f_{LC} = 1/\{2\pi(R_C)C_C\} = 361.71$ Hz.
(b) $f_{LC} = 1/\{2\pi(R_C || R_L)C_C\} = 514.75$ Hz.
(c) $f_{LC} = 1/\{2\pi(R_C + R_L)C_C\} = 107.53$ Hz.
(d) $f_{LC} = 1/\{2\pi(R_L)C_C\} = 153.03$ Hz.

***SHORT ANSWER***

12. For any inverting amplifier the input capacitance will be increased by a ________ effect capacitance that is sensitive to the gain of the amplifier and the inter electrode and parasitic capacitance between the input and the output terminals of the active device.

## *MULTIPLE CHOICE*

13. If several identical stages of amplifiers; each having the exact same upper and lower cutoff frequencies; are connected in cascade, then the bandwidth of the resulting amplifier will be ______.
    (a) increased
    (b) remain unchanged
    (c) decreased
    (d) be equal to the sum of all the individual bandwidths

14. When you use square wave testing to test two different amplifiers you see on the output the following waveforms. (Figure 11.1.15) What comments can you make about the frequency response of the two amplifiers?
    (a) Amplifier A has poor low frequency response, while amplifier B has poor high frequency response.
    (b) Amplifier A has poor low frequency response, while amplifier B has poor low frequency response.
    (c) Amplifier A has poor high frequency response, while amplifier B has poor high frequency response.
    (d) Amplifier A has poor high frequency response, while amplifier B has poor low frequency response.

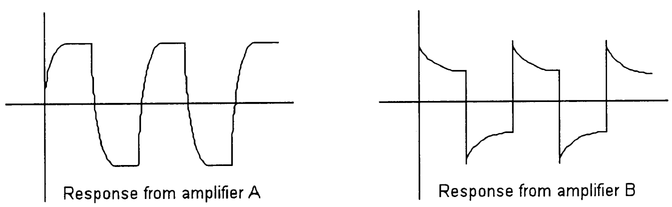


Figure 11.1.15

15. Determine the base 10 logarithm of 100,000.
    (a) 4
    (b) 5
    (c) 6
    (d) none of the above

16. Determine the base 10 logarithm of 1780.331.
    (a) 0.335
    (b) 3.2505
    (c) 33.5
    (d) none of the above

17. Which of the following are properties of logarithms?
    (a) $\log_{base\ n} 0 = 1$
    (b) $\log_{base\ n} a/b = \log_{base\ n} + \log_{base\ n} b$
    (c) $\log_{base\ n} 1/b = -\log_{base\ n} b$
    (d) none of the above

18. Which of the following are properties of logarithms?
    (a) $\log_{\text{base } n} 1 = 0$
    (b) $\log_{\text{base } n} a/b = \log_{\text{base } n} a + \log_{\text{base } n} b$
    (c) $\log_{\text{base } n} 1/b = \log_{\text{base } n} b$
    (d) none of the above
    (e) all of the above

19. Which of the following are properties of logarithms?
    (a) $\log_{\text{base } n} 1 = 0$
    (b) $\log_{\text{base } n} a/b = \log_{\text{base } n} a - \log_{\text{base } n} b$
    (c) $\log_{\text{base } n} 1/b = -\log_{\text{base } n} b$
    (d) all of the above

20. The term semi-log refers to a graphical scale that has:
    (a) a linear axis and a log axis
    (b) a log-log structure
    (c) a linear vertical axis and a log horizontal axis
    (d) all of the above

21. The common log of the ratio of two power levels is called a:
    (a) decibel
    (b) bel
    (c) big bel
    (d) none of the above

22. For the gain in decibels to be completely correct it should be referred to as voltage or current gain in decibels to differentiate it from the normal power level consideration. This occurs when:
    (a) $R_i < R_L$
    (b) $R_i > R_L$
    (c) $R_i$ not equal to $R_L$
    (d) all of the above

23. The gain in decibels of a power gain of 10,000,000 is:
    (a) 5 dB
    (b) 6 dB
    (c) 70 dB
    (d) 80 dB

24. An amplifier has a midband power gain of 24,500. What is the value of the power gain in dB for the circuit?
    (a) 87.78 dB
    (b) 43.9 dB
    (c) 4.39 dB
    (d) none of the above

25. An amplifier has values of $P_N$ = 20 mW and $P_{OUT}$ = 60 W. What is the value of the power gain in dB for the circuit?
    (a) 3000 dB
    (b) 69.5 dB
    (c) 34.8 dB
    (d) none of the above

26. An amplifier normally has a power gain of 12,000. If the power gain of the circuit drops by 3 dB, the value of the new power-gain will be approximately:
   (a) 6,000
   (b) 4,000
   (c) 9,000
   (d) zero

27. Negative dB values represent:
   (a) power gain
   (b) power losses
   (c) power values that do not change
   (d) none of the above

28. Which of the following is an advantage of using dB representations of gain values?
   (a) Positive and negative dB values represent gain and loss values that are reciprocals of each other.
   (b) In multistage amplifiers, gain calculations are simplified by the use of dB values.
   (c) Using db values, we can represent large gain values with relatively small numbers.
   (d) All of the above.

29. An amplifier has an output power of 500 W. What is the value of the power gain in dB for the circuit?
   (a) 26.99 dB
   (b) 53.98 dB
   (c) 56.99 dB
   (d) cannot be determined from the information given

30. An amplifier has an output power of 500 W, which is delivered to a 600 ohm load. What is the value of a in dBm?
   (a) 26.99 dBm
   (b) 53.98 dBm
   (c) 56.99 dBm
   (d) cannot be determined from the information given

31. An amplifier has values of power gain in dB of 49 dB and voltage gain dB of 30 dB. The operating frequency of the circuit is increased until the power gain drops to 42 dB. What is the value of voltage gain in dB frequency?
   (a) 23 dB
   (b) 42 db
   (c) 25.7 db
   (d) cannot be determined from the information given

32. What frequency is two decades above 5 kHz?
   (a) 105 kHz
   (b) 25 kHz
   (c) 500 kHz
   (d) cannot be determined from the information given

33. What frequency lies four octaves above 1 kHz?
    (a) 9 kHz
    (b) 16 kHz
    (c) 8 kHz
    (d) none of the above

34. The roll-off rate for a BJT amplifier is approximately:
    (a) 20 dB per octave
    (b) 6 dB per decade
    (c) 6 dB per octave
    (d) none of the above

35. The low-frequency response of a BJT amplifier is affected by:
    (a) the BJT internal capacitances
    (b) the supply voltage
    (c) the coupling and bypass capacitor values
    (d) all of the above

36. The input value of $f_l$ for a FET amplifier will normally be __________ the input value of $f_l$ for a comparable BJT amplifier.
    (a) similar to
    (b) much lower than
    (c) greater than
    (d) less than or equal to

37. A common-emitter amplifier has values of $C_{bc}$ = 5 pf and $A_{V(dB)}$ = 23.5218 dB. What is the Miller input capacitance for the circuit?
    (a) 80 pf
    (b) 7 pf
    (c) 163.1 pf
    (d) none of the above

38. The BJT gain-bandwidth product is approximately:
    (a) $\text{Alpha}_{MID}\ f_{Beta}$
    (b) $\text{Alpha}_{MID}\ f_{Alpha}$
    (c) $\text{Beta}_{MID}\ f_{Alpha}$ [1-Alpha]
    (d) none of the above

39. The BJT gain-bandwidth product ($f_T$) is:
    (a) inversely related to $r_e$
    (b) inversely related to ($C_{be}$ + $C_{bc}$)
    (c) not related to dc bias conditions
    (d) all of the above

40. A common-emitter amplifier uses a transistor that has a beta of 50, $r_e$ = 10 ohms, $C_{be}$ = 30 Pf, $C_{bc}$ = 3.5 PF, $C_{ce}$ = 1 PF, $C_W$ = 5 Pf. The value of $f_{Beta}$ is:
    (a) 19.04 MHz
    (b) 1.95 MHz
    (c) 9.502 MHz
    (d) none of the above

41. The high-frequency response of a BJT amplifier is affected by:
    (a) the BJT internal capacitances
    (b) the supply voltage
    (c) the coupling and bypass capacitor values
    (d) all of the above

42. Determine the high end cut-off frequency for a FET amplifier that has devices capacitances $C_{WO}$ = 5 PF and $R_{sig}$ = 12 K ohms, $R_G$ = 0.5 M ohms, $R_D$ = 5.6 K ohms and $A_V$ = -5.
    (a) 1.617 MHz
    (b) 16.17 MHz
    (c) 0.1617 MHz
    (d) none of the above

43. Two identical amplifiers are cascaded. The overall bandwidth of the multistage amplifier is _________ the bandwidth of each individual stage.
    (a) equal to
    (b) less than
    (c) greater than
    (d) less than or equal to

1. Answer: $\log_e (a) = 2.3 \log_{10} (a)$
   Difficulty: 1 Section: 2 Objective: 1
2. Answer: 1-d; 2-a; 3-e; 4-b; 5-c
   Difficulty: 1 Section: 2 Objective: 1
3. Answer: semi-log Difficulty: 1 Section: 2 Objective: 1
4. Answer: (a) Difficulty: 2 Section: 3 Objective: 1
5. Answer: (c) Difficulty: 2 Section: 4 Objective: 1
6. Answer: (e) Difficulty: 1 Section: 4 Objective: 1
7. Answer: bandwidth Difficulty: 1 Section: 4 Objective: 1
8. Answer: (d) Difficulty: 1 Section: 5 Objective: 1
9. Answer: 6 Difficulty: 1 Section: 5 Objective: 1
10. Answer: (a) Difficulty: 3 Section: 6 Objective: 1
11. Answer: (c) Difficulty: 3 Section: 6 Objective: 1
12. Answer: Miller Difficulty: 1 Section: 8 Objective: 1
13. Answer: (c) Difficulty: 3 Section: 11 Objective: 1
14. Answer: (d) Difficulty: 3 Section: 11 Objective: 1
15. Answer: (b) Difficulty: 2 Section: 1 Objective: 2
16. Answer: (b) Difficulty: 2 Section: 2 Objective: 2
17. Answer: (c) Difficulty: 2 Section: 3 Objective: 2
18. Answer: (a) Difficulty: 2 Section: 4 Objective: 2
19. Answer: (d) Difficulty: 2 Section: 5 Objective: 2
20. Answer: (a) Difficulty: 2 Section: 6 Objective: 2
21. Answer: (b) Difficulty: 2 Section: 1 Objective: 3
22. Answer: (d) Difficulty: 2 Section: 2 Objective: 3
23. Answer: (c) Difficulty: 2 Section: 3 Objective: 3

24. Answer: (b) Difficulty: 2 Section: 4 Objective: 3

25. Answer: (c) Difficulty: 2 Section: 5 Objective: 3

26. Answer: (a) Difficulty: 2 Section: 6 Objective: 3

27. Answer: (b) Difficulty: 2 Section: 7 Objective: 3

28. Answer: (d) Difficulty: 2 Section: 8 Objective: 3

29. Answer: (d) Difficulty: 2 Section: 9 Objective: 3

30. Answer: (c) Difficulty: 2 Section: 10 Objective: 3

31. Answer: (a) Difficulty: 2 Section: 11 Objective: 3

32. Answer: (c) Difficulty: 2 Section: 1 Objective: 5

33. Answer: (b) Difficulty: 2 Section: 2 Objective: 5

34. Answer: (c) Difficulty: 2 Section: 3 Objective: 5

35. Answer: (c) Difficulty: 2 Section: 1 Objective: 6

36. Answer: (a) Difficulty: 2 Section: 1 Objective: 7

37. Answer: (a) Difficulty: 2 Section: 1 Objective: 8

38. Answer: (c) Difficulty: 2 Section: 1 Objective: 9

39. Answer: (d) Difficulty: 2 Section: 2 Objective: 9

40. Answer: (c) Difficulty: 2 Section: 3 Objective: 9

41. Answer: (a) Difficulty: 2 Section: 4 Objective: 9

42. Answer: (a) Difficulty: 2 Section: 1 Objective: 10

43. Answer: (b) Difficulty: 2 Section: 1 Objective: 11

# Chapter 12: Compound Configurations

***SHORT ANSWER***

1. The input impedance of the overall cascaded amplifier is ______ as the input impedance of the first amplifier in the chain.

2. The output impedance of the overall cascaded amplifier is ______ as the output impedance of the last amplifier in the chain.

***MULTIPLE CHOICE***

3. The Cascade connection arrangement is designed to provide high input impedance with low voltage gain to ensure that the Miller capacitance is at a minimum with the CB stage so that the amplifier provides good operation in the ______ frequency range.
   (a) high
   (b) low
   (c) mid range
   (d) entire frequency range

4. The Cascade connection of a common emitter (CE) amplifier followed by a common base (CB) stage provides.
   (a) high input impedance
   (b) low voltage gain
   (c) good high frequency performance
   (d) all of the above

5. The typical range of $\beta$ for a Darlington amplifier is in the range of:
   (a) a very small value in the range 4 to 40
   (b) a moderate value in the range of 40 to 400
   (c) a slightly higher value in the range 400 to 4000
   (d) a much higher value in the range of 4000 to about 40,000

6. Replacing a standard transistor with a Darlington pair in an emitter follower will cause the value of the voltage gain of the circuit to:
   (a) decrease
   (b) increase
   (c) remain the same
   (d) be exactly equal to 1

7. The feedback pair and the Darlington pair are very similar to each other. One difference between them is:
   (a) the feedback pair uses one NPN and one PNP transistor
   (b) the Darlington pair uses one NPN and one PNP transistor
   (c) there is no difference between them
   (d) there is no similarity between them

8. When $V_{GS}$ voltage of a JFET is held constant then the JFET is operating as a:
   (a) voltage controlled resistor
   (b) voltage controlled voltage source
   (c) constant current source
   (d) constant voltage source

9. In the circuit shown in Figure 12.1.9 calculate the current flowing in Resistor $R_1$:
   (a) 6.0 mA
   (b) must know the value of $R_2$ to calculate the current
   (c) 5.3 mA
   (d) must know how much current is flowing through the Zener diode

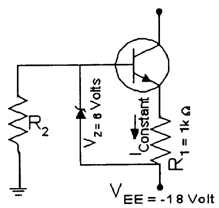

Figure 12.1.9

10. In the circuit shown in Figure 12.1.10 calculate the current flowing in the collector of transistor $Q_2$:
    (a) 6.0 mA
    (b) must know the value of transistor $\beta$ to calculate the current
    (c) 5.65 mA
    (d) must know the rest of the circuit connected to transistor $Q_2$

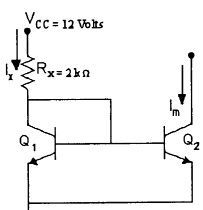

Figure 12.1.10

11. The main features of a *difference pair* like the one shown in figure 12.1.11 are:
    (a) very high input impedance and very high voltage gain
    (b) very high input impedance and moderate voltage gain
    (c) moderate input impedance and very high voltage gain
    (d) moderate input impedance and moderate voltage gain

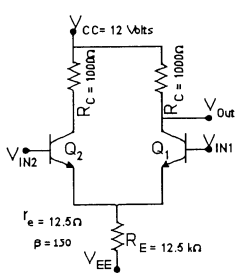

Figure 12.1.11

12. Under single-ended operation the voltage gain for the circuit of Figure 12.1.11 is equal to:
    (a) 20
    (b) 40
    (c) 80
    (d) 160

13. Under common mode operation, the common mode voltage gain, for the circuit shown in Figure 12.1.11 is equal to:
(a) 0.0397
(b) 80
(c) 40
(d) 0.08

14. Under difference mode operation, the difference mode voltage gain, for the circuit shown in Figure 12.1.11 is equal to:
(a) 0.0397
(b) 80
(c) 40
(d) 0.08

15. Under single-ended operation the voltage gain for the circuit of Figure 12.1.15 is equal to:
(a) 33.33
(b) 66.66
(c) 133.33
(d) 266.66

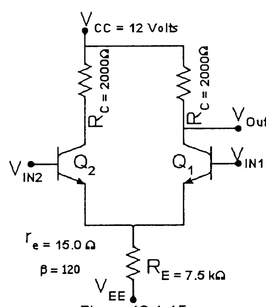

Figure 12.1.15

16. Under common mode operation, the common mode voltage gain, for the circuit shown in Figure 12.1.15 is equal to:
(a) 0.133
(b) 33.33
(c) 66.66
(d) 0.266

17. Under difference mode operation, the difference mode voltage gain, for the circuit shown in Figure 12.1.15 is equal to:
(a) 0.133
(b) 33.33
(c) 66.66
(d) 0.266

18. Two identical common source amplifiers have bypassed source capacitors. The bias point is $V_{GSQ}$ = -2V, $I_{DQ}$ = 2.6 mA, and both transistors have a $g_{m0}$ = 5 mS with $I_{DSS}$ = 10 mA and VP = -4 V. The circuits resistors are RG = 3.3 M ohms, $R_D$ = 2.4 K ohms and RS = 680 ohms. What is the total gain?
   (a) 36
   (b) -6
   (c) 6
   (d) none of the above

19. A cascade common-emitter amplifier consists of two identical stages with their bias point set at $V_{CEQ}$ = 6.9 V and $I_{CQ}$ = 4.1 mA. What is the total voltage gain if the circuit parameters are: Beta = 200, $R_C$ = 2.2 K ohms, $R_B$ = 3.58 ohms and $R_L$ = 10 K ohms.
   (a) -104
   (b) -286.2
   (c) -390.2
   (d) 29.77 K

20. A cascade connection of a CE stage and a CB stage provides:
   (a) high input impedance
   (b) low voltage gain
   (c) minimum input Miller capacitance
   (d) good high frequency performance
   (e) all of the above

21. A Darlington pair has values of $h_{fe1}$ = $h_{fe2}$ = 150. What is the overall value of Beta d for the pair?
   (a) 300
   (b) 150
   (c) 22,500
   (d) none of the above

22. A Darlington pair has values of $h_{fe1}$ = $h_{fe2}$ = 150, and its value of $R_E$ = 1 K ohms and $R_B$ = 4.7 M ohms. The value of $Z_i$ for the circuit is
   (a) 4.7 M ohms
   (b) 22.5 M ohms
   (c) 3.88 M ohms
   (d) cannot be determined with the information given

23. Replacing a standard transistor with a Darlington pair in an emitter follower will cause the value of the input impedance for the circuit to:
   (a) increase
   (b) decrease
   (c) remain the same
   (d) equal the value of $Beta_D$

24. A feedback pair is formed by connecting:
   (a) two PNP transistors collector-emitter, emitter-base
   (b) a NPN and a PNP transistor, collector-base, collector-emitter
   (c) two NPN transistors, collector-base, collector-emitter
   (d) a PNP and a NPN, emitter-base, emitter-base

25. The feedback pair is similar to the Darlington circuit but it is:
(a) simpler to analyze
(b) more complex
(c) more used
(d) none of the above

26. CMOS circuits have operating characteristics such that when:
(a) $V_i$ = 0V, the nMOS is on, the pMOS is off
(b) $V_i$ = 0V, the nMOS is off, the pMOS is on
(c) $V_i$ = + 5V, the nMOS is off, the pMOS is on
(d) none of the above

27. CMOS circuits have operating characteristics such that when:
(a) $V_i$ = 0V, the nMOS is on, and pMOS is off
(b) $V_i$ = +5V, the nMOS is off, and pMOS is on
(c) $V_i$ = +5V, the nMOS is on, and pMOS is off
(d) none of the above

28. Constant current sources can be built using:
(a) FET devices
(b) BJT devices
(c) FET and BJT devices in combination
(d) all of the above

29. If a JFET's $V_{GS}$ is set to zero a simple current source is provided and fixed at $I_D$ = ________.
(a) 10 mA
(b) 20 mA
(c) $I_{DSS}$
(d) none of the above

30. A Zener diode-BJT constant current source circuit has $V_Z$ = 11.7 V, R = 2.2 K ohms, the transistor is npn silicon and $V_{EE}$ = -20 V. What is I?
(a) 9.1 mA
(b) 5.318 mA
(c) 5.64 mA
(d) 5 mA

31. Current mirror circuits provide ________ used in ________.
(a) constant voltage sources; integrated circuits
(b) constant current sources; power circuits
(c) constant current sources; integrated circuits
(d) constant voltage sources; power circuits

32. For the differential amplifier circuit if an input signal is applied to one of the inputs and the other connected to ground such operation is referred to as:
(a) single-ended
(b) double-ended
(c) common-mode
(d) none of the above

33. For the differential amplifier circuit if two opposite polarity input signals are applied, the operation is referred to as:
    (a) single-ended
    (b) double-ended
    (c) common-mode
    (d) none of the above

34. For the differential amplifier circuit if the same input is applied to both inputs, the operation is called:
    (a) single-ended
    (b) double-ended
    (c) common-mode
    (d) none of the above

35. CMOS differential amplifiers are used when ________ is desired.
    (a) the highest gain
    (b) low power dissipation
    (c) lower input impedance
    (d) all of the above

36. When BJT's and FET's are used together in differential amplifiers they are called:
    (a) BiFET circuits
    (b) BiCMOS circuits
    (c) CMOS
    (d) none of the above

1. Answer: the same Difficulty: 1 Section: 2 Objective: 1
2. Answer: the same Difficulty: 1 Section: 2 Objective: 1
3. Answer: (a) Difficulty: 2 Section: 3 Objective: 1
4. Answer: (d) Difficulty: 2 Section: 3 Objective: 1
5. Answer: (d) Difficulty: 2 Section: 4 Objective: 1
6. Answer: (a) Difficulty: 2 Section: 4 Objective: 1
7. Answer: (a) Difficulty: 2 Section: 5 Objective: 1
8. Answer: (c) Difficulty: 2 Section: 7 Objective: 1
9. Answer: (c) Difficulty: 2 Section: 7 Objective: 1
10. Answer: (c) Difficulty: 2 Section: 8 Objective: 1
11. Answer: (a) Difficulty: 2 Section: 9 Objective: 1
12. Answer: (a) Difficulty: 2 Section: 9 Objective: 1
13. Answer: (a) Difficulty: 2 Section: 9 Objective: 1
14. Answer: (c) Difficulty: 2 Section: 9 Objective: 1
15. Answer: (b) Difficulty: 2 Section: 9 Objective: 1
16. Answer: (d) Difficulty: 2 Section: 9 Objective: 1
17. Answer: (c) Difficulty: 2 Section: 9 Objective: 1
18. Answer: (a) Difficulty: 2 Section: 1 Objective: 2
19. Answer: (d) Difficulty: 2 Section: 2 Objective: 2
20. Answer: (e) Difficulty: 2 Section: 1 Objective: 3
21. Answer: (c) Difficulty: 2 Section: 1 Objective: 4
22. Answer: (c) Difficulty: 2 Section: 2 Objective: 4
23. Answer: (a) Difficulty: 2 Section: 3 Objective: 4
24. Answer: (b) Difficulty: 2 Section: 1 Objective: 5
25. Answer: (b) Difficulty: 2 Section: 2 Objective: 5

26. Answer: (c) Difficulty: 2 Section: 1 Objective: 6

27. Answer: (c) Difficulty: 2 Section: 2 Objective: 6

28. Answer: (d) Difficulty: 2 Section: 1 Objective: 7

29. Answer: (c) Difficulty: 2 Section: 2 Objective: 7

30. Answer: (d) Difficulty: 2 Section: 3 Objective: 7

31. Answer: (c) Difficulty: 2 Section: 1 Objective: 8

32. Answer: (a) Difficulty: 2 Section: 1 Objective: 9

33. Answer: (b) Difficulty: 2 Section: 2 Objective: 9

34. Answer: (c) Difficulty: 2 Section: 3 Objective: 9

35. Answer: (b) Difficulty: 2 Section: 1 Objective: 10

36. Answer: (a) Difficulty: 2 Section: 2 Objective: 10

# Chapter 13: Operational Amplifiers

## *SHORT ANSWER*

1. An operational amplifier is a very _______ gain differential amplifier with _____ input impedance and ______ output impedance.

## *MULTIPLE CHOICE*

2. The operational amplifier will only slightly amplify signals:
   (a) when the supply voltages are more then ±25Volts
   (b) when the supply voltages are less then ±5Volts
   (c) that are common on both the inputs
   (d) that are different on both the inputs

3. Which of the following statements are true about an operational amplifier?
   (a) op-amps are very high gain DC amplifiers
   (b) op-amps have very low output impedance
   (c) op-amps have very high input impedance
   (d) all the above statements

4. The Common Mode Rejection Ration (CMRR) is the ratio of:
   (a) the difference mode gain to the common mode gain
   (b) the common mode gain to the difference mode gain
   (c) noninverting gain
   (d) inverting gain

5. The AC equivalent circuit of an op-amp is shown in Figure 13.1.5. The input signal is applied between the input terminals and sees an input impedance $R_i$. This impedance is:
   (a) A few hundred ohms.
   (b) A few kilo ohms.
   (c) A few hundred kilo ohms.
   (d) Depends on the op-amp used. Could be a few hundred ohms to a few hundred-kilo ohms.

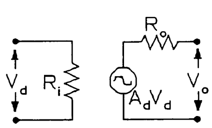


Figure 13.1.5

6. One basic circuit connection using an op-amp is shown in Figure 13.1.6. If the input voltage is 0.25 Volts calculate the output voltage:
   (a) -10.0 Volts
   (b) -5.0 Volts
   (c) -2.5 Volts
   (d) -1.25 Volts

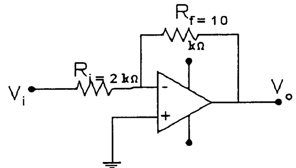


Figure 13.1.6

7. For basic circuit connection using an op-amp is shown in Figure 13.1.6. If the input voltage is 0.25 Volts and the required output voltage is -2.0 Volts then the resistor $R_f$ should be changed to:
(a) 40.0 K ohms
(b) 20.0 K ohms
(c) 10.0 K ohms
(d) 5.0 K ohms

8. Another basic circuit connection using an op-amp is shown in Figure 13.1.8. If the input voltage is 0.25 Volts calculate the output voltage:
(a) 10.0 Volts
(b) 5.0 Volts
(c) 3.0 Volts
(d) 1.5 Volts

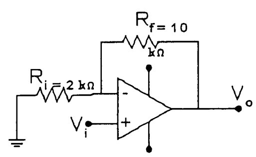

Figure 13.1.8

9. For basic circuit connection using an op-amp is shown in Figure 13.1.8. If the input voltage is 0.25 Volts and the required output voltage is 2.75 Volts then the resistor $R_f$ should be changed to:
(a) 40.0 K ohms
(b) 20.0 K ohms
(c) 10.0 K ohms
(d) 5.0 K ohms

10. For summing circuit connection using an op-amp shown in Figure 13.1.10. Calculate the output voltage when $V_{i1}$ = 0.25 Volts and $V_{i2}$ = 0.5 Volts:
(a) 1.125 Volts
(b) 2.25 Volts
(c) 4.5 Volts
(d) 9.0 Volts

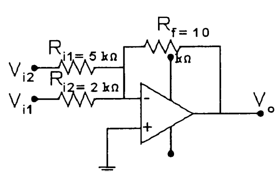

Figure 13.1.10

11. The operational amplifier circuit shown in Figure 13.1.11 is that of a/an ________.
   (a) level comparator
   (b) differentiator
   (c) integrator
   (d) difference amplifier

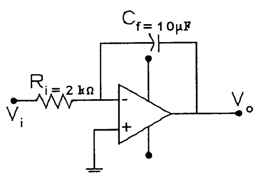


Figure 13.1.11

12. The operational amplifier circuit shown in Figure 13.1.12 is that of a/an ________.
   (a) level comparator
   (b) differentiator
   (c) integrator
   (d) difference amplifier

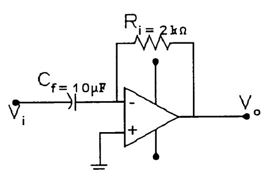


Figure 13.1.12

13. The inverting and noninverting inputs to an op-amp are used to drive a/an:
   (a) inverting amplifier
   (b) noninverting amplifier
   (c) differential amplifier
   (d) open-loop amplifier

14. An op-amp will amplify only slightly when:
   (a) the supply voltages are less than +5 V
   (b) the input offset voltage is less than 100 mV
   (c) the inverting or noninverting inputs have a common input
   (d) the input offset current is less than 1 mA

15. When a given op-amp has a common-mode input of 10 V, the output of the device is 10 V. When the device has a differential input of 2 mV, the output of the device is 10 V. What is the CMPR of the device?
   (a) 5 : 1
   (b) 5000 : 1
   (c) 1000 : 1
   (d) 5,000,000 : 1

16. Which of the following statements is true?
   (a) Op-amps are high-gain dc amplifiers.
   (b) Op-amps have extremely high input impedance.
   (c) Op-amps have extremely low output impedance.
   (d) All of the above.

17. Why is the CMRR of an inverting amplifier always lower than that of its op-amp?
    (a) Because the common-mode gain of an op-amp increases when it is used in an inverting amplifier.
    (b) Because the value of differential gain for an inverting amplifier is lower than that of its op-amp.
    (c) Because slew-rate limiting decreases the common-mode gain of the op-amp.
    (d) Because of the lower input impedance of the inverting amplifier.

18. The op-amp circuit that adds each input voltage to the output multiplied by its separate constant-gain multiplier is called a/an:
    (a) unity follower
    (b) integrator
    (c) differentiator
    (d) summing amplifier

19. The op-amp circuit that has a capacitor as the feedback component is called a/an:
    (a) unity follower
    (b) integrator
    (c) differentiator
    (d) summing amplifier

20. An op-amp integrator circuit has a 2M ohm input resistor and a 5 μF feedback loop capacitor. If the inverting input voltage is 2 Volts dc what is the final value of the output voltage?
    (a) -20
    (b) -2
    (c) -0.2
    (d) 0.02
    (e) 2

21. A summing integrator is an op-amp integrator that has:
    (a) multiple feedback capacitors
    (b) multiple input resistors
    (c) multiple input resistors and feedback capacitors
    (d) none of the above

22. The op-amp differentiator circuit differs from the integrator in that it:
    (a) is not as useful
    (b) has a scale factor of -RC
    (c) has a resistor in the feedback loop
    (d) all of the above

23. A voltage follower has values of $R_L$ = 12 K ohms, $V_S$ = 12 V, and $V_{IN}$ = 10 PK. What is the peak-to-peak output from the circuit?
    (a) 20 $V_{PP}$
    (b) 21 $V_{PP}$
    (c) 12 $V_{PP}$
    (d) cannot be determined from the information given

24. An inverting amplifier and a noninverting amplifier are built using the same values of $R_f$ and $R_i$. Assuming that the op-amps being used in the two circuits have identical common-mode gain values:
(a) the inverting amplifier has the higher CMRR
(b) the noninverting amplifier has the higher CMRR
(c) the CMRR is the same for the inverting and noninverting amplifiers
(d) none of the above

25. An inverting amplifier with + 11 V supply voltages normally has a sinusoidal output of 10 $V_{PP}$. When checking the circuit with an oscilloscope it was determined that the output is 0 V. Which of the following could account for this problem?
(a) $R_i$ open
(b) $V_{IN} = 0$
(c) R shorted by a solder bridge
(d) all of the above

26. The voltage follower typically has a voltage gain value of:
(a) 1000
(b) 500
(c) 100
(d) 50
(e) 1

27. Op-amp output offset voltage can be totally explained by:
(a) the input offset voltage
(b) input offset current
(c) the external circuit connection components
(d) none of the above

28. A standard inverting op-amp circuit has an $R_i$ of 10 K ohms and an $R_f$ of 220 K ohms, the offset voltage is given as 0.003 Volts. What is the $V_o$(offset)?
(a) 3 mV
(b) 6.6 mV
(c) 69 mv
(d) 200 mV
(e) none of the above

29. A standard inverting op-amp circuit has an $R_i$ of 10 K ohms and an $R_f$ of 220 K ohms, the offset current is given as 100 nA. What is the output offset voltage due to this current?
(a) 10 mV
(b) 22 mV
(c) 32 mv
(d) 8 mv
(e) none of the above

30. When calculating the total offset voltage the absolute values are used to accommodate the fact that:
(a) offset current can be negative or positive
(b) offset voltage can be negative or positive
(c) both the offset current and voltage can be negative or positive
(d) none of the above

31. Op-amp roll-off characteristics are caused by the fact that:
    (a) they are designed to have high-gain and wide-bandwidth
    (b) the uncompensated circuit would be unstable
    (c) an effective compensation circuit is used
    (d) all of the above

32. Determine the op-amp cutoff-frequency for a device whose unity-gain bandwidth is 1.5 MHz and the differential-gain is 300 V/mV.
    (a) 5 Hz
    (b) 10 Hz
    (c) 50 Hz
    (d) 150 Hz
    (e) none of the above

33. Slew Rate, SR is the:
    (a) ratio of the change in time to the change in output voltage
    (b) maximum rate at which the op-amp output voltage can change
    (c) maximum rate at which the amplifier input voltage can change
    (d) none of the above

34. Exceeding the op-amp SR results in:
    (a) improved gain and reduced distortion
    (b) increased power and reduced distortion
    (c) clipping and increased distortion
    (d) none of the above

35. An op-amp has a SR of 4 V/μsec. What is the maximum closed-loop voltage gain if the input voltage rises at a rate of 5 V/100 μsec?
    (a) 20
    (b) 40
    (c) 80
    (d) 200
    (e) none of the above

36. What is the maximum useful frequency of a 2 Volt input signal that an inverting op-amp can operate at if the closed-loop gain is 50 and the SR is 5 V/μsec?
    (a) 5 K rads/sec
    (b) 10 K rads/sec
    (c) 50 K rads/sec
    (d) 100 K rads/sec
    (e) none of the above

37. The bandwidth of an amplifier is:
    (a) the range of frequencies over which gain remains relatively constant
    (b) the range of frequencies between the lower and upper 3 dB frequencies
    (c) the range of frequencies found using $f_2 - f_1$
    (d) all of the above

38. Op-amps are available in a number of packages; among the most usual form is the:
    (a) dual in-line packages (8 pin)
    (b) integration packages
    (c) type TO-5 metal cans
    (d) type TO-8 metal cans

39. An op-amp circuit has + 15 V supply voltages and a voltage gain of 20. The noninverting voltage (v+) is 0.3 V and the inverting voltage (v-) is 0.35 V. What is the output voltage from the device?
    (a) +1 V
    (b) +6 V
    (c) -0.8 V
    (d) -7 V

1. Answer: high; high; low Difficulty: 1 Section: 1 Objective: 1
2. Answer: (c) Difficulty: 2 Section: 2 Objective: 1
3. Answer: (d) Difficulty: 2 Section: 2 Objective: 1
4. Answer: (a) Difficulty: 2 Section: 2 Objective: 1
5. Answer: (c) Difficulty: 2 Section: 3 Objective: 1
6. Answer: (d) Difficulty: 2 Section: 3 Objective: 1
7. Answer: (b) Difficulty: 2 Section: 3 Objective: 1
8. Answer: (d) Difficulty: 2 Section: 4 Objective: 1
9. Answer: (b) Difficulty: 2 Section: 4 Objective: 1
10. Answer: (b) Difficulty: 2 Section: 4 Objective: 1
11. Answer: (c) Difficulty: 2 Section: 4 Objective: 1
12. Answer: (b) Difficulty: 2 Section: 4 Objective: 1
13. Answer: (c) Difficulty: 2 Section: 1 Objective: 1
14. Answer: (c) Difficulty: 2 Section: 1 Objective: 2
15. Answer: (d) Difficulty: 2 Section: 2 Objective: 2
16. Answer: (d) Difficulty: 2 Section: 1 Objective: 3
17. Answer: (b) Difficulty: 2 Section: 2 Objective: 3
18. Answer: (d) Difficulty: 2 Section: 1 Objective: 4
19. Answer: (b) Difficulty: 2 Section: 2 Objective: 4
20. Answer: (c) Difficulty: 2 Section: 3 Objective: 4
21. Answer: (b) Difficulty: 2 Section: 4 Objective: 4
22. Answer: (d) Difficulty: 2 Section: 5 Objective: 4
23. Answer: (a) Difficulty: 2 Section: 6 Objective: 4
24. Answer: (b) Difficulty: 2 Section: 7 Objective: 4
25. Answer: (d) Difficulty: 4 Section: 8 Objective: 4

26. Answer: (b) Difficulty: 2 Section: 9 Objective: 4

27. Answer: (d) Difficulty: 2 Section: 1 Objective: 5

28. Answer: (c) Difficulty: 2 Section: 2 Objective: 5

29. Answer: (b) Difficulty: 2 Section: 3 Objective: 5

30. Answer: (c) Difficulty: 2 Section: 4 Objective: 5

31. Answer: (d) Difficulty: 2 Section: 1 Objective: 6

32. Answer: (a) Difficulty: 2 Section: 2 Objective: 6

33. Answer: (b) Difficulty: 2 Section: 3 Objective: 6

34. Answer: (c) Difficulty: 2 Section: 4 Objective: 6

35. Answer: (c) Difficulty: 2 Section: 5 Objective: 6

36. Answer: (c) Difficulty: 2 Section: 6 Objective: 6

37. Answer: (d) Difficulty: 2 Section: 7 Objective: 6

38. Answer: (a) Difficulty: 2 Section: 1 Objective: 7

39. Answer: (c) Difficulty: 2 Section: 2 Objective: 7

# Chapter 14: Op-Amp Applications

## *SHORT ANSWER*

1. One of the most common op-amp circuits is the inverting constant gain multiplier. Figure 14.1.1 shows a standard circuit. The resulting gain for the circuit is given by ________.

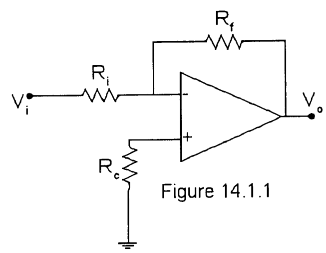


Figure 14.1.1

2. One of the most common op-amp circuits is the inverting constant gain multiplier. Figure 14.1.1 shows a standard circuit. The resulting gain for the circuit is given by ________.

## *MULTIPLE CHOICE*

3. An inverting gain of 6 is required from an op-amp shown in circuit 14.1.1. If the input resistor $R_i$ is 5 kΩ what should be the value of the feedback resistor $R_f$?
   (a) 30 kΩ
   (b) 15 kΩ
   (c) 7.5 kΩ
   (d) 5 kΩ

4. A noninverting gain of 7 is required from an op-amp shown in circuit 14.1.2. If the input resistor $R_i$ is 5 kΩ what should be the value of the feedback resistor $R_f$?
   (a) 30 kΩ
   (b) 15 kΩ
   (c) 7.5 kΩ
   (d) 5 kΩ

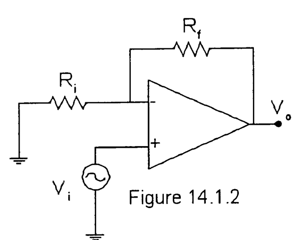


Figure 14.1.2

5. For the cascade amplifier shown in Figure 14.1.5 the input voltage swing is 0.2 Volts P-P. Calculate the peak-to-peak swing on the output voltage.
   (a) 9.6 Volts peak-to-peak
   (b) 4.8 Volts peak-to-peak
   (c) 2.4 Volts peak-to-peak
   (d) 1.2 Volts peak-to-peak

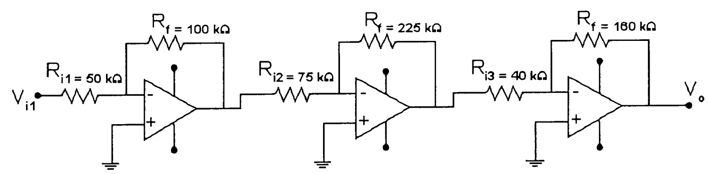


Figure 14.1.5

6. For the circuit shown in Figure 14.1.6 calculate the voltage gain's $V_{o1}$ and $V_{o2}$.
   (a) $V_{o1}$ = -5 and $V_{o2}$ = -4
   (b) $V_{o1}$ = -4 and $V_{o2}$ = -5
   (c) $V_{o1}$ = 6 and $V_{o2}$ = 5
   (d) $V_{o1}$ = 5 and $V_{o2}$ = 6

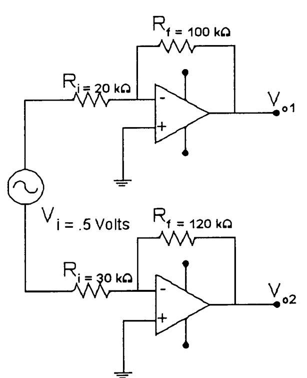


Figure 14.1.6

7. For the circuit shown in Figure 14.1.7, if the two input voltages are exactly equal then the output voltage will be:
   (a) 5 times any one input voltage
   (b) -5 times the input voltage on the inverting input
   (c) 6 times the input voltage on the noninverting input
   (d) exactly equal to zero Volts

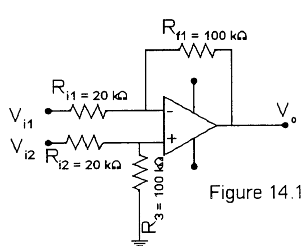


Figure 14.1.7

8. The circuit shown in Figure 14.1.8 is known as a:
   (a) noninverting amplifier
   (b) voltage buffer
   (c) low-pass filter
   (d) high-pass filter

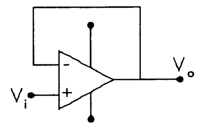


Figure 14.1.8

9. By carefully configuring the op-amp external circuit components the op-amp can be made to function as:
   (a) voltage-controlled voltage source
   (b) voltage-controlled current source
   (c) current-controlled voltage source
   (d) current-controlled current source
   (e) all of the above

10. The circuit shown in Figure 14.1.10 is a:
   (a) voltage-controlled voltage source
   (b) voltage-controlled current source
   (c) current-controlled voltage source
   (d) current-controlled current source

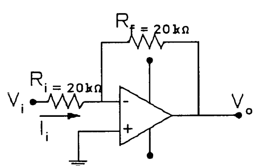


Figure 14.1.10

11. When using an op-amp as a display driver as shown in Figure 14.1.11 a transistor is required because:
   (a) the transistor is required to invert the output voltage
   (b) only transistors can drive displays. Op-amps are not permitted to
   (c) the transistor comes packaged with the display so you have to use the transistor
   (d) the display needs 600 mAmps and the op-amp cannot provide that much current but the transistor can provide it

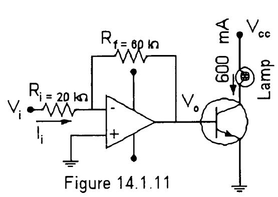


Figure 14.1.11

12. A low pass active filter connection using an operational amplifier will provide a constant output:
    (a) from dc to $f_{oh}$
    (b) for all frequencies higher then $f_{ol}$
    (c) from $f_{ol}$ to $f_{oh}$
    (d) from dc to infinite frequency

13. A high pass active filter connection using an operational amplifier will provide a constant output:
    (a) from dc to $f_{oh}$
    (b) for all frequencies higher then $f_{ol}$
    (c) from $f_{ol}$ to $f_{oh}$
    (d) from dc to infinite frequency

14. A band pass active filter connection using an operational amplifier will provide a constant output:
    (a) from dc to $f_{oh}$
    (b) for all frequencies higher then $f_{ol}$
    (c) from $f_{ol}$ to $f_{oh}$
    (d) from dc to infinite frequency

15. The roll-off rate of a second order filter is:
    (a) 60 dB/decade or 18 dB/octave
    (b) 40 dB/decade or 12 dB/octave
    (c) 20 dB/decade or 6 dB/octave
    (d) 0 dB/decade or 0 dB/octave

16. A constant-gain multiplier has three stages and a gain of 22,200. The values of the $R_f$ are all the same at 470 K ohms and 2 of the 3 $R_i$ values are 33 K ohms. What is the value of the gain of the stage that is different?
    (a) 14.2
    (b) -14.2
    (c) 110.3
    (d) -110.3

17. A constant-gain multiplier has three stages and a gain of 22,200. The values of $R_f$ are all the same at 470 K ohms and 2 of the 3 $R_i$ values are 33 K ohms. What is the individual value of the voltage gain for the 2 stages that are identical?
    (a) 14.2
    (b) -14.2
    (c) 110.3
    (d) -110.3

18. A constant-gain multiplier has three stages and a gain of 22,200. The values of $R_f$ are all the same at 470 K ohms and 2 of the 3 $R_i$ values are 33 K ohms. What is the value of the third $R_i$ and what is the nature of its stage?
    (a) 4.26 K ohms, inverting
    (b) 4.3 K ohms, noninverting
    (c) 4.3 K ohms, inverting
    (d) 4.6 K ohms, noninverting

19. A single op-amp circuit has a noninverting input through a voltage divider of $R_1 = R_2 = 27$ K ohms and on the inverting input side. $R_i = R_f + 120$ K ohms. The resulting total output voltage characterizes this circuit as a/an:
    (a) integrater
    (b) differentiator
    (c) summing amplifier
    (d) substrator
    (e) none of the above

20. An op-amp circuit that has unity-gain, no phase inversion with high input impedance and low output impedance is applied as a/an:
    (a) voltage buffer
    (b) substractor
    (c) summing amplifier
    (d) differentiator

21. By careful configuring of the op-amp external circuit components it can be made to function as a/an:
    (a) voltage-controlled current source
    (b) current-controlled voltage source
    (c) current-controlled current source
    (d) voltage-controlled voltage source
    (e) all of the above

22. An active filter that provides a constant output from dc to $f_{oh}$ then passes no signal above $f_{oh}$ is called an ideal:
    (a) low-pass filter
    (b) high-pass filter
    (c) bandpass filter
    (d) none of the above

23. An active filter that provides a constant output for input signals above $f_{ol}$ is called an ideal:
    (a) low-pass filter
    (b) high-pass filter
    (c) bandpass filter
    (d) none of the above

24. An active filter that provides a constant output for input signals from $f_{ol}$ to $f_{oh}$ is called an ideal:
    (a) low-pass filter
    (b) high-pass filter
    (c) bandpass filter
    (d) none of the above

25. A second order high-pass filter has a low end roll-off of:
    (a) 60 dB/octave
    (b) 40 dB/decade
    (c) 20 dB/octave
    (d) 6 dB/decade

1. Answer: $A = -(R_f / R_i)$ Difficulty: 2 Section: 1 Objective: 1
2. Answer: $A = (1 + R_f / R_i)$ Difficulty: 2 Section: 1 Objective: 1
3. Answer: (a) Difficulty: 2 Section: 1 Objective: 1
4. Answer: (a) Difficulty: 2 Section: 1 Objective: 1
5. Answer: (a) Difficulty: 2 Section: 1 Objective: 1
6. Answer: (c) Difficulty: 2 Section: 1 Objective: 1
7. Answer: (d) Difficulty: 2 Section: 2 Objective: 1
8. Answer: (b) Difficulty: 2 Section: 3 Objective: 1
9. Answer: (e) Difficulty: 2 Section: 4 Objective: 1
10. Answer: (b) Difficulty: 2 Section: 4 Objective: 1
11. Answer: (a) Difficulty: 2 Section: 5 Objective: 1
12. Answer: (a) Difficulty: 2 Section: 6 Objective: 1
13. Answer: (b) Difficulty: 2 Section: 6 Objective: 1
14. Answer: (c) Difficulty: 2 Section: 6 Objective: 1
15. Answer: (b) Difficulty: 2 Section: 6 Objective: 1
16. Answer: (c) Difficulty: 2 Section: 1 Objective: 1
17. Answer: (b) Difficulty: 2 Section: 2 Objective: 1
18. Answer: (b) Difficulty: 2 Section: 3 Objective: 1
19. Answer: (d) Difficulty: 2 Section: 1 Objective: 2
20. Answer: (a) Difficulty: 2 Section: 1 Objective: 3
21. Answer: (e) Difficulty: 2 Section: 1 Objective: 4
22. Answer: (a) Difficulty: 2 Section: 1 Objective: 6
23. Answer: (b) Difficulty: 2 Section: 2 Objective: 6
24. Answer: (c) Difficulty: 2 Section: 3 Objective: 6
25. Answer: (b) Difficulty: 2 Section: 4 Objective: 6

# Chapter 15: Power Amplifiers

***SHORT ANSWER***

1. The class A amplifier conducts for _______ degrees of the input cycle.

2. The class B amplifier conducts for _______ degrees of the input cycle.

3. The class AB amplifier conducts more than _______ degrees but less than _______ degrees of the input cycle.

4. The class C amplifier is used mostly in _______ circuits and conducts for _______ degrees.

***MULTIPLE CHOICE***

5. The maximum possible efficiency of a class A amplifier is equal to:
(a) 30%
(b) 25%
(c) 20%
(d) 15%

6. With transformer coupling the maximum theoretical efficiency of a class A amplifier can be increased up to:
(a) 60%
(b) 55%
(c) 50%
(d) 45%

7. A transformer coupled class A amplifier has a transformer turns ratio of 4.5 : 1 and a load resistance of 30 Ω. The peak-to-peak value of $V_{CE}$ is 12 Volts. What is the approximate power that is delivered to the load?
(a) 47 W
(b) 71 W
(c) 95 W
(d) 119 W

8. A transformer coupled class A amplifier has a transformer turns ratio of 4.5 : 1 and a load resistance of 30 Ω. What is approximately the value of the effective ac load resistance seen by the collector of the transistor?
(a) 400 Ω
(b) 500 Ω
(c) 600 Ω
(d) 700 Ω

9. The class B amplifier suffer from distortion known as:
(a) fundamental distortion
(b) crossover distortion
(c) harmonic distortion
(d) noise figure distortion

10. The cross over distortion in a class B amplifier is prevented by:
    (a) biasing the individual transistors *deeply* into cutoff
    (b) biasing the transistors just slightly above cutoff
    (c) biasing the transistors just slightly into cutoff
    (d) by adjusting the load resistance so that the transistor will turn on and off faster

11. A class AB transistor amplifier using complementary transistors is biased by power supply that is ±18VDC. The value of $V_{CE(OFF)}$ for either transistor is approximately equal to:
    (a) 8 Volts
    (b) 10 Volts
    (c) 18 Volts
    (d) 36 Volts

12. For class B or for class AB amplifiers closely matched complementary transistors are used because they:
    (a) can carry more current than push-pull transistors
    (b) require individual power supplies
    (c) do not need an output transformer
    (d) are complementary so use complementary transistors

13. Calculate the total harmonic distortion for a signal that has amplitude components given: Fundamental 2.5 Volts; Second harmonic 0.25 Volts; Third harmonic 0.1 Volts. Fourth harmonic 0.025 Volts.
    (a) THD% = 10.81%
    (b) THD% = 10.95%
    (c) THD% = 10.74%
    (d) THD% = 10.68%

14. Determine the maximum dissipation that should be allowed for a 75 W Silicon transistor rated at 22° C. De-rating is required above 22° C by a de-rating factor of 0.35 W/° C at a case temp of 142° C
    (a) 30 W
    (b) 27 W
    (c) 25 W
    (d) 22 W

15. A given transistor has a power de-rating factor of 0.25m W/° C. This transistor has a power dissipation rating of 0.5 W at 27° C. What is the max temp the device can be allowed to operate at if it has to dissipate 450 mW?
    (a) 220° C
    (b) 210° C
    (c) 200° C
    (d) 190° C

16. Which of the following is true?
    (a) Efficiency is the ratio of power output to power input.
    (b) The power that an amplifier delivers to a load is equal to the difference between the power that the circuit draws from the power supply and the power that the circuit dissipates.
    (c) Power amplifiers are typically used to drive low impedance loads.
    (d) All of the above.

17. Class B amplifiers:
    (a) provide an output signal for 1/2 the input signal cycle
    (b) usually contain an LC tank circuit in the BJT collector circuit
    (c) usually contain a single BJT that conducts through 360 degrees of the ac input cycle
    (d) usually contain a single BJT that conducts through 270 degrees of the ac input signal

18. Class C amplifiers:
    (a) usually contain two transistors
    (b) usually contain an LC tank circuit in the BJT collector circuit
    (c) usually contain a single BJT that conducts through 360 degrees of the ac input cycle
    (d) usually contain a signal BJT that conducts through 270 degrees of the ac input cycle

19. Class D amplifiers have a maximum theoretical efficiency of:
    (a) 25%
    (b) 78.5%
    (c) 50%
    (d) over 90%

20. A class A amplifier has values of $V_{CC} = 10$ V, $I_B = 450\ \mu A$, and $I_{CQ} = 10.55$ mA. What is the total power that the circuit is drawing from the dc power supply?
    (a) 4.5 mW
    (b) 1.21 mW
    (c) 110 mW
    (d) cannot be determined from the information given

21. A class A amplifier has an 8 $V_{PP}$ output that is being applied to a 200 ohm load. What is the total ac load power?
    (a) 320 mW
    (b) 640 mW
    (c) 40 mW
    (d) 80 mW

22. The maximum theoretical efficiency of an RC-coupled class A amplifier is:
    (a) 25%
    (b) 50%
    (c) 78.5%
    (d) 99%

23. An RC-coupled class A amplifier has values of $I_B = 1$ mA $I_{CQ} = 50$ mA, $V_{CC} = 15$ V, $V_{PP} = 9.3$ V, and $R_C = 68$ ohms. What is the maximum efficiency of the amplifier?
    (a) 16.6%
    (b) 15.9%
    (c) 21.2%
    (d) 25%

24. Impedance matching is important for:
    (a) maximum voltage transfer from source to load
    (b) maximum power transfer from source to load
    (c) maximum impedance transfer from source to load
    (d) maximum current transfer from source

25. The transformer-coupled class A amplifier:
    (a) is 60% efficient
    (b) is able to provide for impedance transformation
    (c) usually contains two transistors
    (d) all of the above

26. The dc load line of a transformer-coupled class A amplifier is:
    (a) identical to that of an RC-coupled class A amplifier
    (b) a near-horizontal line
    (c) a near-vertical line
    (d) none of the above

27. The maximum value of $V_{CE(MAX)}$ in a transformer-coupled class A amplifier will be greater than $V_{CC}$. This is caused by:
    (a) the input biasing network
    (b) the efficiency characteristics of the amplifier
    (c) the counter emf produced by the transformer primary
    (d) the natural relationship between $V_{CE}$, $V_{CC}$ and $V_{PP}$

28. A transformer-coupled class A amplifier has the following values: turns ratio = 3 : 1, $R_L$ = 200 ohms, $V_{CEQ}$ = 6 V, and $I_{CQ}$ = 12 mA. What is the maximum possible change in $V_{CE}$ for the circuit?
    (a) 3 V
    (b) 6 V
    (c) 12 V
    (d) cannot be determined from the information given

29. A transformer-coupled class A amplifier has a transformer turns ratio of 4 : 1 and a load resistance of 25 ohms. The peak-to-peak value of $V_{CE}$ is 12 V. What is the approximate load power for the circuit?
    (a) 45 mW
    (b) 160 mW
    (c) 90 mW
    (d) 60 mW

30. A transformer-coupled class A amplifier has a transformer turns ratio of 4 : 1 and a $R_L$ of 25 ohms, the peak-to-peak value of $V_E$ is 12 V; it draws 220 mW from the dc power supply. What is the efficiency of the circuit?
    (a) 27.3%
    (b) 40.9%
    (c) 73%
    (d) 20.5%

31. Complementary-symmetry amplifiers are generally preferred over standard push-pull amplifiers because:
    (a) they use complementary transistors
    (b) they do not require the use of an output transformer
    (c) they have high efficiency ratings
    (d) they can drive lower impedance loads

32. Crossover distortion in class B amplifiers is prevented by:
    (a) biasing the transistors deeply into cutoff
    (b) biasing the transistors slightly above cutoff
    (c) using complementary-symmetry transistors
    (d) increasing the load resistance

33. A class AB amplifier has a supply voltage that is equal to +15 Vdc. The value of $V_{CE\ (OFF)}$ for either transistor is approximately equal to:
    (a) 15 V
    (b) 5 V
    (c) 7.55 V
    (d) 0.7 V

34. A given transistor has a power de-rating factor of 1.8 mW/° C and a power dissipation rating of 400 mW at 25 degrees C. How much power can the device dissipate at 120 degrees C?
    (a) 216 mW
    (b) 81.9 mW
    (c) 184 mW
    (d) 355 mW

1. Answer: full 360 Difficulty: 2 Section: 1 Objective: 1
2. Answer: only 180 Difficulty: 2 Section: 1 Objective: 1
3. Answer: full 360; only 180 Difficulty: 2 Section: 1 Objective: 1
4. Answer: tuned; less than 180 Difficulty: 2 Section: 1 Objective: 1
5. Answer: (b) Difficulty: 1 Section: 2 Objective: 1
6. Answer: (c) Difficulty: 1 Section: 3 Objective: 1
7. Answer: (c) Difficulty: 1 Section: 3 Objective: 1
8. Answer: (c) Difficulty: 1 Section: 3 Objective: 1
9. Answer: (b) Difficulty: 1 Section: 5 Objective: 1
10. Answer: (b) Difficulty: 2 Section: 5 Objective: 1
11. Answer: (c) Difficulty: 2 Section: 5 Objective: 1
12. Answer: (c) Difficulty: 2 Section: 5 Objective: 1
13. Answer: (a) Difficulty: 2 Section: 6 Objective: 1
14. Answer: (b) Difficulty: 2 Section: 6 Objective: 1
15. Answer: (c) Difficulty: 2 Section: 7 Objective: 1
16. Answer: (d) Difficulty: 2 Section: 1 Objective: 1
17. Answer: (a) Difficulty: 2 Section: 2 Objective: 1
18. Answer: (b) Difficulty: 2 Section: 3 Objective: 1
19. Answer: (d) Difficulty: 2 Section: 4 Objective: 1
20. Answer: (c) Difficulty: 2 Section: 1 Objective: 2
21. Answer: (c) Difficulty: 2 Section: 2 Objective: 2
22. Answer: (a) Difficulty: 2 Section: 3 Objective: 2
23. Answer: (c) Difficulty: 2 Section: 4 Objective: 2
24. Answer: (b) Difficulty: 2 Section: 1 Objective: 3
25. Answer: (d) Difficulty: 2 Section: 2 Objective: 3

26. Answer: (c) Difficulty: 2 Section: 3 Objective: 3

27. Answer: (d) Difficulty: 2 Section: 4 Objective: 3

28. Answer: (b) Difficulty: 2 Section: 5 Objective: 3

29. Answer: (a) Difficulty: 2 Section: 6 Objective: 3

30. Answer: (d) Difficulty: 2 Section: 7 Objective: 3

31. Answer: (b) Difficulty: 2 Section: 1 Objective: 5

32. Answer: (b) Difficulty: 2 Section: 2 Objective: 5

33. Answer: (c) Difficulty: 2 Section: 3 Objective: 5

34. Answer: (b) Difficulty: 2 Section: 1 Objective: 7

# Chapter 16: Linear-Digital ICs

## *MULTIPLE CHOICE*

1. Figure 16.1.1 shows a 741 op-amp used as a comparator. What will the output voltage be when the input voltage is 1.5 Volts?
   (a) + 5 Volts
   (b) + 2 Volts
   (c) - 2 Volts
   (d) - 5 Volts

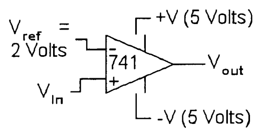


Figure 16.1.1

2. The output of the 311 comparator is taken from _____ so that it can be used to drive a variety of loads such as a lamp or a relay.
   (a) the strobe pins of the op-amp
   (b) the output pin of the op-amp
   (c) a bipolar transistor
   (d) the noninverting input of the op-amp

3. Figure 16.1.3 shows a 311 comparator. The output will change state when the input voltage ______.
   (a) crosses zero Volts going from negative to positive only
   (b) crosses zero Volts in any direction
   (c) crosses zero Volts going from positive to negative only
   (d) none of the above

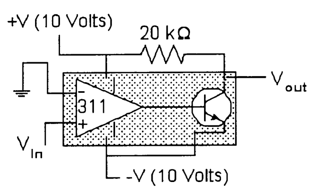


Figure 16.1.3

4. In Figure 16.1.4 the input voltage at the noninverting terminal is greater than the reference voltage at the inverting terminal. Now the output voltage will be _______.
   (a) open circuit
   (b) equal to the $V^+$ input voltage
   (c) equal to the $V^-$ input voltage
   (d) short circuit

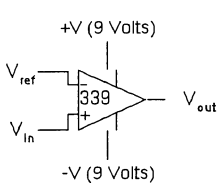


Figure 16.1.4

5. The circuit shown in Figure 16.1.5 is a ________.
   (a) level detector
   (b) window detector
   (c) door detector
   (d) zero crossing detector

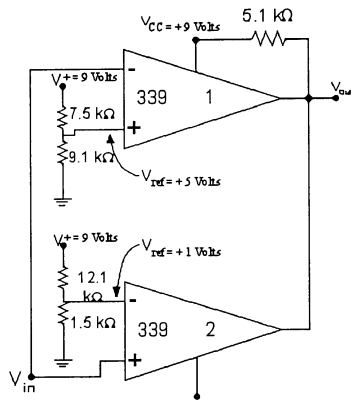


Figure 16.1.5

6. When the input voltage to the circuit of Figure 16.1.5 is less than 1 Volt the output voltage will be ________.
   (a) zero Volts
   (b) nine Volts
   (c) output will be open circuit
   (d) input voltage is not allowed to be less than 1 Volt

7. When the input voltage to the circuit of Figure 16.1.5 is more than 1 Volt but less than 5 Volts the output voltage will be ________.
   (a) zero Volts
   (b) nine Volts
   (c) output will be open circuit
   (d) input voltage is not allowed to be in the specified voltage range

8. When the input voltage to the circuit of Figure 16.1.5 is more than 5 Volts the output voltage will be ________.
   (a) zero Volts
   (b) nine Volts
   (c) output will be open circuit
   (d) input voltage is not allowed to be more than 5 Volts

9. The ladder network for Digital to Analog conversion uses resistors ________.
   (a) that are required to be very precise
   (b) that are wire wound so they can carry a large current
   (c) that have a ratio that is 2 : 1 the actual value is not very important
   (d) that have a ration that is 1 : 2 : 4 : 8 and so on depending on how many legs you need for the ladder

10. In the *Dual Slope A/D* converter the first slope—which charges the capacitor—is ________.
    (a) at a constant slope
    (b) always at a constant voltage
    (c) always till the capacitor charges up to a predetermined voltage level
    (d) as always for a fixed time interval

11. In the *Dual Slope A/D* converter the second slope—which discharges the capacitor—is ________.
    (a) at a constant slope
    (b) always at a constant voltage
    (c) always till the capacitor charges up to a predetermined voltage level
    (d) as always for a fixed time interval

12. The 555 timer can be used as ______.
    (a) a mono-stable multivibrator
    (b) an astable multivibrator
    (c) a pulse width modulator
    (d) all of the above

13. In the 566 VCO the output frequency is controlled by the ________.
    (a) capacitor
    (b) resistor
    (c) external input voltage
    (d) all of the above

14. The circuit shown in Figure 16.1.14 is that of a/an ______.
    (a) open collector output
    (b) open drain output
    (c) regular output of an op-amp
    (d) totem pole; or a tri-state output

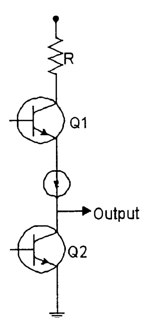

Figure 16.1.14

15. The circuit shown in Figure 16.1.15 is that of a/an ______.
   (a) open collector output
   (b) open drain output
   (c) regular output of an op-amp
   (d) totem pole; or a tri-state output

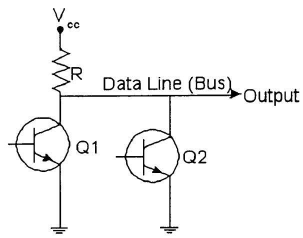

Figure 16.1.15

16. A comparator has a:
   (a) digital input and a linear output
   (b) digital input and a digital output
   (c) linear input and a linear output
   (d) linear input and a digital output

17. Typical gain of a comparator is:
   (a) 100
   (b) 1000
   (c) 10,000
   (d) 100,000

18. Which of the following represents an improvement in comparators due to the IC circuit?
   (a) faster switching
   (b) built-in noise immunity
   (c) variety of output drive capability
   (d) all of the above

19. Which of these is an application of the 555 IC?
   (a) Astable multivibrator
   (b) A/D converter
   (c) D/A converter
   (d) Comparator

20. Which of these is an application of the 555 IC?
   (a) Monostable multivibrator
   (b) A/D converter
   (c) D/A converter
   (d) Comparator

21. Which of the following is an application of the 566 IC?
   (a) Monostable multivibrator
   (b) VCO
   (c) Comparator
   (d) Astable multivibrator

22. A circuit that contains a phase detector, a low-pass filter and a VCO is a/an:
    (a) comparator
    (b) astable multivibrator
    (c) phase-locked loop
    (d) none of the above

23. A common application of the PLL is:
    (a) frequency synthesis
    (b) FM demodulation
    (c) demodulation of two carrier frequencies
    (d) all of the above

24. A circuit that provides an output signal at the voltage and/or current levels suitable to operate a particular load is called a/an:
    (a) RS232
    (b) driver
    (c) polarizer
    (d) none of the above

1. Answer: (d) Difficulty: 2 Section: 2 Objective: 1
2. Answer: (c) Difficulty: 2 Section: 2 Objective: 1
3. Answer: (b) Difficulty: 2 Section: 2 Objective: 1
4. Answer: (c) Difficulty: 2 Section: 2 Objective: 1
5. Answer: (b) Difficulty: 1 Section: 2 Objective: 1
6. Answer: (a) Difficulty: 2 Section: 2 Objective: 1
7. Answer: (b) Difficulty: 2 Section: 2 Objective: 1
8. Answer: (a) Difficulty: 2 Section: 2 Objective: 1
9. Answer: (c) Difficulty: 2 Section: 3 Objective: 1
10. Answer: (c) Difficulty: 2 Section: 3 Objective: 1
11. Answer: (c) Difficulty: 2 Section: 3 Objective: 1
12. Answer: (d) Difficulty: 2 Section: 4 Objective: 1
13. Answer: (d) Difficulty: 2 Section: 5 Objective: 1
14. Answer: (d) Difficulty: 2 Section: 7 Objective: 1
15. Answer: (a) Difficulty: 2 Section: 7 Objective: 1
16. Answer: (d) Difficulty: 2 Section: 1 Objective: 2
17. Answer: (d) Difficulty: 2 Section: 2 Objective: 2
18. Answer: (d) Difficulty: 2 Section: 3 Objective: 2
19. Answer: (a) Difficulty: 2 Section: 1 Objective: 4
20. Answer: (a) Difficulty: 2 Section: 2 Objective: 4
21. Answer: (b) Difficulty: 2 Section: 1 Objective: 5
22. Answer: (c) Difficulty: 2 Section: 1 Objective: 6
23. Answer: (d) Difficulty: 2 Section: 2 Objective: 6
24. Answer: (b) Difficulty: 2 Section: 1 Objective: 7

# Chapter 17: Feedback and Oscillator Circuits

*MULTIPLE CHOICE*

1. The advantages of negative feedback are ______.
   (a) higher input impedance
   (b) voltage gain that is more stable
   (c) improved frequency response
   (d) lower output impedance
   (e) reduced noise in the response
   (f) all of the above

2. Calculate the gain of a negative feedback amplifier having **A** = -2000 and β = -1/16.
   (a) Gain = -2000
   (b) Gain = -1/16
   (c) Gain = -125
   (d) Gain = 125

3. The feedback circuit connection shown in Figure 17.2.3 is ________.
   (a) voltage series feedback
   (b) voltage shunt feedback
   (c) current series feedback
   (d) current shunt feedback

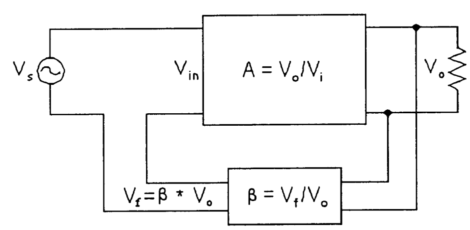

Figure 17.2.3

4. The feedback circuit connection shown in Figure 17.2.4 is ________.
   (a) voltage series feedback
   (b) voltage shunt feedback
   (c) current series feedback
   (d) current shunt feedback

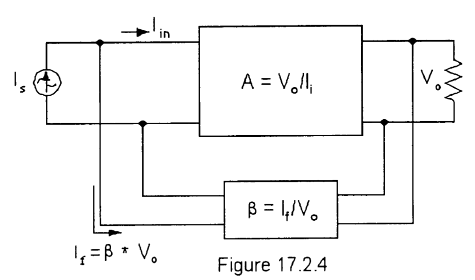

Figure 17.2.4

5. Calculate the voltage gain for voltage series feedback when the amplifier gain is **A** = -2000 and β = -1/50.
   (a) Gain ≈ -2000
   (b) Gain ≈ -1/50
   (c) Gain ≈ 50
   (d) Gain ≈ -48.75

6. Calculate the input impedance for voltage series feedback when the amplifier has $\mathbf{R}_i$ = 10 kΩ, amplifier gain is $\mathbf{A}$ = -2000 and β = -1/50.
   (a) Input impedance with feedback ≈ 10 kΩ.
   (b) Input impedance with feedback ≈ 410 kΩ.
   (c) Input impedance with feedback ≈ 244 Ω.
   (d) Input impedance with feedback ≈ 50 Ω.

7. The feedback amplifier is unstable if the *Nyquist curve* plotted _____ the (-1 + j0) point and it is stable otherwise.
   (a) passes to the left of
   (b) encloses (encircles)
   (c) passes right over
   (d) does not come close to

8. The _______ margin is defined as the negative of the value of |βA| in decibels at the frequency at which the phase angle is 180° .
   (a) error
   (b) phase
   (c) gain
   (d) feedback

9. The _______ margin is defined as the angle of 180° minus the magnitude of the angle at which the value |βA| is unity (0 dB).
   (a) error
   (b) phase
   (c) gain
   (d) feedback

10. For oscillations to exist and the voltage to sustain the loop operations, the *Barkhausen Criterion* tells us that the loop gain βA must be exactly equal to ______.
    (a) unity (1)
    (b) minus one
    (c) equal to the reciprocal of β
    (d) more than one

11. The tank circuit shown is for a ________ oscillator.
    (a) Hartley's
    (b) Colpitts
    (c) Phase Shift
    (d) Crystal

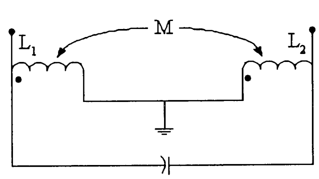


Figure 17.8.11

12. The tank circuit shown is for a ________ oscillator.
(a) Hartley's
(b) Colpitts
(c) Phase Shift
(d) Crystal

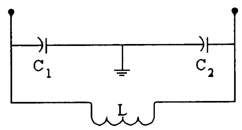


Figure 17.8.12

## *SHORT ANSWER*

13. The ________ effect is the effect that a quartz crystal exhibits when mechanical stress is applied across the face of the crystal and a potential difference develops across the opposite faces of the crystal.

14. When the reactances in the RLC leg of a crystal are equal and opposite we get a resonant condition. This resonant condition is known as the __________ resonant condition.

15. The frequency of oscillation for one relaxation oscillator, using a *Uni Junction Transistor* is given by $f_o = 1/[R_TC_T\ln(1/(1-\eta))]$. If $R_T = 5\ \text{k}\Omega$, $C_T = 0.05\ \mu\text{F}$ and $\eta = 0.5$ then the frequency is _______.

## *MULTIPLE CHOICE*

16. Adding a negative voltage-feedback network to an amplifier will have no effect on the value of __________ for the circuit.
(a) input impedance
(b) frequency response
(c) signal distortion
(d) none of the above

17. Voltage-series feedback __________ the input impedance of an op-amp.
(a) increases
(b) decreases
(c) reduces by half
(d) has no affect on

18. Voltage-series feedback __________ the output impedance of an op-amp.
(a) increases
(b) decreases
(c) reduces by half
(d) has no affect on

19. Voltage-series feedback __________ the bandwidth of an op-amp.
(a) increases
(b) decreases
(c) reduces by half
(d) has no affect on

20. The input impedance of a voltage-shunt feedback amplifier is _________ the input impedance of its op-amp.
    (a) increased when compared to
    (b) decreased when compared to
    (c) reduced by half when compared to
    (d) has no affect on

21. The output impedance of a voltage-shunt feedback amplifier is _________ the output impedance of its op-amp.
    (a) increased when compared to
    (b) decreased when compared to
    (c) reduced by half when compared to
    (d) has no affect on

22. Current-series feedback _________ the input impedance of an op-amp.
    (a) increases
    (b) decreases
    (c) reduces by half
    (d) has no affect on

23. Current-series feedback _________ the output impedance of an op-amp.
    (a) increases
    (b) decreases
    (c) reduces by half
    (d) has no affect on

24. Current-series feedback _________ the bandwidth of an op-amp.
    (a) increases
    (b) decreases
    (c) reduces by half
    (d) has no affect on

25. The input impedance of current-shunt feedback amplifier is _________ the input impedance of its op-amp.
    (a) increased when compared to
    (b) decreased when compared to
    (c) reduced by half when compared to
    (d) has no affect on

26. An amplifier has a gain-bandwidth product of 200 MHz. A feedback network is added that has a feedback factor (1 + Beta A) of 18.88. What is the gain-bandwidth product for the circuit with the added feedback network?
    (a) 10.59 MHz
    (b) 18.88 MHz
    (c) 200 MHz
    (d) none of the above

27. Negative voltage feedback:
    (a) increases $A_V$
    (b) decreases bandwidth
    (c) decreases $A_V$
    (d) increases $A_i$

28. Negative current feedback:
    (a) increases $A_i$
    (b) decreases $A_i$
    (c) decreases bandwidth
    (d) increases $A_V$

29. Positive feedback is used to produce a special type of circuit called a/an:
    (a) inverting amplifier
    (b) noninverting amplifier
    (c) oscillator
    (d) feedback regulator

30. Positive feedback is also called:
    (a) degenerative feedback
    (b) additive feedback
    (c) Barkhausen oscillation
    (d) regressive feedback

31. An oscillator has the following values: $A_V$ = 188 and Beta = 0.00488. Which of the following statements is true?
    (a) The circuit has a constant amplitude output.
    (b) The output from the circuit fades out after several cycles.
    (c) The output from the circuit clips after several cycles.
    (d) None of the above.

32. The Barkhausen criterion states that __________ in an oscillator.
    (a) Beta = 10
    (b) Beta = -1
    (c) Beta $A_V$ = 1
    (d) none of the above

33. Which of the following is not a requirement for oscillator operation?
    (a) The circuit must fulfill the Barkhausen criterion.
    (b) The circuit must initially be triggered into operation.
    (c) The feedback network must contain an RC circuit.
    (d) The circuit must provide positive feedback.

34. The total phase shift around a negative feedback loop of a common-emitter circuit is:
    (a) 360 degrees or 0 degrees
    (b) 180 degrees
    (c) 90 degrees
    (d) 45 degrees

35. The total phase shift around a positive feedback loop for a common-emitter circuit is:
    (a) 360 degrees or 0 degrees
    (b) 180 degrees
    (c) 90 degrees
    (d) 45 degrees

36. In a positive feedback system the feedback signal and the amplifier input signal are:
 (a) in phase
 (b) 45 degrees out of phase
 (c) 90 degrees out of phase
 (d) 180 degrees out of phase

37. In a practical phase-shift oscillator, each RC circuit section produces a:
 (a) 30 degree phase shift
 (b) 60 degree phase shift
 (c) 90 degree phase shift
 (d) 180 degree phase shift

38. The negative feedback circuit in an op-amp Wien-bridge oscillator is used to:
 (a) determine the frequency of operation
 (b) control the gain of the circuit
 (c) bias the positive feedback network
 (d) prevent unwanted oscillations

39. The positive feedback circuit in a Wien-bridge oscillator is used to:
 (a) determine the frequency of operation
 (b) control the gain of the circuit
 (c) bias the negative feedback network
 (d) prevent unwanted oscillations

40. The circuit recognition feature of the Colpitts oscillator is:
 (a) a pair of tapped capacitors in parallel with an inductor
 (b) a pair of tapped inductors in parallel with a capacitor
 (c) a feedback transformer with a capacitor in parallel with its primary winding
 (d) a pair of tapped capacitors in parallel with an inductor and a third small-value capacitor

41. The circuit recognition feature of the Hartley oscillator is:
 (a) a pair of tapped capacitors in parallel with an inductor
 (b) a pair of tapped inductors in parallel with a capacitor
 (c) a feedback transformer with a capacitor in parallel with its primary winding
 (d) a pair of tapped capacitors in parallel with an inductor and a third small-value capacitor

42. A Colpitts oscillator has values of $C1 = 1\ \mu F$, $C2 = 33\ \mu F$ and $L = 100\ \mu H$. What is the frequency of oscillation?
 (a) 12.154 kHz
 (b) 16.154 kHz
 (c) 20.3 kHz
 (d) 100.5 kHz

43. A Colpitts oscillator has $C_i$ = 1 mF, C2 = 33 mF and L = 4.7 mH. What is the approximate operating frequency of the circuit?
(a) 74.5 kHz
(b) 25.6 kHz
(c) 12.8 kHz
(d) none of the above

44. A Hartley oscillator has the following values: RFC = 1 mH, L1 = 100 μH, L2 = 22 μH, and C = 0.001 μF. Assuming that the mutual inductance in the circuit is too small to be considered, what is the approximate output frequency of the oscillator?
(a) 456 kHz
(b) 152 kHz
(c) 503 kHz
(d) none of the above

45. The biggest advantage that LC oscillators have over RC oscillators is the fact that LC oscillators generally:
(a) can be operated at a much higher frequency
(b) can be constructed more economically
(c) require less physical space
(d) none of the above

46. At the ________ a crystal acts as a short circuit.
(a) series-resonant frequency
(b) parallel-resonant frequency
(c) non-resonant frequency
(d) none of the above

47. At the ________ a crystal acts as an open circuit.
(a) series-resonant frequency
(b) parallel-resonant frequency
(c) non-resonant frequency
(d) none of the above

48. CCOs have:
(a) very low operating frequencies
(b) very stable output frequencies
(c) extremely simple biasing circuits
(d) all of the above

49. The Q of a crystal is typically ________.
(a) 5000
(b) 20,000
(c) 500,000
(d) 1,000,000

1. Answer: (f) Difficulty: 2 Section: 1 Objective: 1
2. Answer: (d) Difficulty: 2 Section: 2 Objective: 1
3. Answer: (a) Difficulty: 1 Section: 2 Objective: 1
4. Answer: (b) Difficulty: 1 Section: 2 Objective: 1
5. Answer: (d) Difficulty: 2 Section: 2 Objective: 1
6. Answer: (b) Difficulty: 2 Section: 2 Objective: 1
7. Answer: (b) Difficulty: 2 Section: 4 Objective: 1
8. Answer: (c) Difficulty: 2 Section: 4 Objective: 1
9. Answer: (b) Difficulty: 2 Section: 4 Objective: 1
10. Answer: (a) Difficulty: 2 Section: 4 Objective: 1
11. Answer: (a) Difficulty: 2 Section: 8 Objective: 1
12. Answer: (b) Difficulty: 2 Section: 8 Objective: 1
13. Answer: piezoeiectric Difficulty: 1 Section: 9 Objective: 1
14. Answer: series Difficulty: 1 Section: 9 Objective: 1
15. Answer: 5760 Hz Difficulty: 1 Section: 9 Objective: 1
16. Answer: (d) Difficulty: 2 Section: 1 Objective: 1
17. Answer: (a) Difficulty: 2 Section: 1 Objective: 2
18. Answer: (b) Difficulty: 2 Section: 2 Objective: 2
19. Answer: (a) Difficulty: 2 Section: 3 Objective: 2
20. Answer: (b) Difficulty: 2 Section: 4 Objective: 2
21. Answer: (c) Difficulty: 2 Section: 5 Objective: 2
22. Answer: (a) Difficulty: 2 Section: 6 Objective: 2
23. Answer: (a) Difficulty: 2 Section: 7 Objective: 2
24. Answer: (a) Difficulty: 2 Section: 8 Objective: 2
25. Answer: (b) Difficulty: 2 Section: 9 Objective: 2

26. Answer: (c) Difficulty: 2 Section: 10 Objective: 2

27. Answer: (c) Difficulty: 2 Section: 1 Objective: 3

28. Answer: (b) Difficulty: 2 Section: 2 Objective: 3

29. Answer: (c) Difficulty: 2 Section: 1 Objective: 5

30. Answer: (c) Difficulty: 2 Section: 2 Objective: 5

31. Answer: (b) Difficulty: 2 Section: 3 Objective: 5

32. Answer: (c) Difficulty: 2 Section: 4 Objective: 5

33. Answer: (c) Difficulty: 2 Section: 5 Objective: 5

34. Answer: (a) Difficulty: 2 Section: 1 Objective: 6

35. Answer: (b) Difficulty: 2 Section: 2 Objective: 6

36. Answer: (a) Difficulty: 2 Section: 3 Objective: 6

37. Answer: (b) Difficulty: 2 Section: 4 Objective: 6

38. Answer: (b) Difficulty: 2 Section: 1 Objective: 7

39. Answer: (a) Difficulty: 2 Section: 2 Objective: 7

40. Answer: (d) Difficulty: 2 Section: 1 Objective: 8

41. Answer: (b) Difficulty: 2 Section: 2 Objective: 8

42. Answer: (a) Difficulty: 2 Section: 3 Objective: 8

43. Answer: (a) Difficulty: 2 Section: 4 Objective: 8

44. Answer: (a) Difficulty: 2 Section: 5 Objective: 8

45. Answer: (a) Difficulty: 2 Section: 6 Objective: 8

46. Answer: (b) Difficulty: 2 Section: 1 Objective: 9

47. Answer: (a) Difficulty: 2 Section: 2 Objective: 9

48. Answer: (b) Difficulty: 2 Section: 3 Objective: 9

49. Answer: (b) Difficulty: 2 Section: 4 Objective: 9

# Chapter 18: Power Supplies (Voltage Regulators)

*MULTIPLE CHOICE*

1. The typical parts of a power supply are:
   (a) a transformer
   (b) diode rectifier and filter
   (c) voltage drop element
   (d) all of the above

*SHORT ANSWER*

2. Although a battery has essentially a constant or a dc output voltage, the ac voltage derived from an ac source signal by rectifying and filtering will have some ac variation known as _____.

3. __________ __________ in a power supply is the amount the dc output voltage changes over a range of circuit operation (from no-load operation to full load condition).

*MULTIPLE CHOICE*

4. A dc voltage supply provides an output voltage of 25 Volts under no load condition. This output voltage drops to 22.5 Volts under full load condition. Calculate the percent voltage regulation.
   (a) 10%
   (b) 90%
   (c) 11.1%
   (d) 2.5%

5. Figure 18.5.5 shows a series voltage regulator. Calculate the output voltage for the circuit shown.
   (a) 20.0 Volts
   (b) 12.0 Volts
   (c) 11.3 Volts
   (d) 8.0 Volts

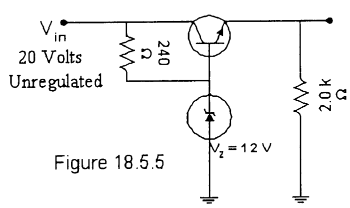

Figure 18.5.5

6. Figure 18.5.5 shows a series voltage regulator. Calculate the current through the Zener diode for the circuit shown.
   (a) 50 mAmps
   (b) 33 mAmps
   (c) 83.33 mAmps
   (d) none of the above

7. Figure 18.5.7 shows an improved series voltage regulator. Calculate the output voltage for the circuit shown.
(a) 20.0 Volts
(b) 12.0 Volts
(c) 18.5 Volts
(d) 8.0 Volts

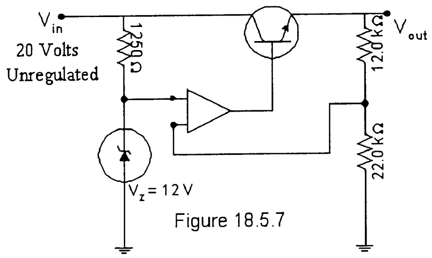

Figure 18.5.7

8. Figure 18.5.7 shows a series voltage regulator. Calculate the current through the Zener diode for the circuit shown.
(a) 9.6 mAmps
(b) 16 mAmps
(c) 6.4 mAmps
(d) 14.8 mAmps

9. Figure 18.5.9 shows an improved series voltage regulator with current limit circuit protection. Calculate the approximate output current when the circuit triggers the short circuit protection.
(a) 0.5 Amps
(b) 8 Amps
(c) 5.33 Amps
(d) 13.33 Amps

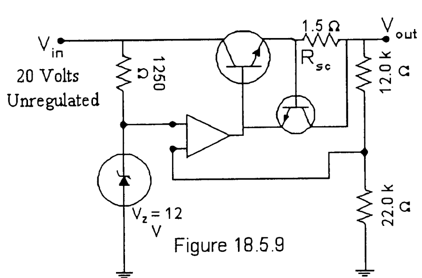

Figure 18.5.9

10. Figure 18.5.9 shows an improved series voltage regulator with current limit circuit protection. Calculate the approximate load resistance that the voltage regulator can drive before the circuit triggers the current limit circuit protection.
(a) 40 K ohms and more
(b) 400 ohms and more
(c) 40 ohms and more
(d) 37 ohms and less

11. Figure 18.5.9 shows an improved series voltage regulator with current limit circuit protection. Calculate the approximate resistance $R_{SC}$ required to provide current limit circuit protection at the 0.75 Amps level.
    (a) 0.5 ohms
    (b) 0.75 ohms
    (c) 1.0 ohms
    (d) 0.93 ohms

12. A shunt voltage regulator is shown in Figure 18.5.12. What is the output voltage that the load will see?
    (a) 10 Volts
    (b) 8.2 Volts
    (c) 20 Volts
    (d) 8.9 Volts

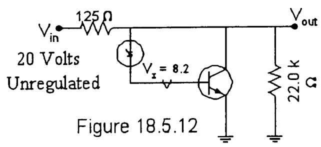

Figure 18.5.12

13. A shunt voltage regulator is shown in Figure 18.5.12. What is the minimum load resistance that the voltage regulator can drive without dropping out of regulation?
    (a) 10000 ohms
    (b) 1000 ohms
    (c) 100 ohms
    (d) 10 ohms

14. A three terminal voltage regulator affords several different types of protection. They are ______.
    (a) short circuit protection
    (b) thermal shut down protection
    (c) all of the above

15. A three terminal voltage regulator drops out of regulation if the difference between the input voltage and the expected regulated output voltage is less than ____.
    (a) 10% expected regulated output voltage
    (b) 90% expected regulated output voltage
    (c) 2.0 Volts
    (d) the input and the expected output voltage can be exactly same

16. A rectifier is used to:
    (a) convert ac to pulsating dc
    (b) reduce the variations in a pulsating dc signal
    (c) maintain a constant power supply dc output voltage
    (d) convert one dc level to another

17. The basic power supply is made up of:
    (a) a regulator, a follower, and a rectifier
    (b) a filter, a follower, and a regulator
    (c) a rectifier, a filter, and a regulator
    (d) none of the above

18. A voltage regulator:
    (a) maintains a constant power supply dc output voltage
    (b) limits the primary voltage of a power supply transformer
    (c) reduces the power supply ripple output voltage
    (d) none of the above

19. The ideal voltage regulator maintains a constant dc output voltage regardless of changes in:
    (a) its input voltage
    (b) its output voltage demand
    (c) its load current demand
    (d) either its load current demand or its input voltage

20. The term full load means:
    (a) load resistance is at a maximum value
    (b) load resistance is at a minimum value
    (c) no load resistance is present
    (d) load current is at a minimum value

21. A rectified dc voltage was measured with both an ac and a dc voltmeter. It was found that Vdc = 50 V and Vac = 2.16 $V_{rms}$. What was the percent ripple?
    (a) 6%
    (b) 4.32%
    (c) 0.432%
    (d) 0.86%

22. A voltage regulator is rated for an output current range of $I_L$ = 0 to 40 mA. Under no-load conditions the output voltage from the circuit is 4 Vdc. Under full-load conditions, the output voltage from the circuit is 3.984 Vdc. What is the percent load regulation of the circuit?
    (a) 400%
    (b) 2.5%
    (c) 0.4%
    (d) none of the above

23. The ideal line percent regulation rating is:
    (a) 100%
    (b) 75%
    (c) 50%
    (d) zero

24. The _________ the percent load regulation rating of a voltage regulator, the higher the quality of the circuit.
    (a) lower
    (b) higher
    (c) larger the change in
    (d) none of the above

25. A voltage regulator has a dc supply voltage of 50 V when the output is unloaded. When a load is connected the output voltage is 46 V. What is the percent regulation?
(a) 4%
(b) 8.7%
(c) 92%
(d) none of the above

26. A capacitive filter is added to a half-wave rectifier. The initial value of capacitance is 22 μF. If this value is increased to 100 μF, the ripple output from the circuit will:
(a) increase
(b) decrease
(c) remain the same
(d) cannot be predicted

27. A filtered rectifier has a 15 Vdc output with 100 $mV_{PP}$ of ripple. The peak output voltage for the circuit is:
(a) 15.1 VPK
(b) 14.9 VPK
(c) 15.05 VPK
(d) 47.2 VPK

28. A capacitive filter is added to a full-wave rectifier. The value of capacitance is 22 μF. If the circuit $R_L$ = 1000 ohms, what is the circuit's ripple factor r?
(a) 15.2%
(b) 12.7%
(c) 10.9%
(d) cannot be determined from the information given

29. Calculate the ripple of a capacitor filter for a peak rectified voltage of 40 V, a capacitor of 80 MF and a 100 mA load current.
(a) 2.84%
(b) 4.3%
(c) 8.33%
(d) 10.24%

30. Calculate the percent ripple for a RC filter if the inputs are Vdc = 150 V, $V_{r(rms)}$ = 15 V. The filter components are $C_1 = C_2$ = 50 MF, R = 500 ohms and $R_L$ = 5 K ohms.
(a) 0.572%
(b) 0.884%
(c) 1.27%
(d) 4.39%

31. The reduction of the ac component of the output voltage is due to the __________ __________ action of the RC filter sections.
(a) voltage gain
(b) voltage divider
(c) current gain
(d) current divider
(e) none of the above

32. Shunt voltage regulators require:
    (a) shorted-load protection
    (b) load voltage sampling
    (c) high-frequency protection
    (d) open-load protection

33. Which of the following is not a type of voltage regulator?
    (a) Fixed negative
    (b) Adjustable
    (c) Variable polarity
    (d) Fixed positive

34. The ability of an IC voltage regulator to attenuate any input ripple voltage is called its ________ rating.
    (a) ripple attenuation
    (b) ripple reduction
    (c) ripple rejection ratio in db
    (d) ripple elimination

1. Answer: (d) Difficulty: 2 Section: 1 Objective: 1
2. Answer: ripple Difficulty: 2 Section: 2 Objective: 1
3. Answer: Voltage regulation Difficulty: 2 Section: 2 Objective: 1
4. Answer: (c) Difficulty: 2 Section: 2 Objective: 1
5. Answer: (c) Difficulty: 2 Section: 5 Objective: 1
6. Answer: (b) Difficulty: 2 Section: 5 Objective: 1
7. Answer: (c) Difficulty: 2 Section: 5 Objective: 1
8. Answer: (c) Difficulty: 2 Section: 5 Objective: 1
9. Answer: (a) Difficulty: 2 Section: 5 Objective: 1
10. Answer: (d) Difficulty: 2 Section: 5 Objective: 1
11. Answer: (d) Difficulty: 2 Section: 5 Objective: 1
12. Answer: (d) Difficulty: 2 Section: 5 Objective: 1
13. Answer: (d) Difficulty: 2 Section: 5 Objective: 1
14. Answer: (c) Difficulty: 2 Section: 6 Objective: 1
15. Answer: (c) Difficulty: 2 Section: 6 Objective: 1
16. Answer: (a) Difficulty: 2 Section: 1 Objective: 1
17. Answer: (c) Difficulty: 2 Section: 2 Objective: 1
18. Answer: (d) Difficulty: 2 Section: 3 Objective: 1
19. Answer: (d) Difficulty: 2 Section: 4 Objective: 1
20. Answer: (b) Difficulty: 2 Section: 1 Objective: 2
21. Answer: (b) Difficulty: 2 Section: 2 Objective: 2
22. Answer: (c) Difficulty: 2 Section: 3 Objective: 2
23. Answer: (d) Difficulty: 2 Section: 4 Objective: 2
24. Answer: (a) Difficulty: 2 Section: 6 Objective: 2
25. Answer: (b) Difficulty: 2 Section: 7 Objective: 2

26. Answer: (b) Difficulty: 2 Section: 1 Objective: 3

27. Answer: (c) Difficulty: 2 Section: 2 Objective: 3

28. Answer: (c) Difficulty: 2 Section: 3 Objective: 3

29. Answer: (c) Difficulty: 2 Section: 4 Objective: 3

30. Answer: (a) Difficulty: 2 Section: 1 Objective: 4

31. Answer: (b) Difficulty: 2 Section: 2 Objective: 4

32. Answer: (b) Difficulty: 2 Section: 1 Objective: 5

33. Answer: (c) Difficulty: 2 Section: 1 Objective: 6

34. Answer: (c) Difficulty: 2 Section: 2 Objective: 6

# Chapter 19: Other Two-Terminal Devices

## *SHORT ANSWER*

1. We have studied the regular and the Zener diode. They are made from a PN junction. Some other devices that are formed from a PN junction are _____, _____, _____, ______ and _____.

2. With no external applied voltage, the surface barrier formed in a 'Hot Carrier Diode' is formed by ______ _____ in the metal at the boundary of the metal and the semiconductor junction.

3. The application of a forward bias will reduce the surface barrier and the result is a heavy flow of electrons in a 'Hot-Carrier diode'. The current produced by this heavy flow of electrons is _____ than the current in a regular diode at the same applied bias.

## *MULTIPLE CHOICE*

4. The commonly used symbol for a 'Hot-Carrier' diode is:
   (a) See graph I
   (b) See graph II
   (c) See graph III
   (d) See graph IV

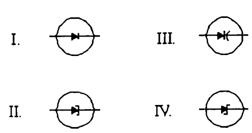


Figure 19.1.4

5. The capacitance of a varactor diode depends on ________.
   (a) area of the depletion region
   (b) width of the depletion region
   (c) the permittivity of the semiconductor material
   (d) all of the above

6. As the reverse bias potential across a varactor diode increases, the transition capacitance will ________.
   (a) decrease
   (b) increase
   (c) remain the same
   (d) increase exponentially

7. The most frequent use of power diodes occurs in the ________ process.
   (a) rectification
   (b) high frequency control
   (c) high voltage operation
   (d) low voltage operation

8. The most unique feature of the characteristics of the Tunnel diode is:
   (a) very low positive resistance region
   (b) very high positive resistance region
   (c) negative resistance region
   (d) almost zero break down voltage implying almost non-existent depletion region

9. Optical-electronic devices are generally classified as:
   (a) optical couplers or optical isolators
   (b) optically discrete or optically integrated
   (c) optical emitters or optical detectors
   (d) optical diodes or optical transistors

10. The photo-diode characteristics show equal spacing between the diode current curves for an equal increase in *photon* energy. So a graph of radiant flux versus diode current will be _________.
   (a) an exponential relationship
   (b) a parabolic relationship
   (c) a linear relationship
   (d) a square relationship

11. The resistance of the photo-conductive device will vary with the intensity of the incident light. The relationship between the resistance and the light intensity is ________.
   (a) an exponential relationship
   (b) a parabolic relationship
   (c) a linear relationship
   (d) a square relationship

12. The Liquid Crystal Display (LCD) has power dissipation on the order of:
   (a) Watts
   (b) millie-Watts
   (c) micro-Watts
   (d) none of the above

13. The *field effect* or *twisted neumatic* Liquid Crystal Display (LCD) require a/an:
   (a) constant current applied for the light to be seen by the viewer
   (b) constant voltage applied for the light to be seen by the viewer
   (c) alternating current applied for the light to be seen by the viewer
   (d) alternating voltage applied for the light to be seen by the viewer

14. A typical solar cell has an efficiency of approximately:
   (a) 1 - 3%
   (b) 10 - 12%
   (c) 25 - 30%
   (d) 75 - 80%

15. A thermistor is a temperature sensitive semiconductor resistor that has:
   (a) negative temperature coefficient
   (b) positive temperature coefficient
   (c) negative temperature coefficient at low temperature, positive temperature coefficient at high temperature
   (d) a temperature coefficient that may be either positive or negative

16. The Schottky diode is used for:
    (a) very high frequency applications
    (b) low noise applications
    (c) low voltage/high current power supplies
    (d) all of the above

17. In the Schottky diode the injected carriers have a very high kinetic energy level compared to the electrons of the metal; as a result the device is called a/an __________ diode.
    (a) junction
    (b) energy
    (c) hot-carrier
    (d) none of the above

18. The varactor acts as a:
    (a) current-controlled capacitance when forward biased
    (b) voltage-controlled capacitance when forward biased
    (c) current-controlled capacitance when reverse biased
    (d) voltage-controlled capacitance when reverse biased

19. The capacitance of a varactor is:
    (a) inversely proportional to the permittivity of the semiconductor material
    (b) directly proportional to the width of the depletion layer
    (c) inversely proportional to the amount of diode reverse voltage
    (d) none of the above

20. A varactor with a high capacitance ratio (CR) rating would be well suited for:
    (a) fine tuning applications
    (b) course tuning applications
    (c) crystal-controlled oscillator applications
    (d) extremely high-Q applications

21. A tuned amplifier contains a 2.2 mH inductor in its tank circuit, along with a varactor with the following ratings: $CT_i$ = 80 pf when $V_R$ = 3 Vdc and $C_R$ = 3 for $V_R$ = 3 Vdc to 6 Vdc. What is the resonant frequency of the circuit when $V_R$ = 3 Vdc?
    (a) 904.3 kHz
    (b) 758.7 kHz
    (c) 379.4 kHz
    (d) 189.9 kHz

22. A tuned amplifier contains a 2.2 mH inductor in its tank circuit, along with a varactor with a CT = 80 pf when $V_R$ = 3 Vdc and $C_R$ = 3 for $V_R$ = 3 Vdc to Vdc. What is the resonant frequency of the circuit when V = 6 Vdc?
    (a) 599.8 kHz
    (b) 479.9 kHz
    (c) 219.0 kHz
    (d) 1.20 MHz

23. Power diodes are constructed using silicon because of its:
    (a) higher current
    (b) higher temperature capacity
    (c) higher PIV
    (d) all of the above

24. The tunnel diode is a:
    (a) lightly doped diode that greatly reduces the depletion region
    (b) lightly doped diode that greatly increases the depletion region
    (c) heavily doped diode that greatly reduces the depletion region
    (d) heavily doped diode that greatly increases the depletion region

25. The tunnel diode region of operation between $V_P$ and $V_V$ is called the:
    (a) constant resistance region
    (b) constant current region
    (c) negative resistance region
    (d) negative current region

26. The tunnel diode is often used as the active device in:
    (a) constant resistance amplifiers
    (b) negative resistance oscillators
    (c) negative current rectifiers
    (d) negative resistance linear amplifiers

27. Optoelectronic devices are generally classified as being either:
    (a) couplers or isolators
    (b) discrete or integrated
    (c) emitters or detectors
    (d) input or output devices

28. The typical infrared-emitting diode has a radiant flux versus dc current curve that is:
    (a) an exponential relationship
    (b) a square relationship
    (c) an almost linear relationship
    (d) none of the above

29. The Liquid-Crystal Display (LCD) has power dissipation on the order of:
    (a) Watts
    (b) milli-Watts
    (c) micro-Watts
    (d) none of the above

30. LCDs require a/an:
    (a) constant current
    (b) constant voltage
    (c) large heat sink
    (d) internal light source

31. LCDs are limited to a temperature range of:
    (a) 0 to 10 degrees C
    (b) 0 to 60 degrees C
    (c) 0 to 100 degrees C
    (d) 30 to 100 degrees C

32. LCDs degrade:
    (a) chemically
    (b) quickly
    (c) in a dry place
    (d) all of the above

33. Typical solar cell efficiency is:
    (a) 1%
    (b) 10%
    (c) 30%
    (d) 70%

34. The most widely used material for solar cells are ________.
    (a) selenium and silicon
    (b) indium arsenide and gold
    (c) gallium arsenide and cadmium sulfide
    (d) none of the above

35. A typical four solar cell array can deliver ________ Watts of power.
    (a) 20 mW
    (b) 10.7 mW
    (c) 5.83 mW
    (d) 4.16 mW

36. A thermistor is a temperature-sensitive semiconductor resistor that has ________ PN junctions.
    (a) zero
    (b) one
    (c) two
    (d) three

1. Answer: Schottky Diode; Tunnel Diode; Varactor Diode; Solar Cell; Photo Cell
   Difficulty: 2 Section: 1 Objective: 1
2. Answer: Negative Wall Difficulty: 2 Section: 2 Objective: 1
3. Answer: higher Difficulty: 2 Section: 2 Objective: 1
4. Answer: (d) Difficulty: 2 Section: 2 Objective: 1
5. Answer: (d) Difficulty: 2 Section: 3 Objective: 1
6. Answer: (a) Difficulty: 2 Section: 3 Objective: 1
7. Answer: (a) Difficulty: 2 Section: 4 Objective: 1
8. Answer: (c) Difficulty: 2 Section: 5 Objective: 1
9. Answer: (c) Difficulty: 2 Section: 6 Objective: 1
10. Answer: (c) Difficulty: 2 Section: 6 Objective: 1
11. Answer: (c) Difficulty: 2 Section: 7 Objective: 1
12. Answer: (c) Difficulty: 2 Section: 9 Objective: 1
13. Answer: (b) Difficulty: 2 Section: 9 Objective: 1
14. Answer: (b) Difficulty: 2 Section: 10 Objective: 1
15. Answer: (b) Difficulty: 2 Section: 10 Objective: 1
16. Answer: (c) Difficulty: 2 Section: 1 Objective: 2
17. Answer: (c) Difficulty: 2 Section: 2 Objective: 2
18. Answer: (d) Difficulty: 2 Section: 1 Objective: 3
19. Answer: (c) Difficulty: 2 Section: 2 Objective: 3
20. Answer: (b) Difficulty: 2 Section: 3 Objective: 3
21. Answer: (c) Difficulty: 2 Section: 4 Objective: 3
22. Answer: (c) Difficulty: 2 Section: 5 Objective: 3
23. Answer: (d) Difficulty: 2 Section: 1 Objective: 4
24. Answer: (c) Difficulty: 2 Section: 1 Objective: 5

25. Answer: (c) Difficulty: 2 Section: 2 Objective: 5

26. Answer: (b) Difficulty: 2 Section: 3 Objective: 5

27. Answer: (c) Difficulty: 2 Section: 1 Objective: 8

28. Answer: (c) Difficulty: 2 Section: 2 Objective: 8

29. Answer: (c) Difficulty: 2 Section: 1 Objective: 9

30. Answer: (c) Difficulty: 2 Section: 2 Objective: 9

31. Answer: (b) Difficulty: 2 Section: 3 Objective: 9

32. Answer: (a) Difficulty: 2 Section: 4 Objective: 9

33. Answer: (b) Difficulty: 2 Section: 1 Objective: 10

34. Answer: (a) Difficulty: 1 Section: 2 Objective: 10

35. Answer: (d) Difficulty: 1 Section: 3 Objective: 10

36. Answer: (a) Difficulty: 2 Section: 1 Objective: 11

# Chapter 20: PNPN and Other Devices

## *MULTIPLE CHOICE*

1. Some of the popular applications of the Silicon Controlled Rectifier (SCR) are ______.
   (a) relay control, time delay circuits, and regulated power supplies
   (b) choppers, inverters, and battery chargers
   (c) static switches, heater controls, and phase controls
   (d) all of the above

2. Thyristors are electronic devices that act as a _______.
   (a) silicon controlled rectifier
   (b) unijunction transistor
   (c) gate turn off switch
   (d) all of the above

## *SHORT ANSWER*

3. The SCR cannot be turned off by simply removing the gate signal. Two general methods that are used to turn off an SCR are _____ and _____.

4. ________ is the value of the current below which the SCR switches from the conduction state to the blocking region under existing conditions.

## *MULTIPLE CHOICE*

5. One region of the SCR curve when it is forward biased represents the non-conducting region of operation. What is this region called?
   (a) forward turn off region
   (b) forward dropout region
   (c) forward blocking region
   (d) forward non-conduction region

6. A Silicon Controlled Switch (SCS) like the SCR is a four-layer device. The characteristics of the SCS are also essentially the same as those of the SCR. The SCR can be turned off by applying a/an:
   (a) opposite level pulse to the anode gate
   (b) a low-level pulse on the cathode gate terminal
   (c) essential short-circuits from anode to cathode
   (d) all of the above

7. Figure 20.1.7 shows the circuit diagram used for a SCS is:
   (a) See graph I
   (b) See graph II
   (c) See graph III
   (d) See graph IV

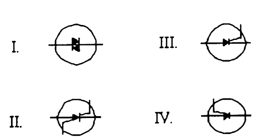


Figure 20.1.7

8. Figure 20.1.9 shows the circuit diagram used for a Gate Turn-off Switch (GTO) is:
   (a) See graph I
   (b) See graph II
   (c) See graph III
   (d) See graph IV

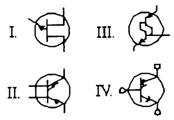

Figure 20.1.9

9. One of the very important characteristics of the GTO is:
   (a) improved current handling characteristics
   (b) improved noise characteristics
   (c) improved blocking region characteristics
   (d) improved turn-off time

10. The LASCR is a device that can be turned on by:
   (a) noise intensity of dB level
   (b) harmonic content of the signal present at the gate
   (c) light intensity
   (d) wavelength of the light input

11. The ____ is generally used to trigger the SCR.
   (a) PUT
   (b) UJT
   (c) Diac
   (d) Shockley diode

12. A TIAC is a ______ switching device.
   (a) bilateral
   (b) unilateral
   (c) multi-lateral
   (d) trilateral

13. The UJT's are commonly used as:
   (a) breakover devices
   (b) amplifiers
   (c) tuned oscillators
   (d) thyristor triggering devices

14. A sample relaxation oscillator using the UJT's is shown in Figure 20.1.15. Determine the frequency of oscillation.
    (a) 18 Hz
    (b) 180 Hz
    (c) 218 Hz
    (d) 82 Hz

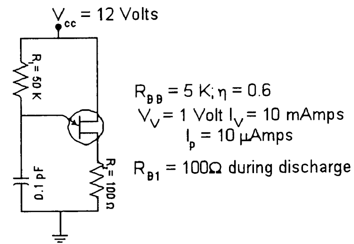

Figure 20.1.15

15. Thyristors are electronic devices that act as a:
    (a) silicon-controlled switch
    (b) silicon-controlled rectifier
    (c) unijuction transistor
    (d) all of the above

16. The Pnpn device that is of greatest interest today is the:
    (a) TRIAC
    (b) SCR
    (c) PUT
    (d) DIAC

17. Silicon was chosen for the construction of the SCR because of its:
    (a) high frequency characteristics
    (b) switching speed characteristics
    (c) temperature and power capabilities
    (d) all of the above

18. Anode-current interruption and forced-commutation are the two methods that are used to _________ an SCR.
    (a) turn off
    (b) turn on
    (c) hold on
    (d) none of the above

19. The silicon-controlled rectifier (SCR) is forced into forward conduction when $V_F$ exceeds the _________ rating of the device.
    (a) forward conducting voltage
    (b) forward breakover voltage
    (c) forward trigger voltage
    (d) forward breakdown voltage

20. Once an SCR is forced into forward conduction, it continues to conduct until $I_F$ drops below the _________ rating of the device.
    (a) minimum forward current
    (b) forward breakover current
    (c) holding current
    (d) dropout current

21. What are the two methods that are commonly used to return an SCR to its nonconducting state?
    (a) anode current interruption and forced commutation
    (b) current holding and forced commutation
    (c) anode current interruption and current holding
    (d) forced commutation and current dropout

22. The region of the SCR forward operating curve that represents the nonconducting region of operation is called the:
    (a) forward off-state region
    (b) forward blocking region
    (c) forward dropout region
    (d) none of the above

23. Which of the following distinguishes the silicon-controlled rectifier (SCR) from the SCS?
    (a) The SCS has a fourth terminal, called the anode gate.
    (b) The SCS is driven into cutoff using entirely different methods.
    (c) The SCS has less means of being forced into its forward conducting state.
    (d) All of the above.

24. The forward operating curve of the SCR is identical to that for the:
    (a) SCS
    (b) GTO
    (c) DIAC
    (d) TIAC

25. The silicon controlled switch has two _________.
    (a) anodes
    (b) cathodes
    (c) gates
    (d) none of the above

26. Which of the following devices can be driving into its conducting or nonconducting state by applying the proper pulse to its gate terminal?
    (a) the Shockley diode
    (b) the SBS
    (c) the GTO device
    (d) the TRIAC

27. The LASCR is a device whose state is controlled by:
    (a) light intensity
    (b) spectral wavelength
    (c) light amplitude
    (d) the light-area product

28. Which of the following devices acts as an SCR with _________ $I_G = 0$?
    (a) the Shockley diode
    (b) the SBS
    (c) the GTO device
    (d) the TRIAC

29. The primary difference between the DIAC and the SCS is the fact that:
    (a) the DIAC has a higher maximum power dissipation rating
    (b) the SCS is capable of conducting in only one direction
    (c) the DIAC is no longer used in any practical applications
    (d) the SCS requires the use of a snubber

30. A TIAC is a _________ switching device.
    (a) bilateral
    (b) unilateral
    (c) multilateral
    (d) trilateral

31. The _________ is commonly used to control SCR triggering.
    (a) UJT
    (b) DIAC
    (c) SCR
    (d) JFET

32. A UJT has the following values: n = 0.72 (maximum) and $V_{EBB}$ = 12 V. What is the maximum value of $V_{EB1}$ required to trigger the device into conduction?
    (a) 8.64 V
    (b) 17.4 V
    (c) 12 V
    (d) 9.34 V

33. UJTs are commonly used as:
    (a) breakover devices
    (b) amplifiers
    (c) thyristor triggering devices
    (d) tuned oscillators

34. A PUT has a value of $V_{GK}$ = +8 V. What value of $V_{AK}$ is needed to trigger the device into conduction?
    (a) -8.7 V
    (b) +16.7 V
    (c) +8.7 V
    (d) cannot be determined from the information given

35. Which of the following devices is actually an integrated circuit rather than a single discrete component?
    (a) the SIDAC
    (b) the OPTD ISOLATOR
    (c) the GTO device
    (d) the triac

1. Answer: (d) Difficulty: 2 Section: 2 Objective: 1
2. Answer: (d) Difficulty: 2 Section: 2 Objective: 1
3. Answer: anode current interruption; forced communication
   Difficulty: 2 Section: 5 Objective: 1
4. Answer: Holding current Difficulty: 2 Section: 4 Objective: 1
5. Answer: (c) Difficulty: 2 Section: 4 Objective: 1
6. Answer: (d) Difficulty: 2 Section: 7 Objective: 1
7. Answer: (c) Difficulty: 2 Section: 7 Objective: 1
8. Answer: (d) Difficulty: 2 Section: 8 Objective: 1
9. Answer: (d) Difficulty: 2 Section: 8 Objective: 1
10. Answer: (c) Difficulty: 2 Section: 9 Objective: 1
11. Answer: (c) Difficulty: 2 Section: 11 Objective: 1
12. Answer: (a) Difficulty: 2 Section: 12 Objective: 1
13. Answer: (d) Difficulty: 2 Section: 13 Objective: 1
14. Answer: (d) Difficulty: 2 Section: 13 Objective: 1
15. Answer: (d) Difficulty: 2 Section: 1 Objective: 1
16. Answer: (b) Difficulty: 1 Section: 1 Objective: 2
17. Answer: (b) Difficulty: 1 Section: 1 Objective: 3
18. Answer: (a) Difficulty: 2 Section: 2 Objective: 3
19. Answer: (b) Difficulty: 2 Section: 1 Objective: 4
20. Answer: (c) Difficulty: 2 Section: 2 Objective: 4
21. Answer: (a) Difficulty: 2 Section: 3 Objective: 4
22. Answer: (b) Difficulty: 2 Section: 4 Objective: 4
23. Answer: (d) Difficulty: 2 Section: 1 Objective: 7
24. Answer: (a) Difficulty: 2 Section: 2 Objective: 7

25. Answer: (c) Difficulty: 2 Section: 3 Objective: 7

26. Answer: (c) Difficulty: 2 Section: 1 Objective: 8

27. Answer: (a) Difficulty: 2 Section: 1 Objective: 9

28. Answer: (a) Difficulty: 2 Section: 1 Objective: 10

29. Answer: (b) Difficulty: 2 Section: 1 Objective: 11

30. Answer: (a) Difficulty: 2 Section: 1 Objective: 12

31. Answer: (a) Difficulty: 2 Section: 1 Objective: 13

32. Answer: (d) Difficulty: 2 Section: 2 Objective: 13

33. Answer: (c) Difficulty: 2 Section: 3 Objective: 13

34. Answer: (c) Difficulty: 2 Section: 1 Objective: 16

35. Answer: (b) Difficulty: 2 Section: 2 Objective: 16

# Chapter 21: Oscilloscope and Other Measuring Devices

## *MULTIPLE CHOICE*

1. A Cathode Ray Oscilloscope (CRO) is used to provide a ______ of any input signal.
   (a) harmonic display
   (b) periodic display
   (c) spectral content display
   (d) visual display

2. A CRO can be built so that it will display signals from ________.
   (a) dc to a few kilohertz
   (b) dc to a few hundred kilohertz
   (c) dc to a few megahertz
   (d) dc to a few hundred megahertz

## *SHORT ANSWER*

3. The number of electrons that are freed at any time controls the intensity of the beam seen on the Cathode Ray Tube (CRT). These electrons are released from a cathode containing an oxide coating indirectly _____ by a filament.

## *MULTIPLE CHOICE*

4. The waveform is displayed on the face of the oscilloscope by an electron beam that is deflected __________ by a sweep voltage, and _______ by a the voltage to be measured.
   (a) horizontally; vertically
   (b) vertically; horizontally
   (c) horizontally; horizontally
   (d) vertically; vertically

5. To view a signal on the CRT face it is necessary to deflect the beam across the CRT with a horizontal sweep signal so that any variation of the vertical signal can be observed. This horizontal sweep signal has a ______ waveform.
   (a) saw tooth
   (b) triangular
   (c) square
   (d) sine

6. If the period on the input signal is 5 mSec and the period of the horizontal sweep signal is 15 mSec, then how many complete cycles of the input signal will be visible on the CRT screen?
   (a) One
   (b) Two
   (c) Three
   (d) Four

7. To see a steady display each time the beam sweeps across the face of the tube, it is necessary to start the sweep at the same point in the input cycle. This can be done from various trigger sources. They are ____.
   (a) internal
   (b) external
   (c) line
   (d) all of the above

8. Most modern oscilloscopes provide for viewing two or more traces on the scope face at the same time. The methods for displaying two traces at the same time are _______ and _______.
   (a) chopped; added
   (b) alternate; added
   (c) added; periodic
   (d) chopped; alternate

9. Calculate the peak-to-peak voltage of the signal shown in Figure 21.1.9.
   (a) 20 mVolts
   (b) 25 mVolts
   (c) 26 mVolts
   (d) 30 mVolts

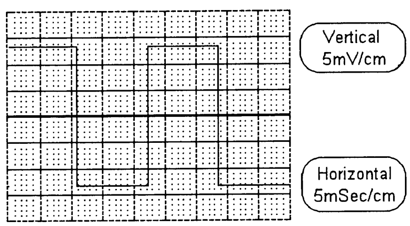


Figure 21.1.9

10. Calculate the period of the signal shown in Figure 21.1.9.
   (a) 20 mSec
   (b) 25 mSec
   (c) 26 mSec
   (d) 30 mSec

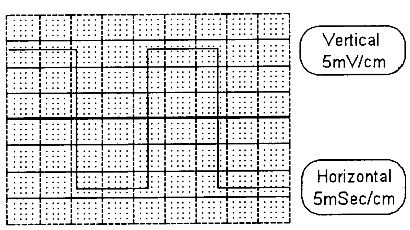


Figure 21.1.9

11. Other then measuring the amplitude and the period, many other measurements can be made with the oscilloscope. Some of these measurements are _________.
   (a) frequency
   (b) pulse width
   (c) pulse delay
   (d) all of the above

12. The precision waveform generator IC 8038 is capable of producing highly accurate ________ waveform.
(a) square
(b) sine
(c) triangle
(d) all of the above

13. The precision waveform generator IC 8038 is shown in a circuit in Figure 21.1.13. Determine the lowest frequency of oscillation.
(a) 27.27 Hz
(b) 30.00 Hz
(c) 300 Hz
(d) cannot determine from the information given

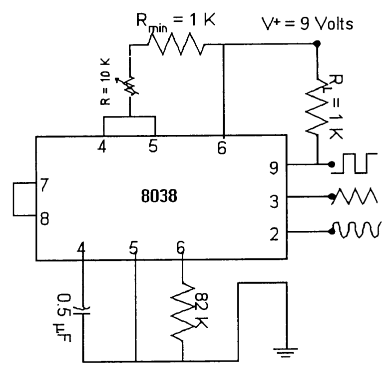


Figure 21.1.13

14. The precision waveform generator IC 8038 is shown in a circuit in Figure 21.1.13. Determine the highest frequency of oscillation.
(a) 27.27 Hz
(b) 30.00 Hz
(c) 300 Hz
(d) cannot determine from the information given

15. The precision waveform generator IC 8038 is shown in a circuit in Figure 21.1.13. What function does the 1KΩ resistor $R_L$ serve?
(a) It is the load resistor.
(b) It is the pull up resistor. The output waveform will rise and fall more quickly.
(c) It serves as the output impedance resistor for the function generator.
(d) It is the current limit resistor so the precision IC will not draw too much current.

16. The cathode ray oscilloscope (CRO) can be built to operate from ________.
(a) dc to hundreds of megahertz
(b) dc to 100 megahertz
(c) dc to 10 megahertz
(d) none of the above

17. The hart of the CRO is a device known as:
    (a) visual amplifier
    (b) crt
    (c) photoelectronic device
    (d) none of the above

18. The CRO's electronic beam is deflected _________ by the sweep circuit and _________ by voltage amplitude.
    (a) vertically; horizontally
    (b) horizontally; vertically
    (c) diagonally; up
    (d) none of the above

19. The process of CRO signal synchronization is called:
    (a) phase-locked loop
    (b) triggering
    (c) cycle latching
    (d) none of the above

20. The CRO has a natural advantage in the measurement of:
    (a) dc signals
    (b) ac signals
    (c) peak-to-peak and peak signals
    (d) all of the above

21. The CRO horizontal scale can be used to measure:
    (a) current
    (b) time
    (c) persistence
    (d) all of the above

22. The CRO vertical scale can be used to measure:
    (a) current
    (b) frequency
    (c) persistence
    (d) all of the above

23. The time interval between pulses is called the:
    (a) pulse width
    (b) rise-time
    (c) pulse delay
    (d) none of the above

1. Answer: (d) Difficulty: 2 Section: 1 Objective: 1
2. Answer: (d) Difficulty: 1 Section: 1 Objective: 1
3. Answer: heated Difficulty: 1 Section: 2 Objective: 1
4. Answer: (a) Difficulty: 2 Section: 3 Objective: 1
5. Answer: (a) Difficulty: 2 Section: 4 Objective: 1
6. Answer: (c) Difficulty: 1 Section: 4 Objective: 1
7. Answer: (d) Difficulty: 2 Section: 5 Objective: 1
8. Answer: (d) Difficulty: 2 Section: 6 Objective: 1
9. Answer: (c) Difficulty: 2 Section: 7 Objective: 1
10. Answer: (c) Difficulty: 2 Section: 7 Objective: 1
11. Answer: (d) Difficulty: 2 Section: 7 Objective: 1
12. Answer: (d) Difficulty: 2 Section: 9 Objective: 1
13. Answer: (a) Difficulty: 2 Section: 9 Objective: 1
14. Answer: (c) Difficulty: 2 Section: 9 Objective: 1
15. Answer: (b) Difficulty: 2 Section: 9 Objective: 1
16. Answer: (a) Difficulty: 2 Section: 1 Objective: 1
17. Answer: (b) Difficulty: 2 Section: 1 Objective: 2
18. Answer: (b) Difficulty: 2 Section: 1 Objective: 3
19. Answer: (b) Difficulty: 2 Section: 1 Objective: 5
20. Answer: (c) Difficulty: 2 Section: 1 Objective: 7
21. Answer: (b) Difficulty: 2 Section: 2 Objective: 7
22. Answer: (a) Difficulty: 2 Section: 3 Objective: 7
23. Answer: (c) Difficulty: 2 Section: 4 Objective: 7