Instructor's Resource Manual
to accompany

Electronic Devices and Circuit Theory

Tenth Edition

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Contents

Chapter 1

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

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

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

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

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

3. –

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

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

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

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

6.

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

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

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

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

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

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

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

12. –

13. –

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

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

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

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

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

18. (a)

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

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

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

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

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

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

21. From 1.19:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

(c) quite close

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

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

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

$R_{DC} >> r_d$

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

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

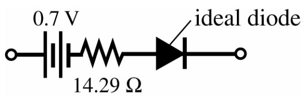
31. $I_D = 1$ mA, $r_d = 2\left(\frac{26 \text{ mV}}{I_D}\right) = 2(26\ \Omega) = \mathbf{52\ \Omega}$ vs 55 Ω (#30)

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

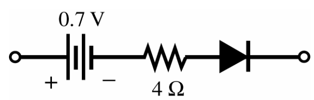
32. $r_{av} = \frac{\Delta V_d}{\Delta I_d} = \frac{0.9 \text{ V} - 0.6 \text{ V}}{13.5 \text{ mA} - 1.2 \text{ mA}} = \mathbf{24.4\ \Omega}$

33. $r_d = \frac{\Delta V_d}{\Delta I_d} \cong \frac{0.8\text{ V} - 0.7\text{ V}}{7\text{ mA} - 3\text{ mA}} = \frac{0.09\text{ V}}{4\text{ mA}} = \mathbf{22.5\ \Omega}$
(relatively close to average value of 24.4 Ω (#32))

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



35. Using the best approximation to the curve beyond $V_D = 0.7$ V:
$r_{av} = \frac{\Delta V_d}{\Delta I_d} \cong \frac{0.8\text{ V} - 0.7\text{ V}}{25\text{ mA} - 0\text{ mA}} = \frac{0.1\text{ V}}{25\text{ mA}} = \mathbf{4\ \Omega}$



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

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

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

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

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

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

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

39. $V_D = 0.2\text{ V}$, $C_D = 7.3\text{ pF}$

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

$V_D = -20\text{ V}$, $C_T = 0.9\text{ pF}$

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

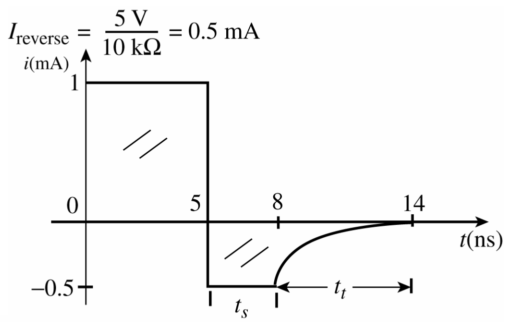
40. $I_f = \dfrac{10\text{ V}}{10\text{ k}\Omega} = 1\text{ mA}$

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

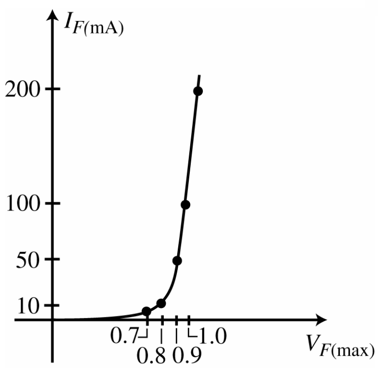
$t_s + 2t_s = 9\text{ ns}$

$t_s = \mathbf{3\ ns}$

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



41.



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

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

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

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

The change is significant.

60 nA: 0.5 nA = **120:1**

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

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

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

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

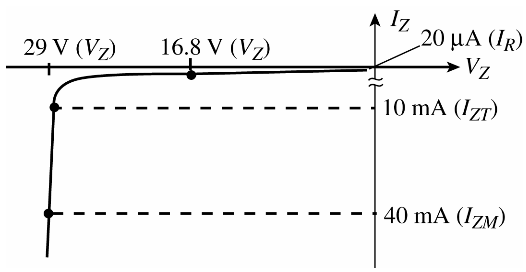
$$I_F = \frac{P_{\max}}{V_F} = \frac{500 \text{ mW}}{0.7 \text{ V}} = \mathbf{714.29 \text{ mA}}$$

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

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

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

48.



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

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

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

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

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

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

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

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

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

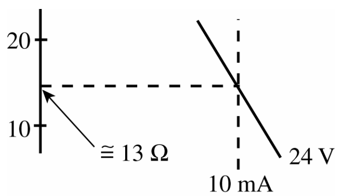
At $I_Z = 0.1$ mA, $T_C \cong 0.06\%/°\text{C}$

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

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

At $I_Z = 0.1$ mA, $T_C \cong$ **–0.025%/°C**

52.



53. 24 V Zener:

0.2 mA: ≅ **400 Ω**

1 mA: ≅ **95 Ω**

10 mA: ≅ **13 Ω**

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

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

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

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

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

@ 10 mA ≅ **1.02**

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

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

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

@ 35 mA ≅ **1.42**

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

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

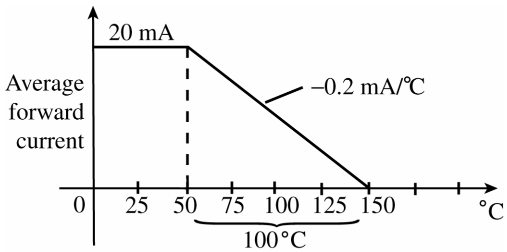
(c) For currents greater than about 30 mA the percent increase is significantly less than for increasing currents of lesser magnitude.

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

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

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

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



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

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

Chapter 2

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

6. (a) Diode forward-biased,

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

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

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

(b) Diode forward-biased,

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

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

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

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

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

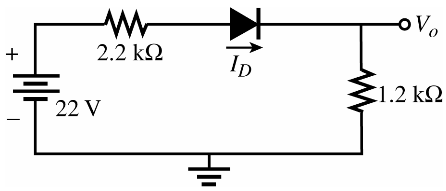
(b) $I = \dfrac{10\text{ V} + 2\text{ V} - 0.7\text{ V})}{1.2\text{ k}\Omega + 4.7\text{ k}\Omega} = \dfrac{11.3\text{ V}}{5.9\text{ k}\Omega} = 1.915\text{ mA}$

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

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

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

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



Diode forward-biased

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

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

(b) Diode forward-biased

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

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

9. (a) $V_{o_1} = 12 \text{ V} - 0.7 \text{ V} = \mathbf{11.3 \text{ V}}$
$V_{o_2} = \mathbf{0.3 \text{ V}}$

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

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

10. (a) Both diodes forward-biased

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

Assuming identical diodes:

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

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

(b) Right diode forward-biased:

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

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

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

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

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

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

12. Both diodes forward-biased:

$V_{o_1} = \mathbf{0.7\ V}$, $V_{o_2} = \mathbf{0.3\ V}$

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

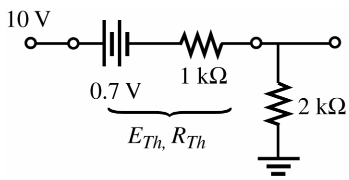
$$I_{0.47\,k\Omega} = \frac{0.7\text{ V} - 0.3\text{ V}}{0.47\text{ k}\Omega} = 0.851\text{ mA}$$

$I(\text{Si diode}) = I_{1\,k\Omega} - I_{0.47\,k\Omega}$

$= 19.3\text{ mA} - 0.851\text{ mA}$

$= \mathbf{18.45\ mA}$

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



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

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

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

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

$V_o = \mathbf{0\ V}$

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

16. Both diodes "on".

$V_o = \mathbf{0.7\ V}$

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

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

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

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

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

The result supports the above assumptions.

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

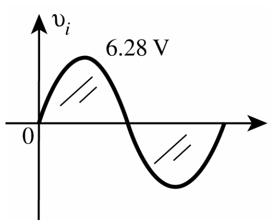
$V_o = \mathbf{+10\ V}$

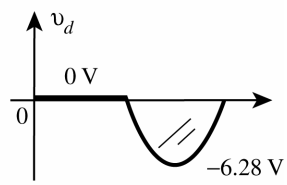
as established by 10 V supply connected to 1 kΩ resistor.

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

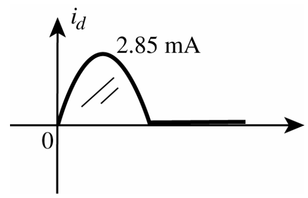
The result: $V_o = 5\text{ V} - 0.3\text{ V} = \mathbf{4.7\text{ V}}$
The result supports the above assumptions.

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

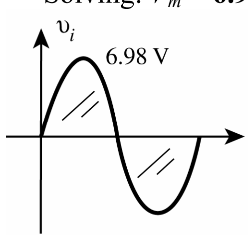


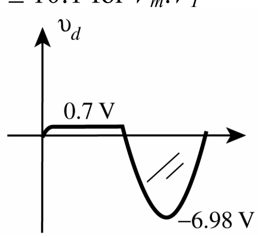


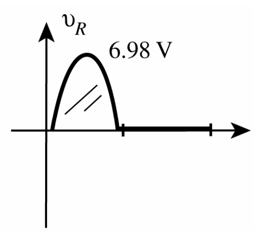
$I_m = \dfrac{V_m}{R} = \dfrac{6.28\text{ V}}{2.2\text{ k}\Omega} = \mathbf{2.85\text{ mA}}$

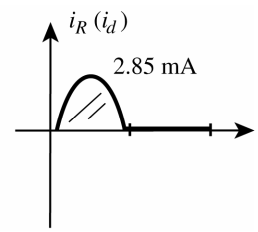


23. Using $V_{dc} \cong 0.318(V_m - V_T)$
$2\text{ V} = 0.318(V_m - 0.7\text{ V})$
Solving: $V_m = \mathbf{6.98\text{ V}} \cong 10{:}1$ for $V_m{:}V_T$

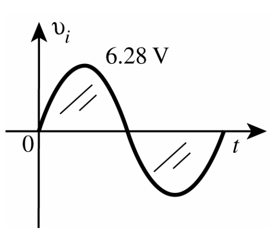


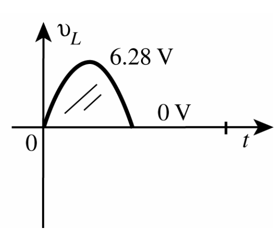




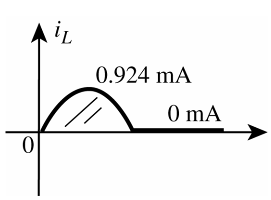


24. $V_m = \dfrac{V_{dc}}{0.318} = \dfrac{2\text{ V}}{0.318} = \mathbf{6.28\text{ V}}$



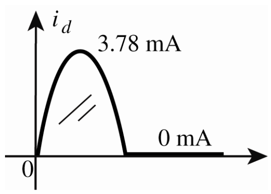


$I_{L_{max}} = \dfrac{6.28\text{ V}}{6.8\text{ k}\Omega} = \mathbf{0.924\text{ mA}}$

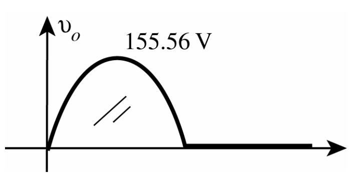


$I_{max}(2.2\ k\Omega) = \dfrac{6.28\ V}{2.2\ k\Omega} = \mathbf{2.855\ mA}$

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



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



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

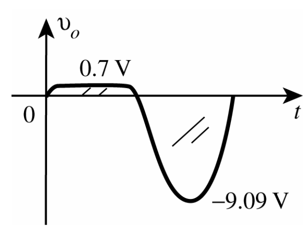
$$v_o = 0.7\ V = \frac{10\ k\Omega(v_i)}{10\ k\Omega + 1\ k\Omega}$$

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

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

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

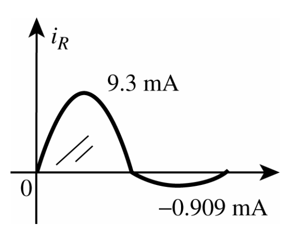
For $v_i = -10$ V:
$v_o = 0.909(-10\ V)$
$= \mathbf{-9.09\ V}$



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

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

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



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

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

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

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

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

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

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

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

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

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

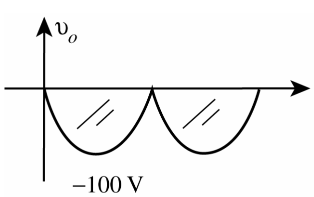
$V_{\text{dc}} = 0.636(168.3 \text{ V}) = \mathbf{107.04 \text{ V}}$

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

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

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

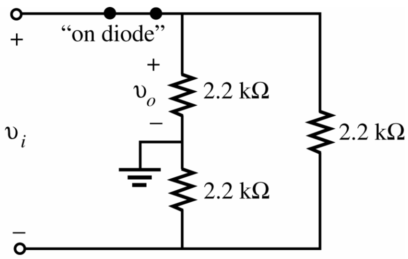
29.



PIV = **100 V**

30. Positive half-cycle of v_i:

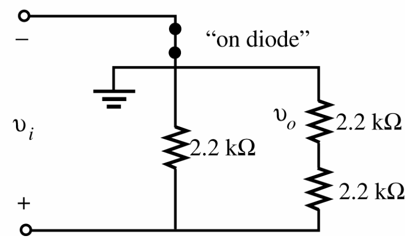
Network redrawn:



Voltage-divider rule:

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

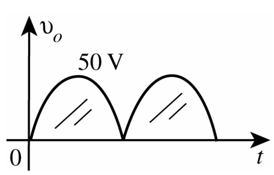
Negative half-cycle of υ_i:



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

Voltage-divider rule:

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



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

31. Positive pulse of v_i:

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

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

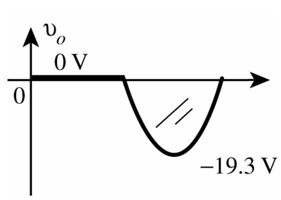
Negative pulse of v_i:

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

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

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

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



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

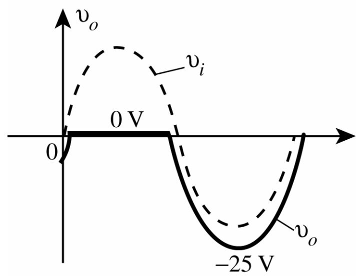
At $v_i = 5$ V

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

At $v_i = -20$ V

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

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

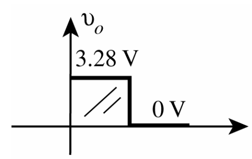


33. (a) Positive pulse of v_i:

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

Negative pulse of v_i:

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

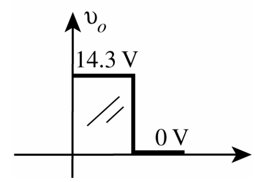


(b) Positive pulse of v_i:

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

Negative pulse of v_i:

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



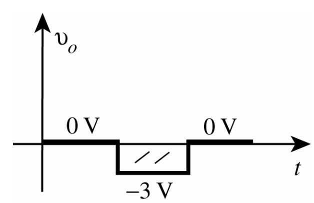
34. (a) For $v_i = 20$ V the diode is reverse-biased and $v_o = \mathbf{0\ V}$.

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

Applying Kirchhoff's voltage law in the clockwise direction:

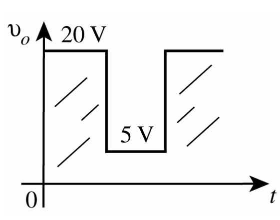
$$-5\text{ V} + 2\text{ V} - v_o = 0$$

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

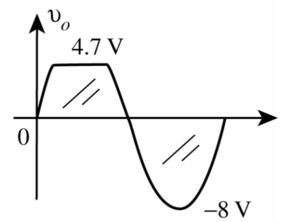


(b) For $v_i = 20$ V the 20 V level overpowers the 5 V supply and the diode is "on". Using the short-circuit equivalent for the diode we find $v_o = v_i = \mathbf{20\ V}$.

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



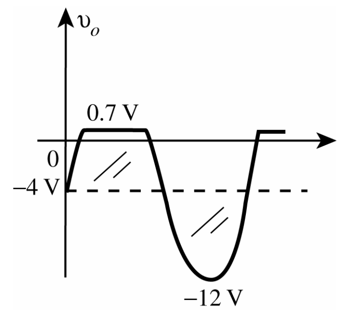
35. (a) Diode "on" for $v_i \geq 4.7$ V
For $v_i > 4.7$ V, $V_o = 4$ V + 0.7 V = **4.7 V**
For $v_i < 4.7$ V, diode "off" and $v_o = \boldsymbol{v_i}$



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

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

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

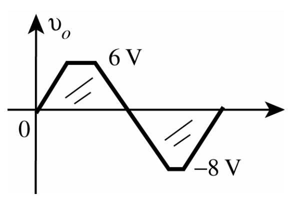


36. For the positive region of v_i:
The right Si diode is reverse-biased.
The left Si diode is "on" for levels of v_i greater than 5.3 V + 0.7 V = 6 V. In fact, v_o = **6 V** for $v_i \geq 6$ V.

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

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

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



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

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

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

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

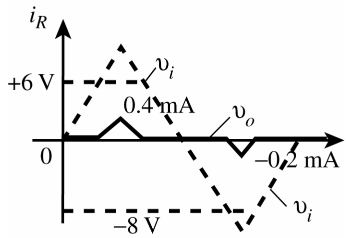
For $v_i \leq -8$ V

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

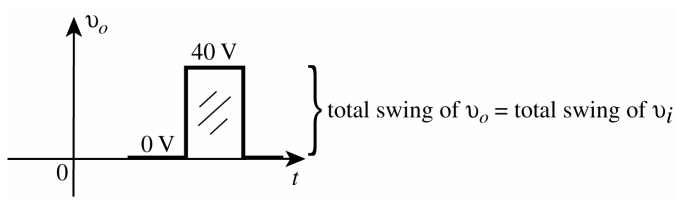
For $v_i = -10$ V

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

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

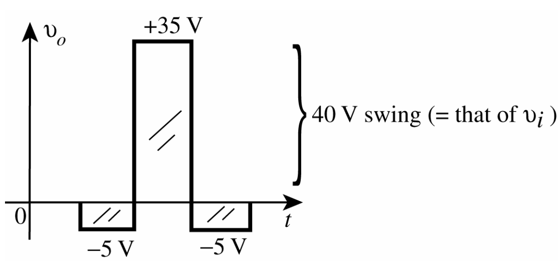


37. (a) Starting with $v_i = -20$ V, the diode is in the "on" state and the capacitor quickly charges to −20 V+. During this interval of time v_o is across the "on" diode (short-current equivalent) and $v_o = 0$ V.
When v_i switches to the +20 V level the diode enters the "off" state (open-circuit equivalent)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

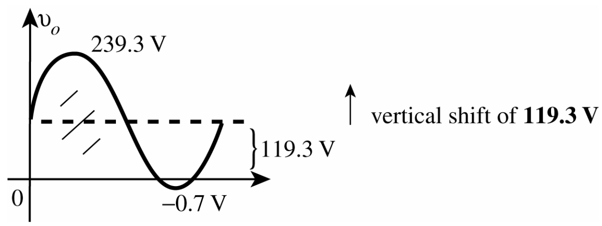


(b) Starting with $v_i = -20$ V, the diode is in the "on" state and the capacitor quickly charges up to −15 V+. Note that $v_i = +20$ V and the 5 V supply are additive across the capacitor. During this time interval v_o is across "on" diode and 5 V supply and $v_o = -5$ V.

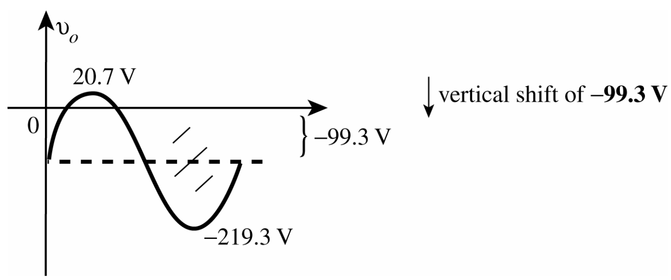
When v_i switches to the +20 V level the diode enters the "off" state and $v_o = v_i + v_C = 20\text{ V} + 15\text{ V} = 35\text{ V}$.



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



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



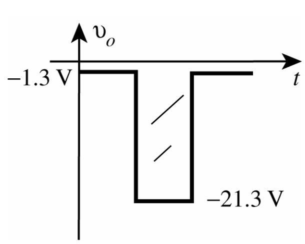
Using the ideal diode approximation the vertical shift of part (a) would be 120 V rather than 119.3 V and –100 V rather than –99.3 V for part (b). Using the ideal diode approximation would certainly be appropriate in this case.

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

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

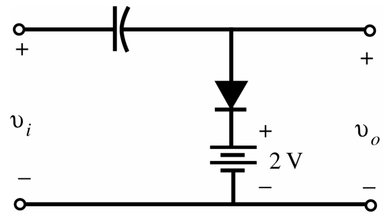
(c) Positive pulse of v_i:
Diode "on" and v_o = –2 V + 0.7 V = –1.3 V
Capacitor charges to 10 V + 2 V – 0.7 V = 11.3 V

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



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

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



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

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

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

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

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

(b) In the absence of the Zener diode

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

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

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

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

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

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

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

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

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

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

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

(d) In the absence of the Zener diode

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

$10R_L + 2200 = 20R_L$

$10R_L = 2200$

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

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

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

$720 + 12R_s = 960$

$12R_s = 240$

R_s = **20 Ω**

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

= (12 V)(200 mA)

= **2.4 W**

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

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

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

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

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

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

= (86.36 mA)(91 Ω) + 8 V = 7.86 V + 8 V = **15.86 V**

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

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

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

Solving, R_s = **0.5 kΩ**

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

$I_{ZM} = I_{R_S} - I_L$ = 60 mA − 20 mA = **40 mA**

46. For v_i = +50 V:

Z_1 forward-biased at 0.7 V

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

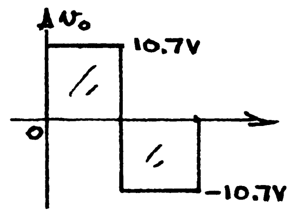
Therefore, $V_o = V_{Z_1} + V_{Z_2}$ = 0.7 V + 10 V = **10.7 V**

For $v_i = -50$ V:

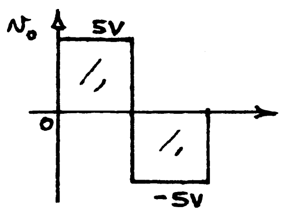
Z_1 reverse-biased at the Zener potential and $V_{Z_1} = -10$ V.

Z_2 forward-biased at -0.7 V.

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



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



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

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

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

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

Chapter 3

1. –

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

3. Forward- and reverse-biased.

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

5. –

6. –

7. –

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

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

10. –

11. $I_E = 5$ mA, $V_{CB} = 1$ V: $V_{BE} =$ **800 mV**
$V_{CB} = 10$ V: $V_{BE} =$ **770 mV**
$V_{CB} = 20$ V: $V_{BE} =$ **750 mV**

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

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

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

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

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

(d) $I_C \cong I_E$

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

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

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

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

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

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

16. –

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

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

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

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

19. –

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

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

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

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

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

(d) $I_{CBO} = (1 - \alpha)I_{CEO}$
$= (1 - 0.992)(0.3 \text{ mA})$ = **2.4 μA**

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

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

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

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

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

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

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

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

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

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

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

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

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

(e)

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

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

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

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

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

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

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

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

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

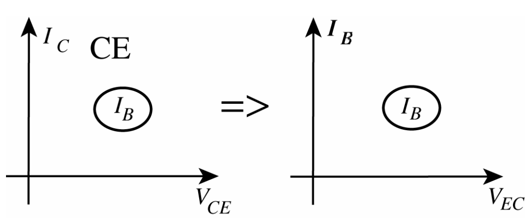
27. –

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

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

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

29. Output characteristics:



Curves are essentially the same with new scales as shown.

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

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

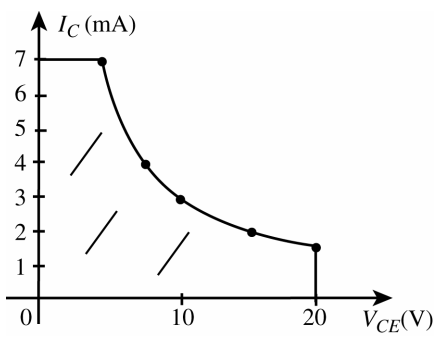
$$I_C = I_{C_{max}},\ V_{CE} = \frac{P_{C_{max}}}{I_{C_{max}}} = \frac{30\text{ mW}}{7\text{ mA}} = 4.29\text{ V}$$

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

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

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

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

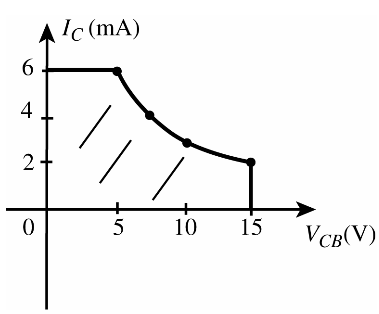


31. $$I_C = I_{C_{max}},\ V_{CE} = \frac{P_{C_{max}}}{I_{C_{max}}} = \frac{30\text{ mW}}{6\text{ mA}} = \mathbf{5\ V}$$

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

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

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



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

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

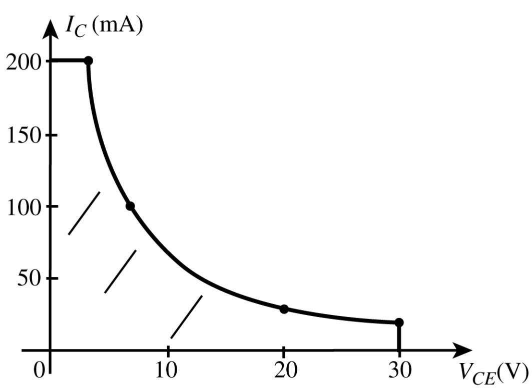
33. $I_{C_{max}} = 200 \text{ mA},\ V_{CE_{max}} = 30 \text{ V},\ P_{D_{max}} = 625 \text{ mW}$

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

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

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

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



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

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

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

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

I_C = 0.1 mA, $h_{FE} \cong 0.43(100) = 43$
↓
I_C = 10 mA, $h_{FE} \cong 0.98(100) = 98$

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

I_C = 0.1 mA, $h_{fe} \cong 72$
↓
I_C = 10 mA, $h_{fe} \cong 160$

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

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

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

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

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

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

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

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

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

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

Chapter 4

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

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

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

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

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

   (f) V_E = **0 V**

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

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

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

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

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

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

   = **15.96 V** ≅ 16 V

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

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

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

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

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

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

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

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

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

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

(g) –

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

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

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

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

$= \mathbf{29.18\ \mu A}$

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

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

$= 20\text{ V} - 11.388\text{ V}$

$= \mathbf{8.61\ V}$

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

$= \mathbf{13\ V}$

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

$= 20\text{ V} - 14.882\text{ V} = \mathbf{5.12\ V}$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

(e) $P = I_C^2 R_C = (4\text{ mA})^2(2.33\text{ k}\Omega)$
$= \mathbf{37.28\ mW}$

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

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

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

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

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

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

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

(d) Problem 6: I_{C_Q} = **2.92 mA**, V_{CE_Q} = **8.61 V** (I_{B_Q} = 29.18 μA)

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

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

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

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

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

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

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

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

(80)(0.68 kΩ) ≥ 10(9.1 kΩ)

54.4 kΩ $\not\geq$ 91 kΩ (No!)

(a) Use exact approach:

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

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

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

= **21.42 μA**

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

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

= 16 V – (1.71 mA)(3.9 kΩ + 0.68 kΩ)

= **8.17 V**

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

= 16 V – (1.71 mA)(3.9 kΩ)

= **9.33 V**

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

= **1.16 V**

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

= **1.86 V**

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

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

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

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

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

$R_1 = \dfrac{V_{R_1}}{I_{R_1}} = \dfrac{15.76\text{ V}}{0.4\text{ mA}}$ = **39.4 kΩ**

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

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

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

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

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

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

$= \dfrac{3.12\text{ V}}{8.2\text{ k}\Omega}$ + 20 μA = 380.5 μA + 20 μA = 400.5 μA

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

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

16. (a) $\beta R_E \geq 10R_2$

$(120)(1\text{ k}\Omega) \geq 10(8.2\text{ k}\Omega)$

$120\text{ k}\Omega \geq 82\text{ k}\Omega$ (checks)

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

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

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

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

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

$= \mathbf{7.55\text{ V}}$

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

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

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

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

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

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

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

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

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

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

(c) **19.02 μA** (vs. 20.25 μA #16)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

(d)

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

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

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

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

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

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

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

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

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

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

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

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

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

(e) Voltage-divider configuration considerably less sensitive.

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

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

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

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

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

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

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

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

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

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

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

$I_C = \beta I_B = (135)(7.28\ \mu\text{A}) = \mathbf{0.983\ mA}$
$V_{CE} = V_{CC} - I_C(R_C + R_E) = 22\text{ V} - (0.983\text{ mA})(9.1\text{ k}\Omega + 9.1\text{ k}\Omega)$
$= \mathbf{4.11\ V}$

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

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

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

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

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

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

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

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

$=$ **5.98 V**

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

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

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

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

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

$=$ **8.31 V**

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

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

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

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

$=$ **11.95 V**

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

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

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

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

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

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

$=$ **2.88 mA**

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

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

$=$ **–2.54 V**

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

$=$ **6.2 μA**

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

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

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

$=$ **7.91 V**

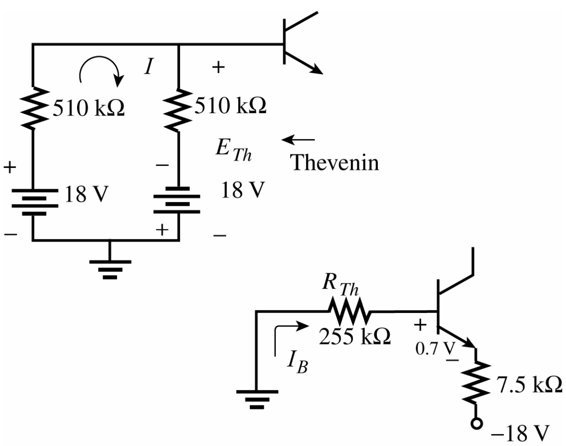
(d) $V_C = V_{CC} - I_C R_C = 16\text{ V} - (0.744\text{ mA})(12\text{ k}\Omega) =$ **7.07 V**

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

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

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

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



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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Standard values:
R_B = **360 kΩ**
R_C = **2.4 kΩ**

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

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

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

$R_C = 4R_E$ = **1.6 kΩ**

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

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

= **415.17 kΩ**

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

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

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

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

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

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

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

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

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

Choose R_2 = **7.5 kΩ**

Substituting in the above equation:

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

R_1 = **41.15 kΩ**

Standard values:

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

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

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

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

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

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

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

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

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

$\beta R_E = 10R_2$

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

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

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

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

Standard values:

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

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

37. For current mirror:

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

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

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

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

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

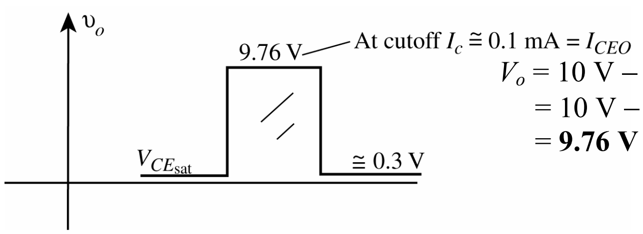
40. $I_E = \dfrac{V_Z - V_{BE}}{R_E} = \dfrac{5.1\text{ V} - 0.7\text{ V}}{1.2\text{ k}\Omega} = \mathbf{3.67\text{ mA}}$

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

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

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

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



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

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

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

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

Use 1.2 (80 μA) = 96 μA

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

Standard values:

R_B = **43 kΩ**
R_C = **0.62 kΩ**

43. (a) From Fig. 3.23c:

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

$t_{on} = t_r + t_d = 48$ ns + 120 ns = **168 ns**

$t_{off} = t_s + t_f = 110$ ns + 38 ns = **148 ns**

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

$t_{on} = t_r + t_d = 15$ ns + 22 ns = **37 ns**

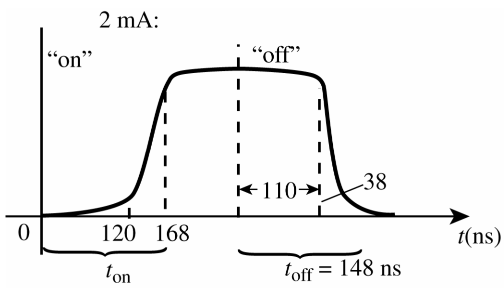
$t_{off} = t_s + t_f = 120$ ns + 12 ns = **132 ns**

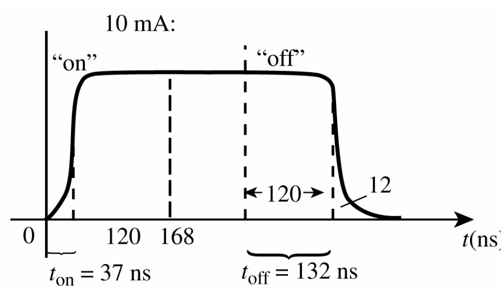
The turn-on time has dropped dramatically

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

while the turn-off time is only slightly smaller

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





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

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

(c) Open-circuit in base circuit
Open transistor

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

If operating properly:

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

As an emitter feedback bias circuit:

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

$= 72.1\ \mu$A

$V_B = V_{CC} - I_B(R_1) = 16$ V − (72.1 μA)(91 kΩ)

= **9.4 V**

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

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

$\therefore$ Assume base circuit "open"

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

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

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

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

(c) Unchanged, $I_{C_{sat}}$ not a function of β

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

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

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

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

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

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

and $\boldsymbol{V_C}\downarrow$

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

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

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

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

(d) $I_B = 0\ \mu\text{A}$, $I_C = I_{CEO}$ and $I_C(R_C + R_E)$ negligible

with $V_{CE} \cong V_{CC} = \mathbf{20\ V}$

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

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

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

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

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

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

(e) Open in the base circuit

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

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

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

$= \mathbf{-4.69\ V}$

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

50. $\beta R_E \geq 10R_2$

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

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

Use approximate approach:

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

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

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

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

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

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

$= \mathbf{-13.53\ V}$

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

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

$= \mathbf{-3.37\ V}$

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

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

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

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

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

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

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

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

$\cong \mathbf{1.66\ mA}$

53. For the emitter-bias:

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

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

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

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

54. (a) $R_{Th} = 62\ \text{k}\Omega \parallel 9.1\ \text{k}\Omega = 7.94\ \text{k}\Omega$
$$S(I_{CO}) = (\beta + 1)\frac{1 + R_{Th}/R_E}{(\beta + 1) + R_{Th}/R_E} = (80+1)\frac{(1 + 7.94\ \text{k}\Omega/0.68\ \text{k}\Omega)}{(80+1) + 7.94\ \text{k}\Omega/0.68\ \text{k}\Omega}$$
$$= \frac{(81)(1 + 11.68)}{81 + 11.68} = \mathbf{11.08}$$

(b) $$S(V_{BE}) = \frac{-\beta}{R_{Th} + (\beta+1)R_E} = \frac{-80}{7.94\ \text{k}\Omega + (81)(0.68\ \text{k}\Omega)}$$
$$= \frac{-80}{7.94\ \text{k}\Omega + 55.08\ \text{k}\Omega} = \mathbf{-1.27 \times 10^{-3}S}$$

(c) $$S(\beta) = \frac{I_{C_1}(1 + R_{Th}/R_E)}{\beta_1(1 + \beta_2 + R_{Th}/R_E)} = \frac{1.71\ \text{mA}(1 + 7.94\ \text{k}\Omega/0.68\ \text{k}\Omega)}{80(1 + 100 + 7.94\ \text{k}\Omega/0.68\ \text{k}\Omega)}$$
$$= \frac{1.71\ \text{mA}(12.68)}{80(112.68)} = \mathbf{2.41 \times 10^{-6}\ A}$$

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

55. For collector-feedback bias:

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

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

$=$ **83.69**

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

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

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

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

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

$= (83.69)(9.8\ \mu\text{A}) + (-1.477 \times 10^{-4}\text{S})(-0.2\text{ V}) + (4.83 \times 10^{-6}\text{A})(49.1)$

$= 8.20 \times 10^{-4}\text{A} + 0.295 \times 10^{-4}\text{A} + 2.372 \times 10^{-4}\text{A}$

$= 10.867 \times 10^{-4}\text{A} =$ **1.087 mA**

56.

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

$S(I_{CO})$: Considerably less for the voltage-divider configuration compared to the other three.
$S(V_{BE})$: The voltage-divider configuration is more sensitive than the other three (which have similar levels of sensitivity).
$S(\beta)$: The voltage-divider configuration is the least sensitive with the fixed-bias configuration very sensitive.

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

57. (a) Fixed-bias:

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

(b) Voltage-divider bias:

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

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

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

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

Chapter 5

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

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

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

2. –

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

4. –

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

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

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

(d) $Z_o = \mathbf{\infty\ \Omega}$

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

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

6. (a) $r_e = \frac{V_i}{I_i} = \frac{48 \text{ mV}}{3.2 \text{ mA}}$ = **15 Ω**

(b) $Z_i = r_e$ = **15 Ω**

(c) $I_C = \alpha I_e$ = (0.99)(3.2 mA) = **3.168 mA**

(d) $V_o = I_C R_L$ = (3.168 mA)(2.2 kΩ) = **6.97 V**

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

(f) $I_b = (1 - \alpha)I_e = (1 - 0.99)I_e$ = (0.01)(3.2 mA)
= **32 μA**

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

$Z_i = \beta r_e$ = (80)(13 Ω)
= **1.04 kΩ**

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

$= \frac{2 \text{ mA}}{81}$ = **24.69 μA**

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

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

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

$= \frac{40 \text{ k}\Omega}{40 \text{ k}\Omega + 1.2 \text{ k}\Omega}(80)$
= **77.67**

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

$= -\frac{1.165 \text{ k}\Omega}{13\,\Omega}$

= **–89.6**

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

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

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

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

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

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

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

$= \mathbf{-298.89}$

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

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

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

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

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

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

(c) $Z_i = \mathbf{497.47\ \Omega}$ (the same)
$Z_o = r_o \parallel R_C = 20\text{ k}\Omega \parallel 2.2\text{ k}\Omega$
$= \mathbf{1.98\ k\Omega}$

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

$A_i = -A_v Z_i / R_C$
$= -(-238.27)(497.47\ \Omega)/2.2\text{ k}\Omega$
$= \mathbf{53.88}$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Use approximate approach:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Use exact analysis:

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

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

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

$= 7.58\ \mu\text{A}$

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

$= 1.372\ \text{mA}$

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

(b) $V_E = I_E R_E = (1.372\ \text{mA})(2.2\ \text{k}\Omega) = 3.02\ \text{V}$

$V_B = V_E + V_{BE} = 3.02\ \text{V} + 0.7\ \text{V}$

$= \mathbf{3.72\ V}$

$V_C = V_{CC} - I_C R_C$

$= 20\ \text{V} - \beta I_B R_C = 20\ \text{V} - (180)(7.58\ \mu\text{A})(6.8\ \text{k}\Omega)$

$= \mathbf{10.72\ V}$

(c) $Z_i = R_1 \parallel R_2 \parallel \beta r_e$

$= 56\ \text{k}\Omega \parallel 220\ \text{k}\Omega \parallel (180)(18.95\ \text{k}\Omega)$

$= 44.64\ \text{k}\Omega \parallel 3.41\ \text{k}\Omega$

$= \mathbf{3.17\ k\Omega}$

$r_o < 10R_C \therefore A_v = -\dfrac{R_C \| r_o}{r_e}$

$= -\dfrac{(6.8\ \text{k}\Omega)\|(50\ \text{k}\Omega)}{18.95\ \Omega}$

$= \mathbf{-315.88}$

15. (a) $I_B = \dfrac{V_{CC} - V_{BE}}{R_B + (\beta + 1)R_E} = \dfrac{20\ \text{V} - 0.7\ \text{V}}{390\ \text{k}\Omega + (141)(1.2\ \text{k}\Omega)}$

$= \dfrac{19.3\ \text{V}}{559.2\ \text{k}\Omega} = 34.51\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (140 + 1)(34.51\ \mu\text{A}) = 4.866\ \text{mA}$

$r_e = \dfrac{26\ \text{mV}}{I_E} = \dfrac{26\ \text{mV}}{4.866\ \text{mA}} = \mathbf{5.34\ \Omega}$

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

$= (140)(5.34\ \text{k}\Omega) + (140 + 1)(1.2\ \text{k}\Omega) = 747.6\ \Omega + 169.9\ \text{k}\Omega$

$= \mathbf{169.95\ k\Omega}$

$Z_i = R_B \parallel Z_b = 390\ \text{k}\Omega \parallel 169.95\ \text{k}\Omega = \mathbf{118.37\ k\Omega}$

$Z_o = R_C = \mathbf{2.2\ k\Omega}$

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

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

$= 747.6\ \Omega \left[\dfrac{(141) + 2.2\ \text{k}\Omega / 20\ \text{k}\Omega}{1 + (3.4\ \text{k}\Omega)/20\ \text{k}\Omega}\right] 1.2\ \text{k}\Omega$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Significant difference in the results for A_v.

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

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

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

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

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

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

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

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

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

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

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

= **83.78 kΩ**

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

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

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

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

= **–4.57**

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

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

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

$= 2.98\ \text{mA}$

$r_e = \dfrac{26\ \text{mV}}{I_E} = \dfrac{26\ \text{mV}}{2.98\ \text{mA}}$ = **8.72 Ω**

$\beta r_e = (110)(8.72\ \Omega)$ = **959.2 Ω**

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

$= 959.2\ \Omega + (111)(2.7\ \text{k}\Omega)$

$= 300.66\ \text{k}\Omega$

$Z_i = R_B \parallel Z_b = 270\ \text{k}\Omega \parallel 300.66\ \text{k}\Omega$

$= 142.25\ \text{k}\Omega$

$Z_o = R_E \parallel r_e = 2.7\ \text{k}\Omega \parallel 8.72\ \Omega$ = **8.69 Ω**

(c) $A_v = \dfrac{R_E}{R_E + r_e} = \dfrac{2.7\ \text{k}\Omega}{2.7\ \text{k}\Omega + 8.69\ \Omega}$ ≅ **0.997**

20. (a) $I_B = \dfrac{V_{CE} - V_{BE}}{R_B + (\beta + 1)R_E} = \dfrac{8\ \text{V} - 0.7\ \text{V}}{390\ \text{k}\Omega + (121)5.6\ \text{k}\Omega} = 6.84\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (121)(6.84\ \mu\text{A}) = 0.828\ \text{mA}$

$r_e = \dfrac{26\ \text{mV}}{I_E} = \dfrac{26\ \text{mV}}{0.828\ \text{mA}} = 31.4\ \Omega$

$r_o < 10R_E$:

$Z_b = \beta r_e + \dfrac{(\beta + 1)R_E}{1 + R_E / r_o}$

$= (120)(31.4\ \Omega) + \dfrac{(121)(5.6\ \text{k}\Omega)}{1 + 5.6\ \text{k}\Omega/40\ \text{k}\Omega}$

$= 3.77\ \text{k}\Omega + 594.39\ \text{k}\Omega$

= **598.16 kΩ**

$Z_i = R_B \parallel Z_b = 390\ \text{k}\Omega \parallel 598.16\ \text{k}\Omega$

= **236.1 kΩ**

$Z_o \cong R_E \parallel r_e$

$= 5.6\ \text{k}\Omega \parallel 31.4\ \Omega$

= **31.2 Ω**

(b) $A_v = \dfrac{(\beta + 1)R_E / Z_b}{1 + R_E / r_o}$

$= \dfrac{(121)(5.6\ \text{k}\Omega)/598.16\ \text{k}\Omega}{1 + 5.6\ \text{k}\Omega/40\ \text{k}\Omega}$

= **0.994**

(c) $A_v = \dfrac{V_0}{V_i} = 0.994$

$V_o = A_v V_i = (0.994)(1\ \text{mV})$ = **0.994 mV**

21. (a) Test $\beta R_E \overset{?}{\geq} 10R_2$

$(200)(2\ \text{k}\Omega) \geq 10(8.2\ \text{k}\Omega)$

$400\ \text{k}\Omega \geq 82\ \text{k}\Omega$ (checks)!

Use approximate approach:

$$V_B = \frac{8.2\ \text{k}\Omega(20\ \text{V})}{8.2\ \text{k}\Omega + 56\ \text{k}\Omega} = 2.5545\ \text{V}$$

$$V_E = V_B - V_{BE} = 2.5545\ \text{V} - 0.7\ \text{V} \cong 1.855\ \text{V}$$

$$I_E = \frac{V_E}{R_E} = \frac{1.855\ \text{V}}{2\ \text{k}\Omega} = \mathbf{0.927\ mA}$$

$$I_B = \frac{I_E}{(\beta+1)} = \frac{0.927\ \text{mA}}{(200+1)} = \mathbf{4.61\ \mu A}$$

$$I_C = \beta I_B = (200)(4.61\ \mu\text{A}) = \mathbf{0.922\ mA}$$

(b) $r_e = \dfrac{26\ \text{mV}}{I_E} = \dfrac{26\ \text{mV}}{0.927\ \text{mA}} = \mathbf{28.05\ \Omega}$

(c) $Z_b = \beta r_e + (\beta + 1)R_E$

$= (200)(28.05\ \Omega) + (200 + 1)2\ \text{k}\Omega$

$= 5.61\ \text{k}\Omega + 402\ \text{k}\Omega = 407.61\ \text{k}\Omega$

$Z_i = 56\ \text{k}\Omega \parallel 8.2\ \text{k}\Omega \parallel 407.61\ \text{k}\Omega$

$= 7.15\ \text{k}\Omega \parallel 407.61\ \text{k}\Omega$

$= \mathbf{7.03\ k\Omega}$

$Z_o = R_E \parallel r_e = 2\ \text{k}\Omega \parallel 28.05\ \Omega = \mathbf{27.66\ \Omega}$

(d) $A_v = \dfrac{R_E}{R_E + r_e} = \dfrac{2\ \text{k}\Omega}{2\ \text{k}\Omega + 28.05\ \Omega} = \mathbf{0.986}$

22. (a) $I_E = \dfrac{V_{EE} - V_{BE}}{R_E} = \dfrac{6\ \text{V} - 0.7\ \text{V}}{6.8\ \text{k}\Omega} = 0.779\ \text{mA}$

$r_e = \dfrac{26\ \text{mV}}{I_E} = \dfrac{26\ \text{mV}}{0.779\ \text{mA}} = \mathbf{33.38\ \Omega}$

(b) $Z_i = R_E \parallel r_e = 6.8\ \text{k}\Omega \parallel 33.38\ \Omega$

$= \mathbf{33.22\ \Omega}$

$Z_o = R_C = 4.7\ \text{k}\Omega$

(c) $A_v = \dfrac{\alpha R_C}{r_e} = \dfrac{(0.998)(4.7\ \text{k}\Omega)}{33.38\ \Omega}$

$= \mathbf{140.52}$

23. $\alpha = \dfrac{\beta}{\beta + 1} = \dfrac{75}{76} = 0.9868$

$$I_E = \frac{V_{EE} - V_{BE}}{R_E} = \frac{5\text{ V} - 0.7\text{ V}}{3.9\text{ k}\Omega} = \frac{4.3\text{ V}}{3.9\text{ k}\Omega} = 1.1\text{ mA}$$

$$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{1.1\text{ mA}} = 23.58\ \Omega$$

$$A_v = \alpha\frac{R_C}{r_e} = \frac{(0.9868)(3.9\text{ k}\Omega)}{23.58\ \Omega} = \mathbf{163.2}$$

24. (a) $I_B = \frac{V_{CC} - V_{BE}}{R_F + \beta R_C} = \frac{12\text{ V} - 0.7\text{ V}}{220\text{ k}\Omega + 120(3.9\text{ k}\Omega)}$

$= 16.42\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (120 + 1)(16.42\ \mu\text{A})$

$= 1.987\text{ mA}$

$$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{1.987\text{ mA}} = \mathbf{13.08\ \Omega}$$

(b) $Z_i = \beta r_e \parallel \frac{R_F}{|A_v|}$

Need A_v!

$A_v = \frac{-R_C}{r_e} = \frac{-3.9\text{ k}\Omega}{13.08\ \Omega} = -298$

$Z_i = (120)(13.08\ \Omega) \parallel \frac{220\text{ k}\Omega}{298}$

$= 1.5696\text{ k}\Omega \parallel 738\ \Omega$

$= \mathbf{501.98\ \Omega}$

$Z_o = R_C \parallel R_F = 3.9\text{ k}\Omega \parallel 220\text{ k}\Omega$

$= \mathbf{3.83\text{ k}\Omega}$

(c) From above, $A_v = \mathbf{-298}$

25. $A_v = \frac{-R_C}{r_e} = -160$

$R_C = 160(r_e) = 160(10\ \Omega) = \mathbf{1.6\text{ k}\Omega}$

$A_i = \frac{\beta R_F}{R_F + \beta R_C} = 19 \Rightarrow 19 = \frac{200R_F}{R_F + 200(1.6\text{ k}\Omega)}$

$19R_F + 3800R_C = 200R_F$

$R_F = \frac{3800R_C}{181} = \frac{3800(1.6\text{ k}\Omega)}{181}$

$= \mathbf{33.59\text{ k}\Omega}$

$I_B = \frac{V_{CC} - V_{BE}}{R_F + \beta R_C}$

$I_B(R_F + \beta R_C) = V_{CC} - V_{BE}$

and $V_{CC} = V_{BE} + I_B(R_F + \beta R_C)$

with $I_E = \dfrac{26\text{ mV}}{r_e} = \dfrac{26\text{ mV}}{10\ \Omega} = 2.6\text{ mA}$

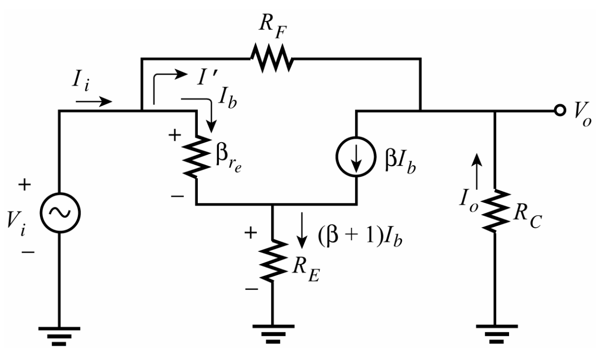
$$I_B = \frac{I_E}{\beta+1} = \frac{2.6\text{ mA}}{200+1} = 12.94\ \mu\text{A}$$

$\therefore V_{CC} = V_{BE} + I_B(R_F + \beta R_C)$

$= 0.7\text{ V} + (12.94\ \mu\text{A})(33.59\text{ k}\Omega + (200)(1.6\text{ k}\Omega))$

$=$ **5.28 V**

26.



(a) A_v: $V_i = I_b\beta r_e + (\beta + 1)I_bR_E$

$I_o + I' = I_C = \beta I_b$

but $I_i = I' + I_b$

and $I' = I_i - I_b$

Substituting, $I_o + (I_i - I_b) = \beta I_b$

and $I_o = (\beta + 1)I_b - I_i$

Assuming $(\beta + 1)I_b \gg I_i$

$I_o \cong (\beta + 1)I_b$

and $V_o = -I_oR_C = -(\beta + 1)I_bR_C$

Therefore, $\dfrac{V_o}{V_i} = \dfrac{-(\beta+1)I_bR_C}{I_b\beta r_e + (\beta+1)I_bR_E}$

$$\cong \frac{\cancel{\beta}\cancel{I_b}R_C}{\cancel{\beta}\cancel{I_b}r_e + \cancel{\beta}\cancel{I_b}R_E}$$

and $A_v = \dfrac{V_o}{V_i} \cong -\dfrac{R_C}{r_e + R_E} \cong -\dfrac{R_C}{R_E}$

(b) $V_i \cong \beta I_b(r_e + R_E)$

For $r_e \ll R_E$

$V_i \cong \beta I_bR_E$

Now $I_i = I' + I_b$

$$= \frac{V_i - V_o}{R_F} + I_b$$

Since $V_o \gg V_i$

$$I_i = -\frac{V_o}{R_F} + I_b$$

$$\text{or } I_b = I_i + \frac{V_o}{R_F}$$

and $V_i = \beta I_b R_E$

$$V_i = \beta R_E I_i + \beta \frac{V_o}{R_F} R_E$$

but $V_o = A_v V_i$

and $V_i = \beta R_E I_i + \dfrac{\beta A_v V_i R_E}{R_F}$

or $V_i - \dfrac{A_v \beta R_E V_i}{R_F} = \beta R_E I_i$

$$V_i\left[1 - \frac{A_v \beta R_E}{R_F}\right] = [\beta R_E] I_i$$

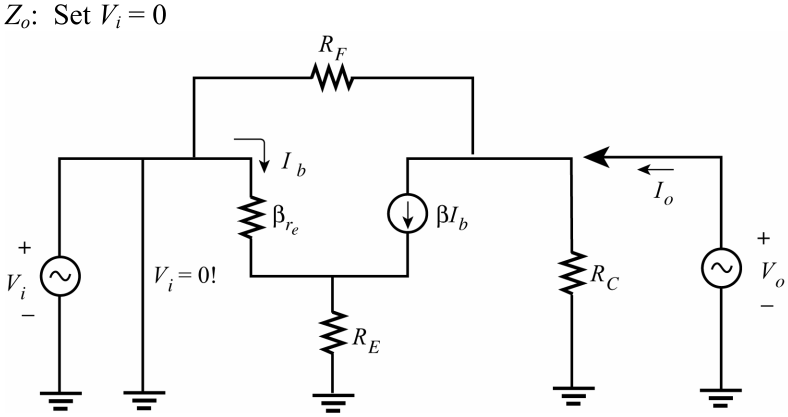
so $Z_i = \dfrac{V_i}{I_i} = \dfrac{\beta R_E}{1 - \dfrac{A_v \beta R_E}{R_F}} = \dfrac{\beta R_E R_F}{R_F + \beta(-A_v) R_E}$

$$Z_i = \frac{V_i}{I_i} = x \parallel y \qquad \text{where } x = \beta R_E \text{ and } y = R_F/|A_v|$$

with $Z_i = \dfrac{x \cdot y}{x + y} = \dfrac{(\beta R_E)(R_F/|A_v|)}{\beta R_E + R_F/|A_v|}$

$$Z_i \cong \boldsymbol{\frac{\beta R_E R_F}{\beta R_E |A_v| + R_F}}$$

Z_o: Set $V_i = 0$



$V_i = I_b \beta r_e + (\beta + 1) I_b R_E$

$V_i \cong \beta I_b (r_e + R_E) = 0$

since β, $r_e + R_E \neq 0$ $\quad I_b = 0$ and $\beta I_b = 0$

$\therefore I_o = \dfrac{V_o}{R_C} + \dfrac{V_o}{R_F} = V_o\left[\dfrac{1}{R_C} + \dfrac{1}{R_F}\right]$

and $Z_o = \dfrac{V_o}{I_o} = \dfrac{1}{\dfrac{1}{R_C} + \dfrac{1}{R_F}} = \dfrac{R_C R_F}{R_C + R_F} = \boldsymbol{R_C \parallel R_F}$

(c) $A_v \cong -\dfrac{R_C}{R_E} = -\dfrac{2.2\text{ k}\Omega}{1.2\text{ k}\Omega} = \mathbf{-1.83}$

$Z_i \cong \dfrac{\beta R_E R_F}{\beta R_E |A_v| + R_F} = \dfrac{(90)(1.2\text{ k}\Omega)(120\text{ k}\Omega)}{(90)(1.2\text{ k}\Omega)(1.83) + 120\text{ k}\Omega}$

$= \mathbf{40.8\ k\Omega}$

$Z_o \cong R_C \parallel R_F$

$= 2.2\text{ k}\Omega \parallel 120\text{ k}\Omega$

$= \mathbf{2.16\ k\Omega}$

27. (a) $I_B = \dfrac{V_{CC} - V_{BE}}{R_F + \beta R_C} = \dfrac{9\text{ V} - 0.7\text{ V}}{(39\text{ k}\Omega + 22\text{ k}\Omega) + (80)(1.8\text{ k}\Omega)}$

$= \dfrac{8.3\text{ V}}{61\text{ k}\Omega + 144\text{ k}\Omega} = \dfrac{8.3\text{ V}}{205\text{ k}\Omega} = 40.49\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (80 + 1)(40.49\ \mu\text{A}) = 3.28\text{ mA}$

$r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{3.28\text{ mA}} = 7.93\ \Omega$

$Z_i = R_{F_1} \parallel \beta r_e$

$= 39\text{ k}\Omega \parallel (80)(7.93\ \Omega) = 39\text{ k}\Omega \parallel 634.4\ \Omega = \mathbf{0.62\ k\Omega}$

$Z_o = R_C \parallel R_{F_2} = 1.8\text{ k}\Omega \parallel 22\text{ k}\Omega = \mathbf{1.66\ k\Omega}$

(b) $A_v = \dfrac{-R'}{r_e} = \dfrac{-R_C \| R_{F_2}}{r_e} = -\dfrac{1.8\text{ k}\Omega \| 22\text{ k}\Omega}{7.93\ \Omega}$

$= \dfrac{-1.664\text{ k}\Omega}{7.93\ \Omega} = \mathbf{-209.82}$

28. $A_i \cong \beta = 60$

29. $A_i \cong \beta = \mathbf{100}$

30. $A_i = -A_v Z_i / R_C = -(-127.6)(1.768\text{ k}\Omega)/3.9\text{ k}\Omega = \mathbf{57.85}$

31. (c) $A_i = \dfrac{\beta R_B}{R_B + Z_b} = \dfrac{(140)(390\text{ k}\Omega)}{390\text{ k}\Omega + 0.746\text{ k}\Omega} = \mathbf{139.73}$

(d) $A_i = -A_v \dfrac{Z_i}{R_C} = -(-370.79)(746.17\ \Omega)/2.2\text{ k}\Omega$

$= \mathbf{125.76}$

32. $A_i = -A_v Z_i / R_E = -(0.986)(7.03\ \text{k}\Omega)/2\ \text{k}\Omega = \mathbf{-3.47}$

33. $A_i = \dfrac{I_o}{I_i} = \dfrac{\alpha I_e}{I_e} = \alpha = \mathbf{0.9868} \cong 1$

34. $A_i = -A_v Z_i / R_C = -(-298)(501.98\ \Omega)/3.9\ \text{k}\Omega = \mathbf{38.37}$

35. $A_i = -A_v \dfrac{Z_i}{R_C} = \dfrac{-(-209.82)(0.62\ \text{k}\Omega)}{1.8\ \text{k}\Omega} = \mathbf{72.27}$

36. (a) $I_B = \dfrac{V_{CC} - V_{BE}}{R_B} = \dfrac{18\ \text{V} - 0.7\ \text{V}}{680\ \text{k}\Omega} = 25.44\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (100 + 1)(25.44\ \mu\text{A})$
$= 2.57\ \text{mA}$

$r_e = \dfrac{26\ \text{mV}}{2.57\ \text{mA}} = 10.116\ \Omega$

$A_{v_{NL}} = -\dfrac{R_C}{r_e} = -\dfrac{3.3\ \text{k}\Omega}{10.116\ \Omega} = \mathbf{-326.22}$

$Z_i = R_B \parallel \beta r_e = 680\ \text{k}\Omega \parallel (100)(10.116\ \Omega)$
$= 680\ \text{k}\Omega \parallel 1{,}011.6\ \Omega$
$= \mathbf{1.01\ k\Omega}$

$Z_o = R_C = \mathbf{3.3\ k\Omega}$

(b) –

(c) $A_{v_L} = \dfrac{R_L}{R_L + R_o} A_{v_{NL}} = \dfrac{4.7\ \text{k}\Omega}{4.7\ \text{k}\Omega + 3.3\ \text{k}\Omega}(-326.22)$
$= \mathbf{-191.65}$

(d) $A_{i_L} = -A_{v_L} \dfrac{Z_i}{R_L} = -(-191.65)\dfrac{(1.01\ \text{k}\Omega)}{4.7\ \text{k}\Omega}$
$= \mathbf{41.18}$

(e) $A_{v_L} = \dfrac{V_o}{V_i} = \dfrac{-\beta \cancel{I_b}(R_C \parallel R_L)}{\cancel{I_b}(\beta r_e)} = \dfrac{-\cancel{100}(1.939\ \text{k}\Omega)}{\cancel{100}(10.116\ \Omega)}$
$= \mathbf{-191.98}$

$Z_i = R_B \parallel \beta r_e = \mathbf{1.01\ k\Omega}$

$I_L = \dfrac{R_C(\beta I_b)}{R_C + R_L} = 41.25 I_b$

$I_b = \dfrac{R_B I_i}{R_B + \beta r_e} = 0.9985 I_i$

$A_{i_L} = \dfrac{I_o}{I_i} = \dfrac{I_L}{I_i} = \dfrac{I_L}{I_b} \cdot \dfrac{I_b}{I_i} = (41.25)(0.9985)$
$= \mathbf{41.19}$

$Z_o = R_C = \mathbf{3.3\ k\Omega}$

37. (a) $A_{v_{NL}} = -326.22$

$$A_{v_L} = \frac{R_L}{R_L + R_o} A_{v_{NL}}$$

$R_L = 4.7\ \text{k}\Omega$: $A_{v_L} = \frac{4.7\ \text{k}\Omega}{4.7\ \text{k}\Omega + 3.3\ \text{k}\Omega}(-326.22) = \mathbf{-191.65}$

$R_L = 2.2\ \text{k}\Omega$: $A_{v_L} = \frac{2.2\ \text{k}\Omega}{2.2\ \text{k}\Omega + 3.3\ \text{k}\Omega}(-326.22) = \mathbf{-130.49}$

$R_L = 0.5\ \text{k}\Omega$: $A_{v_L} = \frac{0.5\ \text{k}\Omega}{0.5\ \text{k}\Omega + 2.3\ \text{k}\Omega}(-326.22) = \mathbf{-42.92}$

As $R_L\downarrow$, $A_{v_L}\downarrow$

(b) No change for Z_i, Z_o, and $A_{v_{NL}}$!

38. (a) $I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{12\ \text{V} - 0.7\ \text{V}}{1\ \text{M}\Omega} = 11.3\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (181)(11.3\ \mu\text{A}) = 2.045\ \text{mA}$

$r_e = \frac{26\ \text{mV}}{I_E} = \frac{26\ \text{mV}}{2.045\ \text{mA}} = 12.71\ \Omega$

$A_{V_{NL}} = -\frac{R_C}{r_e} = -\frac{3\ \text{k}\Omega}{12.71\ \Omega} = \mathbf{-236}$

$Z_i = R_B \parallel \beta r_e = 1\ \text{M}\Omega \parallel (180)(12.71\ \Omega) = 1\ \text{M}\Omega \parallel 2.288\ \text{k}\Omega$
$= \mathbf{2.283\ k\Omega}$

$Z_o = R_C = \mathbf{3\ k\Omega}$

(b) –

(c) No-load: $A_v = A_{v_{NL}} = \mathbf{-236}$

(d) $A_{v_s} = \frac{Z_i}{Z_i + R_s} A_{v_{NL}} = \frac{2.283\ \text{k}\Omega(-236)}{2.283\ \text{k}\Omega + 0.6\ \text{k}\Omega}$
$= \mathbf{-186.9}$

(e) $V_o = -I_oR_C = -\beta I_bR_C$

$V_i = I_b\beta r_e$

$A_v = \frac{V_o}{V_i} = -\frac{\beta I_b R_C}{\beta I_b r_e} = -\frac{R_C}{r_e} = -\frac{3\ \text{k}\Omega}{12.71\ \Omega} = -236$

$A_{v_s} = \frac{V_o}{V_s} = \frac{V_o}{V_i} \cdot \frac{V_i}{V_s}$

$V_i = \frac{(1\ \text{M}\Omega \parallel \beta r_e)V_s}{(1\ \text{M}\Omega \parallel \beta r_e) + R_s} = \frac{2.288\ \text{k}\Omega(V_s)}{2.288\ \text{k}\Omega + 0.6\ \text{k}\Omega} = 0.792\ V_s$

$A_{v_s} = (-236)(0.792)$
$= \mathbf{-186.9}$ (same results)

(f) No change!

(g) $A_{v_s} = \dfrac{Z_i}{Z_i + R_s}(A_{v_{NL}}) = \dfrac{2.283\text{ k}\Omega(-236)}{2.283\text{ k}\Omega + 1\text{ k}\Omega} = \mathbf{-164.1}$

$R_s\uparrow, \quad A_{v_s}\downarrow$

(h) No change!

39. (a) $I_B = \dfrac{V_{CC} - V_{BE}}{R_B} = \dfrac{24\text{ V} - 0.7\text{ V}}{500\text{ k}\Omega} = 41.61\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (80 + 1)(41.61\ \mu\text{A}) = 3.37\text{ mA}$

$r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{3.37\text{ mA}} = 7.715\ \Omega$

$A_{v_{NL}} = -\dfrac{R_L}{r_e} = -\dfrac{4.3\text{ k}\Omega}{7.715\ \Omega} = \mathbf{-557.36}$

$Z_i = R_B \,\|\, \beta r_e = 560\text{ k}\Omega \,\|\, (80)(7.715\ \Omega)$

$= 560\text{ k}\Omega \,\|\, 617.2\ \Omega$

$= \mathbf{616.52\ \Omega}$

$Z_o = R_C = \mathbf{4.3\ k\Omega}$

(b) –

(c) $A_{v_L} = \dfrac{V_o}{V_i} = \dfrac{R_L}{R_L + R_o} A_{v_{NL}} = \dfrac{2.7\text{ k}\Omega(-557.36)}{2.7\text{ k}\Omega + 4.3\text{ k}\Omega}$

$= \mathbf{-214.98}$

$A_{v_s} = \dfrac{V_o}{V_s} = \dfrac{V_o}{V_i} \cdot \dfrac{V_i}{V_s}$

$V_i = \dfrac{Z_i V_s}{Z_i + R_s} = \dfrac{616.52\ \Omega\ V_s}{616.52\ \Omega + 1\text{ k}\Omega} = 0.381\ V_s$

$A_{v_s} = (-214.98)(0.381)$

$= \mathbf{-81.91}$

(d) $A_{i_s} = -A_{v_s}\left(\dfrac{R_s + Z_i}{R_L}\right) = -(-81.91)\left(\dfrac{1\text{ k}\Omega + 616.52\ \Omega}{2.7\text{ k}\Omega}\right)$

$= \mathbf{49.04}$

(e) $A_{v_L} = \dfrac{V_o}{V_i} = \dfrac{R_L}{R_L + R_o} A_{v_{NL}} = \dfrac{5.6\text{ k}\Omega(-557.36)}{5.6\text{ k}\Omega + 4.3\text{ k}\Omega} = -315.27$

$\dfrac{V_i}{V_s}$ the same = 0.381

$A_{v_s} = \dfrac{V_o}{V_i} \cdot \dfrac{V_i}{V_s} = (-315.27)(0.381) = \mathbf{-120.12}$

As $R_L\uparrow$, $A_{v_s}\uparrow$

(f) A_{v_L} the same = –214.98

$$\frac{V_i}{V_s} = \frac{Z_i}{Z_i + R_s} = \frac{616.52\ \Omega}{616.52\ \Omega + 0.5\ \text{k}\Omega} = 0.552$$

$$A_{v_s} = \frac{V_o}{V_i} \cdot \frac{V_i}{V_s} = (-214.98)(0.552) = \mathbf{-118.67}$$

As $R_s \downarrow$, $A_{v_s} \uparrow$

(g) No change!

40. (a) Exact analysis:

$$E_{Th} = \frac{R_2}{R_1 + R_2} V_{CC} = \frac{16\ \text{k}\Omega(16\ \text{V})}{68\ \text{k}\Omega + 16\ \text{k}\Omega} = 3.048\ \text{V}$$

$R_{Th} = R_1 \| R_2 = 68\ \text{k}\Omega \| 16\ \text{k}\Omega = 12.95\ \text{k}\Omega$

$$I_B = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta + 1)R_E} = \frac{3.048\ \text{V} - 0.7\ \text{V}}{12.95\ \text{k}\Omega + (101)(0.75\ \text{k}\Omega)}$$

$= 26.47\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (101)(26.47\ \mu\text{A})$

$= 2.673\ \text{mA}$

$$r_e = \frac{26\ \text{mV}}{I_E} = \frac{26\ \text{mV}}{2.673\ \text{mA}} = 9.726\ \Omega$$

$$A_{v_{NL}} = \frac{-R_C}{r_e} = -\frac{2.2\ \text{k}\Omega}{9.726\ \Omega} = \mathbf{-226.2}$$

$Z_i = 68\ \text{k}\Omega \| 16\ \text{k}\Omega \| \beta r_e$

$= 12.95\ \text{k}\Omega \| (100)(9.726\ \Omega)$

$= 12.95\ \text{k}\Omega \| 972.6\ \Omega$

$= \mathbf{904.66\ \Omega}$

$Z_o = R_C = \mathbf{2.2\ k\Omega}$

(b) –

(c) $$A_{v_L} = \frac{R_L}{R_L + Z_o}(A_{v_{NL}}) = \frac{5.6\ \text{k}\Omega(-226.2)}{5.6\ \text{k}\Omega + 2.2\ \text{k}\Omega} = \mathbf{-162.4}$$

(d) $$A_{i_L} = -A_{v_L}\frac{Z_i}{R_L}$$

$$= -(-162.4)\frac{(904.66\ \Omega)}{5.6\ \text{k}\Omega}$$

$= \mathbf{26.24}$

(e) $A_{v_L} = \dfrac{-R_C \| R_e}{r_e} = \dfrac{-2.2\text{ k}\Omega \| 5.6\text{ k}\Omega}{9.726\ \Omega}$

$= \mathbf{-162.4}$

$Z_i = 68\text{ k}\Omega \,\|\, 16\text{ k}\Omega \,\|\, \underbrace{972.6\ \Omega}_{\beta r_e}$

$= 904.66\ \Omega$

$A_{i_L} = -A_{v_L}\dfrac{Z_i}{R_L}$

$= \dfrac{(-162.4)(904.66\ \Omega)}{5.6\text{ k}\Omega}$

$= \mathbf{26.24}$

$Z_o = R_C = \mathbf{2.2\ k\Omega}$

Same results!

41. (a) $A_{v_L} = \dfrac{R_L}{R_L + Z_o}A_{v_{NL}}$

$R_L = 4.7\text{ k}\Omega$: $A_{v_L} = \dfrac{4.7\text{ k}\Omega}{4.7\text{ k}\Omega + 2.2\text{ k}\Omega}(-226.4) = \mathbf{-154.2}$

$R_L = 2.2\text{ k}\Omega$: $A_{v_L} = \dfrac{2.2\text{ k}\Omega}{2.2\text{ k}\Omega + 2.2\text{ k}\Omega}(-226.4) = \mathbf{-113.2}$

$R_L = 0.5\text{ k}\Omega$: $A_{v_L} = \dfrac{0.5\text{ k}\Omega}{0.5\text{ k}\Omega + 2.2\text{ k}\Omega}(-226.4) = \mathbf{-41.93}$

$R_L\downarrow,\ A_{v_L}\downarrow$

(b) Unaffected!

42. (a) $I_B = \dfrac{V_{CC} - V_{BE}}{R_B + (\beta+1)R_E} = \dfrac{18\text{ V} - 0.7\text{ V}}{680\text{ k}\Omega + (111)(0.82\text{ k}\Omega)}$

$= 22.44\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (110 + 1)(22.44\ \mu\text{A})$

$= 2.49\text{ mA}$

$r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{2.49\text{ mA}} = 10.44\ \Omega$

$A_{v_{NL}} = -\dfrac{R_C}{r_e + R_E} = -\dfrac{3\text{ k}\Omega}{10.44\ \Omega + 0.82\text{ k}\Omega}$

$= \mathbf{-3.61}$

$Z_i \cong R_B \,\|\, Z_b = 680\text{ k}\Omega \,\|\, (\beta r_e + (\beta + 1)R_E)$

$= 680\text{ k}\Omega \,\|\, (610)(10.44\ \Omega) + (110 + 1)(0.82\text{ k}\Omega)$

$= 680\text{ k}\Omega \,\|\, 92.17\text{ k}\Omega$

$= \mathbf{81.17\ k\Omega}$

$Z_o \cong R_C = \mathbf{3\ k\Omega}$

(b) –

(c) $A_{v_L} = \dfrac{V_o}{V_i} = \dfrac{R_L}{R_L + R_o} A_{v_{NL}} = \dfrac{4.7\ \text{k}\Omega(-3.61)}{4.7\ \text{k}\Omega + 3\ \text{k}\Omega}$

$= \mathbf{-2.2}$

$A_{v_s} = \dfrac{V_o}{V_s} = \dfrac{V_o}{V_i} \cdot \dfrac{V_i}{V_s}$

$V_i = \dfrac{Z_i V_s}{Z_i + R_s} = \dfrac{81.17\ \text{k}\Omega\ (V_s)}{81.17\ \text{k}\Omega + 0.6\ \text{k}\Omega} = 0.992\ V_s$

$A_{v_s} = (-2.2)(0.992)$

$= \mathbf{-2.18}$

(d) None!

(e) A_{v_L} – none!

$\dfrac{V_i}{V_s} = \dfrac{Z_i}{Z_i + R_s} = \dfrac{81.17\ \text{k}\Omega}{81.17\ \text{k}\Omega + 1\ \text{k}\Omega} = 0.988$

$A_{v_s} = (-2.2)(0.988)$

$= \mathbf{-2.17}$

$R_s\uparrow$, $A_{v_s}\downarrow$, (but only slightly for moderate changes in R_s since Z_i is typically much larger than R_s)

43. Using the exact approach:

$I_B = \dfrac{E_{Th} - V_{BE}}{R_{Th} + (\beta + 1)R_E}$

$= \dfrac{2.33\ \text{V} - 0.7\ \text{V}}{10.6\ \text{k}\Omega + (121)(1.2\ \text{k}\Omega)}$

$= 10.46\ \mu\text{A}$

$E_{Th} = \dfrac{R_2}{R_1 + R_2} V_{CC}$

$= \dfrac{12\ \text{k}\Omega}{91\ \text{k}\Omega + 12\ \text{k}\Omega}(20\ \text{V}) = 2.33\ \text{V}$

$R_{Th} = R_1 \parallel R_2 = 91\ \text{k}\Omega \parallel 12\ \text{k}\Omega = 10.6\ \text{k}\Omega$

$I_E = (\beta + 1)I_B = (121)(10.46\ \mu\text{A})$

$= 1.266\ \text{mA}$

$r_e = \dfrac{26\ \text{mV}}{I_E} = \dfrac{26\ \text{mV}}{1.266\ \text{mA}} = 20.54\ \Omega$

(a) $A_{v_{NL}} \cong \dfrac{R_E}{r_e + R_E} = \dfrac{1.2\ \text{k}\Omega}{20.54\ \Omega + 1.2\ \text{k}\Omega} = \mathbf{0.983}$

$Z_i = R_1 \parallel R_2 \parallel (\beta r_e + (\beta + 1)R_E)$

$= 91\ \text{k}\Omega \parallel 12\ \text{k}\Omega \parallel ((120)(20.54\ \Omega) + (120 + 1)(1.2\ \text{k}\Omega))$

$= 10.6\ \text{k}\Omega \parallel (2.46\ \text{k}\Omega + 145.2\ \text{k}\Omega)$

$= 10.6\ \text{k}\Omega \parallel 147.66\ \text{k}\Omega$

$= \mathbf{9.89\ k\Omega}$

$Z_o = R_E \parallel r_e = 1.2\ \text{k}\Omega \parallel 20.54\ \Omega$

$= \mathbf{20.19\ \Omega}$

(b) –

(c) $A_{v_L} = \dfrac{R_L}{R_L + Z_o} A_{v_{NL}} = \dfrac{2.7\text{ k}\Omega(0.983)}{2.7\text{ k}\Omega + 20.19\text{ }\Omega}$

= **0.976**

$A_{v_s} = \dfrac{Z_i}{Z_i + R_s} A_{v_L} = \dfrac{9.89\text{ k}\Omega(0.976)}{9.89\text{ k}\Omega + 0.6\text{ k}\Omega}$

= **0.92**

(d) A_{v_L} = 0.976 (unaffected by change in R_s)

$A_{v_s} = \dfrac{Z_i}{Z_i + R_s} A_{v_L} = \dfrac{9.89\text{ k}\Omega(0.976)}{9.89\text{ k}\Omega + 1\text{ k}\Omega}$

= **0.886** (vs. 0.92 with R_s = 0.6 kΩ)

As $R_s\uparrow$, $A_{v_s}\downarrow$

(e) Changing R_s will have no effect on $A_{v_{NL}}$, Z_i, or Z_o.

(f) $A_{v_L} = \dfrac{R_L}{R_L + Z_o}\left(A_{v_{NL}}\right) = \dfrac{5.6\text{ k}\Omega(0.983)}{5.6\text{ k}\Omega + 20.19\text{ }\Omega}$

= **0.979** (vs. 0.976 with R_L = 2.7 kΩ)

$A_{v_s} = \dfrac{Z_i}{Z_i + R_s}(A_{v_L}) = \dfrac{9.89\text{ k}\Omega(0.979)}{9.89\text{ k}\Omega + 0.6\text{ k}\Omega}$

= **0.923** (vs. 0.92 with R_L = 2.7 kΩ)

As $R_L\uparrow$, $A_{v_L}\uparrow$, $A_{v_s}\uparrow$

44. (a) $I_E = \dfrac{V_{EE} - V_{BE}}{R_E} = \dfrac{6\text{ V} - 0.7\text{ V}}{2.2\text{ k}\Omega}$

= 2.41 mA

$r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{2.41\text{ mA}}$ = 10.79 Ω

$A_{v_{NL}} = \dfrac{R_C}{r_e} = \dfrac{4.7\text{ k}\Omega}{10.79\text{ }\Omega}$ = **435.59**

$Z_i = R_E \parallel r_e$ = 2.2 kΩ ‖ 10.79 Ω = **10.74 Ω**

$Z_o = R_C$ = **4.7 kΩ**

(b) –

(c) $A_{v_L} = \dfrac{R_L}{R_L + R_o} A_{v_{NL}} = \dfrac{5.6\text{ k}\Omega(435.59)}{5.6\text{ k}\Omega + 4.7\text{ k}\Omega}$ = **236.83**

$V_i = \dfrac{Z_i}{Z_i + R_s} V_s = \dfrac{10.74\text{ }\Omega\,(V_s)}{10.74\text{ }\Omega + 100\text{ }\Omega}$ = 0.097 V_s

$A_{v_s} = \dfrac{V_o}{V_i}\cdot\dfrac{V_i}{V_s}$ = (236.83)(0.097)

= **22.97**

(d) $V_i = I_e \cdot r_e$

$V_o = -I_o R_L$

$$I_o = \frac{-4.7\text{ k}\Omega(I_e)}{4.7\text{ k}\Omega + 5.6\text{ k}\Omega} = -0.4563 I_e$$

$$A_{v_L} = \frac{V_o}{V_i} = \frac{+(0.4563\cancel{I_e})R_L}{\cancel{I_e}\cdot r_e} = \frac{0.4563(5.6\text{ k}\Omega)}{10.79\ \Omega}$$

$= \mathbf{236.82}$ (vs. 236.83 for part c)

A_{v_s} : 2.2 kΩ || 10.79 Ω = 10.74 Ω

$$V_i = \frac{Z_i}{Z_i + R_s}\cdot V_s = \frac{10.74\ \Omega\,(V_s)}{10.74\ \Omega + 100\ \Omega} = 0.097\ V_s$$

$$A_{v_s} = \frac{V_o}{V_i}\cdot\frac{V_i}{V_s} = (236.82)(0.097)$$

$= \mathbf{22.97}$ (same results)

(e) $$A_{v_L} = \frac{R_L}{R_L + R_o}A_{v_{NL}} = \frac{2.2\text{ k}\Omega}{2.2\text{ k}\Omega + 4.7\text{ k}\Omega}(435.59)$$

$= \mathbf{138.88}$

$$A_{v_s} = \frac{V_0}{V_i}\cdot\frac{V_i}{V_s},\quad \frac{V_i}{V_s} = \frac{Z_i}{Z_i + R_s} = \frac{10.74\ \Omega}{10.74\ \Omega + 500\ \Omega} = 0.021$$

A_{v_s} = (138.88)(0.021) = **2.92**

A_{v_s} very sensitive to increase in R_s due to relatively small Z_i; $R_s\uparrow$, $A_{v_s}\downarrow$

A_{v_L} sensitive to R_L; $R_L\downarrow$, $A_{v_L}\downarrow$

(f) $Z_o = R_C =$ **4.7 kΩ** unaffected by value of R_s!

(g) $Z_i = R_E \parallel r_e$ = 10.74 Ω unaffected by value of R_L!

45. (a) $$A_{v_1} = \frac{R_L A_{v_{NL}}}{R_L + R_o} = \frac{1\text{ k}\Omega(-420)}{1\text{ k}\Omega + 3.3\text{ k}\Omega} = \mathbf{-97.67}$$

$$A_{v_2} = \frac{R_L A_{v_{NL}}}{R_L + R_o} = \frac{2.7\text{ k}\Omega(-420)}{2.7\text{ k}\Omega + 3.3\text{ k}\Omega} = \mathbf{-189}$$

(b) $A_{v_L} = A_{v_1}\cdot A_{v_2}$ = (–97.67)(–189) = $\mathbf{18.46 \times 10^3}$

$$A_{v_s} = \frac{V_o}{V_s} = \frac{V_o}{V_{i_2}}\cdot\frac{V_{o_1}}{V_{i_1}}\cdot\frac{V_{i_1}}{V_s}$$

$$= A_{v_2}\cdot A_{v_1}\cdot\frac{V_i}{V_s}$$

$$V_i = \frac{Z_i V_s}{Z_i + R_s} = \frac{1\text{ k}\Omega(V_s)}{1\text{ k}\Omega + 0.6\text{ k}\Omega} = 0.625$$

A_{v_s} = (–189)(–97.67)(0.625)

$= \mathbf{11.54 \times 10^3}$

(c) $A_{i_1} = -\frac{A_v Z_i}{R_L} = \frac{-(-97.67)(1\text{ k}\Omega)}{1\text{ k}\Omega}$ = **97.67**

$A_{i_2} = \frac{-A_v Z_i}{R_L} = \frac{-(-189)(1\text{ k}\Omega)}{2.7\text{ k}\Omega}$ = **70**

(d) $A_{i_L} = A_{i_1} \cdot A_{i_2}$ = (97.67)(70) = $\mathbf{6.84 \times 10^3}$

(e) No effect!

(f) No effect!

(g) In phase

46. (a) $A_{v_1} = \frac{Z_{i_2}}{Z_{i_2} + Z_{o_1}} A_{v_{1NL}} = \frac{1.2\text{ k}\Omega}{1.2\text{ k}\Omega + 20\ \Omega}(1)$

= 0.984

$A_{v_2} = \frac{R_L}{R_L + Z_{o_2}} A_{v_{2NL}} = \frac{2.2\text{ k}\Omega}{2.2\text{ k}\Omega + 4.6\text{ k}\Omega}(-640)$

= **–207.06**

(b) $A_{v_L} = A_{v_1} \cdot A_{v_2}$ = (0.984)(–207.06)

= **–203.74**

$A_{v_s} = \frac{Z_i}{Z_i + R_s} A_{v_L}$

$= \frac{50\text{ k}\Omega}{50\text{ k}\Omega + 1\text{ k}\Omega}(-203.74)$

= **–199.75**

(c) $A_{i_1} = -A_{v_1} \frac{Z_{i_1}}{Z_{i_2}}$

$= -(0.984)\frac{(50\text{ k}\Omega)}{1.2\text{ k}\Omega}$

= **–41**

$A_{i_2} = -A_{v_2} \frac{Z_{i_2}}{R_L}$

$= -(-207.06)\frac{(1.2\text{ k}\Omega)}{2.2\text{ k}\Omega}$

= **112.94**

(d) $A_{i_L} = -A_{v_L} \frac{Z_{i_1}}{R_L}$

$= -(-203.74)\frac{(50\text{ k}\Omega)}{2.2\text{ k}\Omega}$

= $\mathbf{4.63 \times 10^3}$

(e) A load on an emitter-follower configuration will contribute to the emitter resistance (in fact, lower the value) and therefore affect Z_i (reduce its magnitude).

(f) The fact that the second stage is a CE amplifier will isolate Z_o from the first stage and R_s.

(g) The emitter-follower has zero phase shift while the common-emitter amplifier has a 180° phase shift. The system, therefore, has a total phase shift of 180° as noted by the negative sign in front of the gain for A_{v_T} in part b.

47. For each stage:

$$V_B = \frac{6.2\text{ k}\Omega}{24\text{ k}\Omega + 6.2\text{ k}\Omega}(15\text{ V}) = 3.08\text{ V}$$

$$V_E = V_B - 0.7\text{ V} = 3.08\text{ V} - 0.7\text{ V} = 2.38\text{ V}$$

$$I_E \cong I_C = \frac{V_E}{R_E} = \frac{2.38\text{ V}}{1.5\text{ k}\Omega} = 1.59\text{ mA}$$

$$V_C = V_{CC} - I_C R_C = 15\text{ V} - (1.59\text{ mA})(5.1\text{ k}\Omega)$$
$$= \mathbf{6.89\text{ V}}$$

48. $$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{1.59\text{ mA}} = 16.35\ \Omega$$

$$R_{i_2} = R_1 \,\|\, R_2 \,\|\, \beta r_e = 6.2\text{ k}\Omega \,\|\, 24\text{ k}\Omega \,\|\, (150)(16.35\ \Omega)$$
$$= 1.64\text{ k}\Omega$$

$$A_{v_1} = -\frac{R_C \| R_{i_2}}{r_e} = \frac{5.1\text{ k}\Omega \,\|\, 1.64\text{ k}\Omega}{16.35\ \Omega} = \mathbf{-75.8}$$

$$A_{v_2} = -\frac{R_C}{r_e} = \frac{-5.1\text{ k}\Omega}{16.35\ \Omega} = \mathbf{-311.9}$$

$$A_v = A_{v_1} A_{v_2} = (-75.8)(-311.9) = \mathbf{23{,}642}$$

49. $$V_{B_1} = \frac{3.9\text{ k}\Omega}{3.9\text{ k}\Omega + 6.2\text{ k}\Omega + 7.5\text{ k}\Omega}(20\text{ V}) = \mathbf{4.4\text{ V}}$$

$$V_{B_2} = \frac{6.2\text{ k}\Omega + 3.9\text{ k}\Omega}{3.9\text{ k}\Omega + 6.2\text{ k}\Omega + 7.5\text{ k}\Omega}(20\text{ V}) = \mathbf{11.48\text{ V}}$$

$$V_{E_1} = V_{B_1} - 0.7\text{ V} = 4.4\text{ V} - 0.7\text{ V} = 3.7\text{ V}$$

$$I_{C_1} \cong I_{E_1} = \frac{V_{E_1}}{R_E} = \frac{3.7\text{ V}}{1\text{ k}\Omega} = 3.7\text{ mA} \cong I_{E_2} \cong I_{C_2}$$

$$V_{C_2} = V_{CC} - I_C R_C = 20\text{ V} - (3.7\text{ mA})(1.5\text{ k}\Omega)$$
$$= \mathbf{14.45\text{ V}}$$

50. $r_e = \dfrac{26 \text{ mV}}{I_E} = \dfrac{26 \text{ mV}}{3.7 \text{ mA}} = 7\ \Omega$

$A_{v_1} = -\dfrac{r_e}{r_e} = \mathbf{-1}$

$A_{v_2} = \dfrac{R_E}{r_e} = \dfrac{1.5 \text{ k}\Omega}{7\ \Omega} \cong \mathbf{214}$

$A_{v_T} = A_{v_1} A_{v_2} = (-1)(214) = \mathbf{-214}$

$V_o = A_{v_T} V_i = (-214)(10 \text{ mV}) = \mathbf{-2.14\ V}$

51. $R_o = R_D = 1.5 \text{ k}\Omega$ (V_o (from problem 50) = –2.14 V)

$V_o(\text{load}) = \dfrac{R_L}{R_o + R_L}(V_o) = \dfrac{10 \text{ k}\Omega}{10 \text{ k}\Omega + 1.5 \text{ k}\Omega}(-2.14 \text{ V})$

$= \mathbf{-1.86\ V}$

52. $I_B = \dfrac{V_{CC} - V_{BE}}{\beta_D R_E + R_B} = \dfrac{(16 \text{ V} - 1.6 \text{ V})}{(6000)(510\ \Omega) + 2.4 \text{ M}\Omega}$

$= \dfrac{14.4 \text{ V}}{5.46 \text{ M}\Omega} = 2.64\ \mu\text{A}$

$I_C \cong I_E = \beta_D I_B = 6000(2.64\ \mu\text{A}) = \mathbf{15.8\ mA}$

$V_E = I_E R_E = (15.8 \text{ mA})(510\ \Omega) = \mathbf{8.06\ V}$

53. From problem 69, I_E = 15.8 mA

$r_e = \dfrac{26}{I_E} = \dfrac{26 \text{ V}}{15.8 \text{ mA}} = 1.65\ \Omega$

$A_v = \dfrac{R_E}{r_e + R_E} = \dfrac{510\ \Omega}{1.65\ \Omega + 510\ \Omega} = \mathbf{0.997} \approx 1$

54. dc: $I_B \cong \dfrac{V_{CC} - V_{BE}}{R_B + \beta_D R_E} = \dfrac{16 \text{ V} - 1.6 \text{ V}}{2.4 \text{ M}\Omega + (6000)(510\ \Omega)} = 2.64\ \mu\text{A}$

$I_C = \beta_D I_B = (6000)(2.64\ \mu\text{A}) = 15.84 \text{ mA}$

$r_{e_2} = \dfrac{26 \text{ mV}}{I_{E_2}} = \dfrac{26 \text{ mV}}{15.84 \text{ mA}} = 1.64\ \Omega$

ac: $Z_i \cong \beta_D r_{e_2} = (6000)(1.64\ \Omega) = 9.84 \text{ k}\Omega$

$I_{b_1} = \dfrac{V_i}{9.84 \text{ k}\Omega}$

$V_o = (-\beta_D I_{b_1})(R_C) = -(6000)\left(\dfrac{V_i}{9.84 \text{ k}\Omega}\right)(200\ \Omega)$

$= -121.95\ Vi$

and $A_v = \dfrac{V_o}{V_i} \cong \mathbf{-121.95}$

55. $I_B = \dfrac{V_{CC} - V_{EB_1}}{R_B + \beta_1\beta_2 R_E} = \dfrac{16 \text{ V} - 0.7 \text{ V}}{1.5 \text{ M}\Omega + (160)(200)(100 \ \Omega)}$

$= 3.255 \ \mu\text{A}$

$I_C \cong \beta_1\beta_2 I_B = (160)(200)(3.255\mu\text{A}) \cong$ **104.2 mA**

$V_{C_2} = V_{CC} - I_C R_C = 16 \text{ V} - (104.2 \text{ mA})(100 \ \Omega) =$ **5.58 V**

$V_{B_1} = I_B R_B = (3.255 \ \mu\text{A})(1.5 \text{ M}\Omega) =$ **4.48 V**

56. From problem 55: $I_{E_1} = 0.521$ mA

$r_{e_1} = \dfrac{26 \text{ mV}}{I_E \text{ (mA)}} = \dfrac{26 \text{ mV}}{0.521 \text{ mA}} = 49.9 \ \Omega$

$R_{i_1} = \beta r_{e_i} = 160(49.9 \ \Omega) = 7.98 \text{ k}\Omega$

$A_v = \dfrac{\beta_1\beta_2 R_C}{\beta_1\beta_2 R_C + R_{i_1}} = \dfrac{(160)(200)(100 \ \Omega)}{(160)(200)(100 \ \Omega) + 7.98 \text{ k}\Omega}$

$= 0.9925$

$V_o = A_v V_i = 0.9975 \text{ (120 mV)}$

= **119.7 mV**

57. $r_e = \dfrac{26 \text{ mV}}{I_{E(\text{dc})}} = \dfrac{26 \text{ mV}}{1.2 \text{ mA}} =$ **21.67 Ω**

$\beta r_e = (120)(21.67 \ \Omega) =$ **2.6 kΩ**

58. –

59. –

60. –

61. –

62. (a) $A_v = \dfrac{V_o}{V_i} = -160$

$V_o = \mathbf{-160 \ V_i}$

(b) $I_b = \dfrac{V_i - h_{re}V_o}{h_{ie}} = \dfrac{V_i - h_{re}A_v V_i}{h_{ie}} = \dfrac{V_i(1 - h_{re}A_v)}{h_{ie}}$

$= \dfrac{V_i\left(1 - (2 \times 10^{-4})(160)\right)}{1 \text{ k}\Omega}$

$I_b = \mathbf{9.68 \times 10^{-4} V_i}$

(c) $I_b = \dfrac{V_i}{1 \text{ k}\Omega} = \mathbf{1 \times 10^{-3} V_i}$

(d) % Difference = $\dfrac{1\times10^{-3}V_i - 9.68\times10^{-4}V_i}{1\times10^{-3}V_i} \times 100\%$

$= \mathbf{3.2\ \%}$

(e) Valid first approximation

63. % difference in total load = $\dfrac{R_L - R_L \| 1/h_{oe}}{R_L} \times 100\%$

$= \dfrac{2.2\text{ k}\Omega - (2.2\text{ k}\Omega \| 50\text{ k}\Omega)}{2.2\text{ k}\Omega} \times 100\%$

$= \dfrac{2.2\text{ k}\Omega - 2.1073\text{ k}\Omega}{2.2\text{ k}\Omega} \times 100\%$

$= \mathbf{4.2\ \%}$

In this case the effect of $1/h_{oe}$ can be ignored.

64. (a) $V_o = \mathbf{-180}\boldsymbol{V_i}$ $\quad$ ($h_{ie} = 4\text{ k}\Omega$, $h_{re} = 4.05 \times 10^{-4}$)

(b) $I_b = \dfrac{V_i - (4.05\times10^{-4})(180V_i)}{4\text{ k}\Omega}$

$= \mathbf{2.32 \times 10^{-4}}\boldsymbol{V_i}$

(c) $I_b = \dfrac{V_i}{h_{ie}} = \dfrac{V_i}{4\text{ k}\Omega} = \mathbf{2.5 \times 10^{-4}}\boldsymbol{V_i}$

(d) % Difference = $\dfrac{2.5\times10^{-4}V_i - 2.32\times10^{-4}V_i}{2.5\times10^{-4}V_i} \times 100\% = \mathbf{7.2\%}$

(e) Yes, less than 10%

65. From Fig. 5.18

	min	max
h_{oe}:	1 μS	30 μS

Avg = $\dfrac{(1+30)\mu\text{S}}{2} = \mathbf{15.5\ \mu S}$

66. (a) $h_{fe} = \beta = \mathbf{120}$

$h_{ie} \cong \beta r_e = (120)(4.5\ \Omega) = \mathbf{540\ \Omega}$

$h_{oe} = \dfrac{1}{r_o} = \dfrac{1}{40\text{ k}\Omega} = \mathbf{25\ \mu S}$

(b) $r_e \cong \dfrac{h_{ie}}{\beta} = \dfrac{1\text{ k}\Omega}{90} = \mathbf{11.11\ \Omega}$

$\beta = h_{fe} = \mathbf{90}$

$r_o = \dfrac{1}{h_{oe}} = \dfrac{1}{20\ \mu\text{S}}$

$= \mathbf{50\ k\Omega}$

67. (a) r_e = **8.31 Ω** (from problem 9)

(b) $h_{fe} = \beta$ = **60**

$h_{ie} = \beta r_e$ = (60)(8.31 Ω) = **498.6 Ω**

(c) $Z_i = R_B \| h_{ie}$ = 220 kΩ || 498.6 Ω = **497.47 Ω**

$Z_o = R_C$ = **2.2 kΩ**

(d) $A_v = \dfrac{-h_{fe}R_C}{h_{ie}} = \dfrac{-(60)(2.2\text{ k}\Omega)}{498.6\ \Omega}$ = **–264.74**

$A_i \cong h_{fe}$ = **60**

(e) Z_i = **497.47 Ω** (the same)

$Z_o = r_o \| R_C,\ r_o = \dfrac{1}{25\ \mu\text{S}} = 40\text{ k}\Omega$

= 40 kΩ || 2.2 kΩ

= **2.09 kΩ**

(f) $A_v = \dfrac{-h_{fe}(r_o \| R_C)}{h_{ie}} = \dfrac{-(60)(2.085\text{ k}\Omega)}{498.6\ \Omega}$ = **–250.90**

$A_i = -A_vZ_i/R_C$ = –(–250.90)(497.47 Ω)/2.2 kΩ = **56.73**

68. (a) 68 kΩ || 12 kΩ = 10.2 kΩ

Z_i = 10.2 kΩ || h_{ie} = 10.2 kΩ || 2.75 kΩ

= **2.166 kΩ**

$Z_o = R_C \| r_o$

= 2.2 kΩ || 40 kΩ

= **2.085 kΩ**

(b) $A_v = \dfrac{-h_{fe}R'_C}{h_{ie}}$ $R'_C = R_C \| r_o$ = 2.085 kΩ

$= \dfrac{-(180)(2.085\text{ k}\Omega)}{2.75\text{ k}\Omega}$ = **–136.5**

$$A_i = \frac{I_o}{I_i} = \frac{I_o}{I'_i}\cdot\frac{I'_i}{I_i}$$

$$= \left(\frac{h_{f_e}}{1+h_{oe}R_L}\right)\left(\frac{10.2\text{ k}\Omega}{10.2\text{ k}\Omega+2.68\text{ k}\Omega}\right)$$

$$= \left(\frac{180}{1+(25\ \mu\text{S})(2.2\text{ k}\Omega)}\right)(0.792)$$

= **135.13**

69. (a) $Z_i = R_E \parallel h_{ib}$
$= 1.2\text{ k}\Omega \parallel 9.45\ \Omega$
$= \mathbf{9.38\ \Omega}$

$Z_o = R_C \parallel \dfrac{1}{h_{ob}} = 2.7\text{ k}\Omega \parallel \dfrac{1}{1\times10^{-6}\dfrac{\text{A}}{\text{V}}} = 2.7\text{ k}\Omega \parallel 1\text{ M}\Omega \cong \mathbf{2.7\ k\Omega}$

(b) $A_v = \dfrac{-h_{fb}(R_C \| 1/h_{ob})}{h_{ib}} = \dfrac{-(-0.992)(\cong 2.7\text{ k}\Omega)}{9.45\ \Omega}$
$= \mathbf{284.43}$
$A_i \cong \mathbf{-1}$

(c) $\alpha = -h_{fb} = -(-0.992) = \mathbf{0.992}$
$\beta = \dfrac{\alpha}{1-\alpha} = \dfrac{0.992}{1-0.992} = \mathbf{124}$
$r_e = h_{ib} = \mathbf{9.45\ \Omega}$
$r_o = \dfrac{1}{h_{ob}} = \dfrac{1}{1\ \mu\text{A/V}} = \mathbf{1\ M\Omega}$

70. (a) $Z_i' = h_{ie} - \dfrac{h_{fe}h_{re}R_L}{1+h_{oe}R_L} = 2.75\text{ k}\Omega - \dfrac{(180)(2\times10^{-4})(2.2\text{ k}\Omega)}{(1+25\mu\text{S})(2.2\text{ k}\Omega)}$
$= 2.68\text{ k}\Omega$

$Z_i = 10.2\text{ k}\Omega \parallel Z_i' = \mathbf{2.12\ k\Omega}$

$Z_o' = \dfrac{1}{h_{oe} - (h_{fe}h_{re}/h_{ie})} = \dfrac{1}{25\ \mu\text{S} - (180)(2\times10^{-4})/2.75\text{ k}\Omega}$
$= 83.75\text{ k}\Omega$

$Z_o = 2.2\text{ k}\Omega \parallel 83.75\text{ k}\Omega = \mathbf{2.14\ k\Omega}$

(b) $A_v = \dfrac{-h_{fe}R_L}{h_{ie} + (h_{ie}h_{oe} - h_{fe}h_{re})R_L} = \dfrac{-(180)(2.2\text{ k}\Omega)}{2.75\text{ k}\Omega + \big((2.75\text{ k}\Omega)(25\mu\text{S}) - (180)(2\times10^{-4})\big)2.2\text{ k}\Omega}$
$= \mathbf{-140.3}$

(c) $A_i' = \dfrac{h_{fe}}{1+h_{oe}R_L} = \dfrac{(180)}{1+(25\mu\text{S})(2.2\text{ k}\Omega)} = 170.62$

$A_i = \dfrac{I_o}{I_i} = \dfrac{I_o}{I_i'}\cdot\dfrac{I_i'}{I_i} = (170.62)\left(\dfrac{10.2\text{ k}\Omega}{10.2\text{ k}\Omega + 2.68\text{ k}\Omega}\right)$
$= \mathbf{135.13}$

71. (a) $Z_i = h_{ie} = \dfrac{-h_{fe}h_{re}R_L}{1+h_{oe}R_L}$

$$= 0.86\text{ k}\Omega - \frac{(140)(1.5\times10^{-4})(2.2\text{ k}\Omega)}{1+(25\ \mu\text{S})(2.2\text{ k}\Omega)}$$

$$= 0.86\text{ k}\Omega - 43.79\ \Omega$$

$$= 816.21\ \Omega$$

$$Z_i' = R_B \parallel Z_i$$

$$= 470\text{ k}\Omega \parallel 816.21\ \Omega$$

$$= \mathbf{814.8\ \Omega}$$

(b) $A_v = \dfrac{-h_{fe}R_L}{h_{ie}+(h_{ie}h_{oe}-h_{fe}h_{re})R_L}$

$$= \frac{-(140)(2.2\text{ k}\Omega)}{0.86\text{ k}\Omega+((0.86\text{ k}\Omega)(25\ \mu\text{S})-(140)(1.5\times10^{-4}))2.2\text{ k}\Omega}$$

$$= \mathbf{-357.68}$$

(c) $A_i = \dfrac{I_o}{I_i} = \dfrac{h_{fe}}{1+h_{oe}R_L} = \dfrac{140}{1+(25\ \mu\text{S})(2.2\text{ k}\Omega)}$

$$= 132.70$$

$$A_i' = \frac{I_o}{I_i'} = \left(\frac{I_o}{I_i}\right)\left(\frac{I_i}{I_i'}\right) \qquad I_i = \frac{470\text{ k}\Omega\ I_i'}{470\text{ k}\Omega+0.816\text{ k}\Omega}$$

$$= (132.70)(0.998) \qquad \frac{I_i}{I_i'} = 0.998$$

$$= \mathbf{132.43}$$

(d) $Z_o = \dfrac{1}{h_{oe}-\left(h_{fe}h_{re}/(h_{ie}+R_s)\right)} = \dfrac{1}{25\ \mu\text{S}-\left((140)(1.5\times10^{-4})/(0.86\text{ k}\Omega+1\text{ k}\Omega)\right)}$

$$= \frac{1}{13.71\ \mu\text{S}} \cong \mathbf{72.9\text{ k}\Omega}$$

72. (a) $Z_i' = h_{ib} - \dfrac{h_{fb}h_{rb}R_L}{1+h_{ob}R_L} = 9.45\ \Omega - \dfrac{(-0.997)(1\times10^{-4})(2.2\text{ k}\Omega)}{1+(0.5\mu\text{A/V})(2.2\text{ k}\Omega)}$

$$= 9.67\ \Omega$$

$Z_i = 1.2\text{ k}\Omega \parallel Z_i' = 1.2\text{ k}\Omega \parallel 9.67\ \Omega = \mathbf{9.59\ \Omega}$

(b) $A_i' = \dfrac{h_{fb}}{1+h_{ob}R_L} = \dfrac{-0.997}{1+(0.5\ \mu\text{A/V})(2.2\text{ k}\Omega)} = -0.996$

$$A_i = \frac{I_o}{I_i'}\cdot\frac{I_i'}{I_i} = (-0.996)\left(\frac{1.2\text{ k}\Omega}{1.2\text{ k}\Omega+9.67\text{ k}\Omega}\right)$$

$$\cong \mathbf{-0.988}$$

(c) $A_v = \dfrac{-h_{fb}R_L}{h_{ib} + (h_{ib}h_{ob} - h_{fb}h_{rb})R_L}$

$$= \frac{-(-0.997)(2.2\text{ k}\Omega)}{9.45\ \Omega + \left((9.45\ \Omega)(0.5\ \mu\text{A/V}) - (-0.997)(1\times10^{-4})\right)(2.2\text{ k}\Omega)}$$

$= \mathbf{226.61}$

(d) $Z_o' = \dfrac{1}{h_{ob} - \left[h_{fb}h_{rb}/h_{ib}\right]}$

$$= \frac{1}{0.5\ \mu\text{A/V} - \left[(-0.997)(1\times10^{-4})/9.45\ \Omega\right]}$$

$= 90.5\text{ k}\Omega$

$Z_o = 2.2\text{ k}\Omega \parallel Z_o' = \mathbf{2.15\ k\Omega}$

73. –

74. (a) h_{fe} (0.2 mA) ≅ 0.6 (normalized)
h_{fe} (1 mA) = 1.0

$$\%\text{ change} = \left|\frac{h_{fe}(0.2\text{ mA}) - h_{fe}(1\text{ mA})}{h_{fe}(0.2\text{ mA})}\right| \times 100\%$$

$$= \left|\frac{0.6-1}{0.6}\right| \times 100\%$$

= **66.7%**

(b) h_{fe}(1 mA) = 1.0
h_{fe}(5 mA) ≅ 1.5

$$\%\text{ change} = \left|\frac{h_{fe}(1\text{ mA}) - h_{fe}(5\text{ mA})}{h_{fe}(1\text{ mA})}\right| \times 100\%$$

$$= \left|\frac{1-1.5}{1}\right| \times 100\%$$

= **50%**

75. Log-log scale!

(a) I_c = 0.2 mA, h_{ie} = 4 (normalized)
I_c = 1 mA, h_{ie} = 1(normalized)

$\%$ change = $\left|\dfrac{4-1}{4}\right| \times 100\%$ = **75%**

(b) I_e = 5 mA, h_{ie} = 0.3 (normalized)

$\%$ change = $\left|\dfrac{1-0.3}{1}\right| \times 100\%$ = **70%**

76. (a) $h_{oe} = 20\ \mu S$ @ 1 mA
$I_c = 0.2$ mA, $h_{oe} = 0.2(h_{oe}$ @ 1 mA)
$= 0.2(20\ \mu S)$
$= \mathbf{4\ \mu S}$

(b) $r_o = \dfrac{1}{h_{oe}} = \dfrac{1}{4\ \mu S} = 250\ k\Omega \gg 6.8\ k\Omega$
Ignore $1/h_{oe}$

77. (a) $I_c = 10$ mA, $h_{oe} = 10(20\ \mu S) = \mathbf{200\ \mu S}$

(b) $r_o = \dfrac{1}{h_{oe}} = \dfrac{1}{200\mu S} = 5\ k\Omega$ vs. $\mathbf{8.6\ k\Omega}$
Not a good approximation

78. (a) $h_{re}(0.1\ mA) = 4(h_{re}(1\ mA))$
$= 4(2 \times 10^{-4})$
$= \mathbf{8 \times 10^{-4}}$

(b) $h_{re}V_{ce} = h_{re}A_v \cdot V_i$
$= (8 \times 10^{-4})(210)V_i$
$= \mathbf{0.168\ V_i}$
In this case $h_{re}V_{ce}$ is too large a factor to be ignored.

79. (a) h_{fe}

(b) h_{oe}

(c) $h_{oe} \cong 30$ (normalized) to
$h_{oe} \cong 0.1$ (normalized) at low levels of I_c

(d) mid-region

80. (a) h_{ie} is the most temperature-sensitive parameter of Fig. 5.33.

(b) h_{oe} exhibited the smallest change.

(c) Normalized: $h_{fe(\text{max})} = \mathbf{1.5}$, $h_{fe(\text{min})} = \mathbf{0.5}$
For $h_{fe} = 100$ the range would extend from 50 to 150—certainly significant.

(d) On a normalized basis r_e increased from 0.3 at −65°C to 3 at 200°C—a significant change.

(e) The parameters show the least change in the region 0° → 100°C.

81. (a) Test:

$\beta R_E \geq 10R_2$

$70(1.5\text{ k}\Omega) \geq 10(39\text{ k}\Omega)$

$105\text{ k}\Omega \overset{?}{\geq} 390\text{ k}\Omega$

No!

$R_{Th} = 39\text{ k}\Omega \parallel 150\text{ k}\Omega = 30.95\text{ k}\Omega$

$$E_{Th} = \frac{39\text{ k}\Omega(14\text{ V})}{39\text{ k}\Omega + 150\text{ k}\Omega} = 2.89\text{ V}$$

$$I_B = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta+1)R_E} = \frac{2.89\text{ V} - 0.7\text{ V}}{30.95\text{ k}\Omega + (71)(1.5\text{ k}\Omega)}$$

$= 15.93\ \mu\text{A}$

$V_B = E_{Th} - I_B R_{Th}$

$= 2.89\text{ V} - (15.93\ \mu\text{A})(30.95\text{ k}\Omega)$

$= 2.397\text{ V}$

$V_E = 2.397\text{ V} - 0.7\text{ V} = 1.697\text{ V}$

and $I_E = \dfrac{V_E}{R_E} = \dfrac{1.697\text{ V}}{1.5\text{ k}\Omega} = 1.13\text{ mA}$

$V_{CE} = V_{CC} - I_C(R_C + R_E)$

$= 14\text{ V} - 1.13\text{ mA}(2.2\text{ k}\Omega + 1.5\text{ k}\Omega)$

$= 9.819\text{ V}$

Biasing OK

(b) R_2 not connected at base:

$$I_B = \frac{V_{CC} - 0}{R_B + (\beta+1)R_E} = \frac{14\text{ V} - 0.7\text{ V}}{150\text{ k}\Omega + (71)(1.5\text{ k}\Omega)} = 51.85\ \mu\text{A}$$

$V_B = V_{CC} - I_B R_B = 14\text{ V} - (51.85\ \mu\text{A})(150\text{ k}\Omega)$

$=$ **6.22 V** as noted in Fig. 5.187.

Chapter 6

1. –

2. From Fig. 6.11:

   V_{GS} = 0 V, I_D = **8 mA**
   V_{GS} = –1 V, I_D = **4.5 mA**
   V_{GS} = –1.5 V, I_D = **3.25 mA**
   V_{GS} = –1.8 V, I_D = **2.5 mA**
   V_{GS} = –4 V, I_D = **0 mA**
   V_{GS} = –6 V, I_D = **0 mA**

3. (a) $V_{DS} \cong$ **1.4 V**

   (b) $r_d = \frac{V}{I} = \frac{1.4\text{ V}}{6\text{ mA}} = \mathbf{233.33\ \Omega}$

   (c) $V_{DS} \cong$ **1.6 V**

   (d) $r_d = \frac{V}{I} = \frac{1.6\text{ V}}{3\text{ mA}} = \mathbf{533.33\ \Omega}$

   (e) $V_{DS} \cong$ **1.4 V**

   (f) $r_d = \frac{V}{I} = \frac{1.4\text{ V}}{1.5\text{ mA}} = \mathbf{933.33\ \Omega}$

   (g) $r_o = 233.33\ \Omega$

   $$r_d = \frac{r_o}{\left[1 - V_{GS}/V_P\right]^2} = \frac{233.33\ \Omega}{\left[1-(-1\text{ V})/(-4\text{ V})\right]^2} = \frac{233.33\ \Omega}{0.5625}$$
   $= \mathbf{414.81\ \Omega}$

   (h) $$r_d = \frac{233.33\ \Omega}{\left[1-(-2\text{ V})/(-4\text{ V})\right]^2} = \frac{233.33\ \Omega}{0.25} = \mathbf{933.2\ \Omega}$$

   (i) 533.33 Ω vs. 414.81 Ω
   933.33 Ω vs 933.2 Ω } Eq. (6.1) is valid!

4. (a) V_{GS} = 0 V, I_D = 8 mA (for $V_{DS} > V_P$)
   V_{GS} = –1 V, I_D = 4.5 mA
   ΔI_D = **3.5 mA**

   (b) V_{GS} = –1 V, I_D = 4.5 mA
   V_{GS} = –2 V, I_D = 2 mA
   ΔI_D = **2.5 mA**

(c) $V_{GS} = -2$ V, $I_D = 2$ mA
$V_{GS} = -3$ V, $I_D = 0.5$ mA
$\Delta I_D =$ **1.5 mA**

(d) $V_{GS} = -3$ V, $I_D = 0.5$ mA
$V_{GS} = -4$ V, $I_D = 0$ mA
$\Delta I_D =$ **0.5 mA**

(e) As V_{GS} becomes more negative, the change in I_D gets progressively smaller for the same change in V_{GS}.

(f) Non-linear. Even though the change in V_{GS} is fixed at 1 V, the change in I_D drops from a maximum of 3.5 mA to a minimum of 0.5 mA—a 7:1 change in ΔI_D.

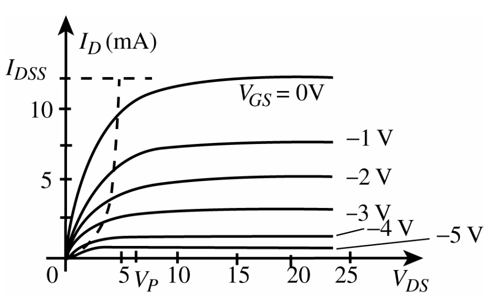
5. The collector characteristics of a BJT transistor are a plot of output current versus the output voltage for different levels of *input current*. The drain characteristics of a JFET transistor are a plot of the output current versus input voltage. For the BJT transistor increasing levels of input current result in increasing levels of output current. For JFETs, increasing magnitudes of input voltage result in lower levels of output current. The spacing between curves for a BJT are sufficiently similar to permit the use of a single beta (on an approximate basis) to represent the device for the dc and ac analysis. For JFETs, however, the spacing between the curves changes quite dramatically with increasing levels of input voltage requiring the use of Shockley's equation to define the relationship between I_D and V_{GS}. $V_{C_{sat}}$ and V_P define the region of nonlinearity for each device.

6. (a) The input current I_G for a JFET is effectively zero since the JFET gate-source junction is reverse-biased for linear operation, and a reverse-biased junction has a very high resistance.

(b) The input impedance of the JFET is high due to the reverse-biased junction between the gate and source.

(c) The terminology is appropriate since it is the electric field established by the applied gate to source voltage that controls the level of drain current. The term "field" is appropriate due to the absence of a conductive path between gate and source (or drain).

7. $V_{GS} = 0$ V, $I_D = I_{DSS} = 12$ mA
$V_{GS} = V_P = -6$ V, $I_D = 0$ mA
Shockley's equation: $V_{GS} = -1$ V, $I_D = 8.33$ mA; $V_{GS} = -2$ V, $I_D = 5.33$ mA; $V_{GS} = -3$ V, $I_D = 3$ mA; $V_{GS} = -4$ V, $I_D = 1.33$ mA; $V_{GS} = -5$ V, $I_D = 0.333$ mA.



8. For a *p*-channel JFET, all the voltage polarities in the network are reversed as compared to an *n*-channel device. In addition, the drain current has reversed direction.

9. (b) I_{DSS} = **10 mA**, V_P = **–6 V**

10. $V_{GS} = 0$ V, $I_D = I_{DSS} = 12$ mA
$V_{GS} = V_P = -4$ V, $I_D = 0$ mA
$V_{GS} = \frac{V_P}{2} = -2$ V, $I_D = \frac{I_{DSS}}{4} = 3$ mA
$V_{GS} = 0.3V_P = -1.2$ V, $I_D = 6$ mA
$V_{GS} = -3$ V, $I_D = 0.75$ mA (Shockley's equation)

11. (a) $I_D = I_{DSS}$ = **9 mA**

(b) $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$
$= 9\text{ mA}(1 - (-2\text{ V})/(-3.5\text{ V}))^2$
= **1.653 mA**

(c) $V_{GS} = V_P = -3.5$ V, I_D = **0 mA**

(d) $V_{GS} < V_P = -3.5$ V, I_D = **0 mA**

12. V_{GS} = **0 V**, I_D = **16 mA**
$V_{GS} = 0.3V_P = 0.3(-5\text{ V})$ = **–1.5 V**, $I_D = I_{DSS}/2$ = **8 mA**
$V_{GS} = 0.5V_P = 0.5(-5\text{ V})$ = **–2.5 V**, $I_D = I_{DSS}/4$ = **4 mA**
$V_{GS} = V_P$ = **–5 V**, I_D = **0 mA**

13. $V_{GS} = 0$ V, $I_D = I_{DSS}$ = **7.5 mA**
$V_{GS} = 0.3V_P = (0.3)(4\text{ V}) = 1.2$ V, $I_D = I_{DSS}/2 = 7.5\text{ mA}/2$ = **3.75 mA**
$V_{GS} = 0.5V_P = (0.5)(4\text{ V}) = 2$ V, $I_D = I_{DSS}/4 = 7.5\text{ mA}/4$ = **1.875 mA**
$V_{GS} = V_P = 4$ V, I_D = **0 mA**

14. (a) $I_D = I_{DSS}(1 - V_{GS}/V_P)^2 = 6\text{ mA}(1 - (-2\text{ V})/(-4.5\text{ V}))^2$
= **1.852 mA**
$I_D = I_{DSS}(1 - V_{GS}/V_P)^2 = 6\text{ mA}(1 - (-3.6\text{ V})/(-4.5\text{ V}))^2$
= **0.24 mA**

(b) $V_{GS} = V_P\left(1 - \sqrt{\frac{I_D}{I_{DSS}}}\right) = (-4.5\text{ V})\left(1 - \sqrt{\frac{3\text{ mA}}{6\text{ mA}}}\right)$
= **–1.318 V**
$V_{GS} = V_P\left(1 - \sqrt{\frac{I_D}{I_{DSS}}}\right) = (-4.5\text{ V})\left(1 - \sqrt{\frac{5.5\text{ mA}}{6\text{ mA}}}\right)$
= **–0.192 V**

15. $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$
$3\text{ mA} = I_{DSS}(1 - (-3\text{ V})/(-6\text{ V}))^2$
$3\text{ mA} = I_{DSS}(0.25)$
I_{DSS} = **12 mA**

16. From Fig. 6.22:

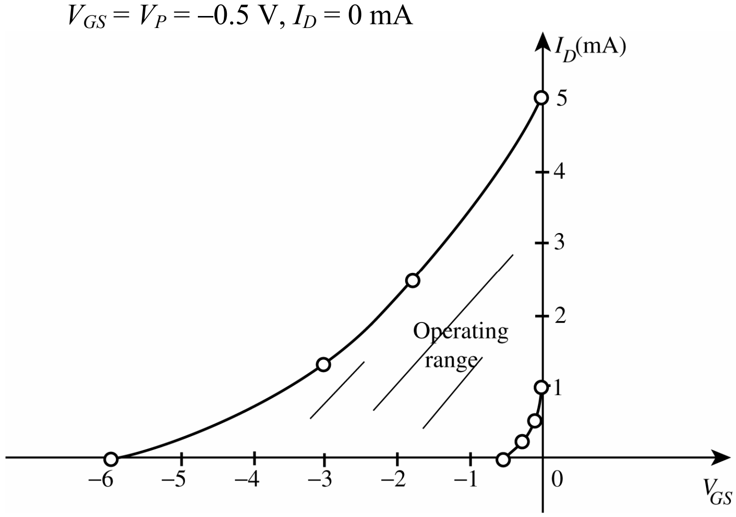
$-0.5 \text{ V} < V_P < -6 \text{ V}$
$1 \text{ mA} < I_{DSS} < 5 \text{ mA}$

For $I_{DSS} = 5$ mA and $V_P = -6$ V:

$V_{GS} = 0 \text{ V}, I_D = 5 \text{ mA}$
$V_{GS} = 0.3V_P = -1.8 \text{ V}, I_D = 2.5 \text{ mA}$
$V_{GS} = V_P/2 = -3 \text{ V}, I_D = 1.25 \text{ mA}$
$V_{GS} = V_P = -6 \text{ V}, I_D = 0 \text{ mA}$

For $I_{DSS} = 1$ mA and $V_P = -0.5$ V:

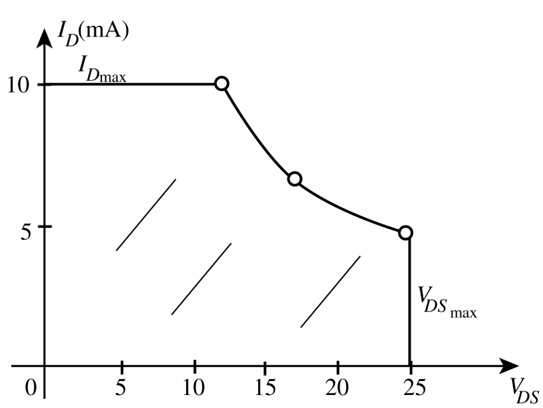
$V_{GS} = 0 \text{ V}, I_D = 1 \text{ mA}$
$V_{GS} = 0.3V_P = -0.15 \text{ V}, I_D = 0.5 \text{ mA}$
$V_{GS} = V_P/2 = -0.25 \text{ V}, I_D = 0.25 \text{ mA}$
$V_{GS} = V_P = -0.5 \text{ V}, I_D = 0 \text{ mA}$



17. $V_{DS} = V_{DS_{max}} = \mathbf{25\ V}$, $I_D = \dfrac{P_{D_{max}}}{V_{DS_{max}}} = \dfrac{120 \text{ mW}}{25 \text{ V}} = \mathbf{4.8\ mA}$

$I_D = I_{DSS} = \mathbf{10\ mA}$, $V_{DS} = \dfrac{P_{D_{max}}}{I_{DSS}} = \dfrac{120 \text{ mW}}{10 \text{ mA}} = \mathbf{12\ V}$

$I_D = \mathbf{7\ mA}$, $V_{DS} = \dfrac{P_{D_{max}}}{I_D} = \dfrac{120 \text{ mW}}{7 \text{ mA}} = \mathbf{17.14\ V}$



18. $V_{GS} = -0.5$ V, $I_D = 6.5$ mA
$V_{GS} = -1$ V, $I_D = 4$ mA } 2.5 mA

Determine ΔI_D above 4 mA line:

$$\frac{2.5 \text{ mA}}{0.5 \text{ V}} = \frac{x}{0.3 \text{ V}} \Rightarrow x = 1.5 \text{ mA}$$

$I_D = 4$ mA + 1.5 mA = **5.5 mA** corresponding with values determined from a purely graphical approach.

19. Yes, all knees of V_{GS} curves at or below $|V_P| = 3$ V.

20. From Fig 6.25, $I_{DSS} \cong 9$ mA
At $V_{GS} = -1$ V, $I_D = 4$ mA
$I_D = I_{DSS}(1 - V_{GS}/V_P)^2$

$$\sqrt{\frac{I_D}{I_{DSS}}} = 1 - V_{GS}/V_P$$

$$\frac{V_{GS}}{V_P} = 1 - \sqrt{\frac{I_D}{I_{DSS}}}$$

$$V_P = \frac{V_{GS}}{1-\sqrt{\dfrac{I_D}{I_{DSS}}}} = \frac{-1 \text{ V}}{1-\sqrt{\dfrac{4 \text{ mA}}{9 \text{ mA}}}}$$

= **–3 V** (an exact match)

21. $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$
= 9 mA$(1 - (-1 \text{ V})/(-3 \text{ V}))^2$
= **4 mA**, which compares very well with the level obtained using Fig. 6.25.

22. (a) $V_{DS} \cong 0.7$ V @ $I_D = 4$ mA (for $V_{GS} = 0$ V)

$$r = \frac{\Delta V_{DS}}{\Delta I_D} = \frac{0.7 \text{ V} - 0 \text{ V}}{4 \text{ mA} - 0 \text{ mA}} = \mathbf{175\ \Omega}$$

(b) For $V_{GS} = -0.5$ V, @ $I_D = 3$ mA, $V_{DS} = 0.7$ V

$$r = \frac{0.7 \text{ V}}{3 \text{ mA}} = \mathbf{233\ \Omega}$$

(c) $$r_d = \frac{r_o}{(1 - V_{GS}/V_P)^2} = \frac{175\ \Omega}{(1-(-0.5 \text{ V})/(-3 \text{ V}))^2}$$

= **252 Ω** vs. 233 Ω from part (b)

23. –

24. The construction of a depletion-type MOSFET and an enchancement-type MOSFET are identical except for the doping in the channel region. In the depletion MOSFET the channel is established by the doping process and exists with no gate-to-source voltage applied. As the gate-to-source voltage increases in magnitude the channel decreases in size until pinch-off occurs. The enhancement MOSFET does not have a channel established by the doping sequence but relies on the gate-to-source voltage to create a channel. The larger the magnitude of the applied gate-to-source voltage, the larger the available channel.

25. –

26. At V_{GS} = 0 V, I_D = **6 mA**
At V_{GS} = –1 V, I_D = 6 mA(1 – (–1 V)/(–3 V))^2 = **2.66 mA**
At V_{GS} = +1 V, I_D = 6 mA(1 – (+1 V)/(–3 V))^2 = 6 mA(1.333)^2 = **10.667 mA**
At V_{GS} = +2 V, I_D = 6 mA(1 – (+2 V)/(–3 V))^2 = 6 mA(1.667)^2 = **16.67 mA**

V_{GS}	I_D	
–1 V	2.66 mA	ΔI_D = **3.34 mA** (–1 V to 0)
0	6.0 mA	ΔI_D = **4.67 mA** (0 to +1 V)
+1 V	10.67 mA	ΔI_D = **6 mA** (+1 V to +2 V)
+2 V	16.67 mA	

From –1 V to 0 V, ΔI_D = 3.34 mA
while from +1 V to +2 V, ΔI_D = 6 mA – almost a 2:1 margin.
In fact, as V_{GS} becomes more and more positive, I_D will increase at a faster and faster rate due to the squared term in Shockley's equation.

27. V_{GS} = 0 V, $I_D = I_{DSS}$ = 12 mA; V_{GS} = –8 V, I_D = 0 mA; $V_{GS} = \frac{V_P}{2}$ = –4 V, I_D = 3 mA;
$V_{GS} = 0.3V_P$ = –2.4 V, I_D = 6 mA; V_{GS} = –6 V, I_D = 0.75 mA

28. From problem 20:

$$V_P = \frac{V_{GS}}{1-\sqrt{\frac{I_D}{I_{DSS}}}} = \frac{+1\text{ V}}{1-\sqrt{\frac{14\text{ mA}}{9.5\text{ mA}}}} = \frac{+1\text{ V}}{1-\sqrt{1.473}} = \frac{+1\text{ V}}{1-1.21395}$$

$$= \frac{1}{-0.21395} \cong \mathbf{-4.67\ V}$$

29. $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$

$$I_{DSS} = \frac{I_D}{(1-V_{GS}/V_P)^2} = \frac{4\text{ mA}}{(1-(-2\text{ V})/(-5\text{ V}))^2} = \mathbf{11.11\ mA}$$

30. From problem 14(b):

$$V_{GS} = V_P\left(1-\sqrt{\frac{I_D}{I_{DSS}}}\right) = (-5\text{ V})\left(1-\sqrt{\frac{20\text{ mA}}{2.9\text{ mA}}}\right)$$

= (–5 V)(1 – 2.626) = (–5 V)(–1.626)
= **8.13 V**

31. From Fig. 6.34, $P_{D_{max}}$ = 200 mW, I_D = 8 mA

$P = V_{DS}I_D$

and $V_{DS} = \frac{P_{max}}{I_D} = \frac{200\text{ mW}}{8\text{ mA}} = \mathbf{25\ V}$

32. (a) In a depletion-type MOSFET the channel exists in the device and the applied voltage V_{GS} controls the size of the channel. In an enhancement-type MOSFET the channel is not established by the construction pattern but induced by the applied control voltage V_{GS}.

(b) –

(c) Briefly, an applied gate-to-source voltage greater than V_T will establish a channel between drain and source for the flow of charge in the output circuit.

33. (a) $I_D = k(V_{GS} - V_T)^2 = 0.4 \times 10^{-3}(V_{GS} - 3.5)^2$

V_{GS}	I_D
3.5 V	0
4 V	0.1 mA
5 V	0.9 mA
6 V	2.5 mA
7 V	4.9 mA
8 V	8.1 mA

(b) $I_D = 0.8 \times 10^{-3}(V_{GS} - 3.5)^2$

V_{GS}	I_D	
3.5 V	0	For same levels of V_{GS}, I_D attains
4 V	0.2 mA	twice the current level as part (a).
5 V	1.8 mA	Transfer curve has steeper slope.
6 V	5.0 mA	For both curves, $I_D = 0$ mA for
7 V	9.8 mA	$V_{GS} < 3.5$ V.
8 V	16.2 mA	

34. (a) $k = \dfrac{I_{D(\text{on})}}{\left(V_{GS(\text{on})} - V_T\right)^2} = \dfrac{4\text{ mA}}{(6\text{ V} - 4\text{ V})^2} = 1\text{ mA/V}^2$

$I_D = k(V_{GS} - V_T)^2 = \mathbf{1 \times 10^{-3}(V_{GS} - 4\ V)^2}$

(b) For $V_{GS} < V_T = 4$ V, $I_D = 0$ mA

V_{GS}	I_D
4 V	0 mA
5 V	1 mA
6 V	4 mA
7 V	9 mA
8 V	16 mA

(c) ($V_{GS} < V_T$)

V_{GS}	I_D
2 V	0 mA
5 V	1 mA
10 V	36 mA

35. From Fig. 6.58, $V_T = 2.0$ V

At $I_D = 6.5$ mA, $V_{GS} = 5.5$ V: $I_D = k(V_{GS} - V_T)^2$

$6.5 \text{ mA} = k(5.5 \text{ V} - 2 \text{ V})^2$

$k = \mathbf{5.31 \times 10^{-4}}$

$I_D = \mathbf{5.31 \times 10^{-4}(V_{GS} - 2)^2}$

36. $I_D = k\left(V_{GS(\text{on})} - V_T\right)^2$

and $\left(V_{GS(\text{on})} - V_T\right)^2 = \dfrac{I_D}{k}$

$V_{GS(\text{on})} - V_T = \sqrt{\dfrac{I_D}{k}}$

$V_T = V_{GS(\text{on})} - \sqrt{\dfrac{I_D}{k}}$

$= 4 \text{ V} - \sqrt{\dfrac{3 \text{ mA}}{0.4 \times 10^{-3}}} = 4 \text{ V} - \sqrt{7.5} \text{ V}$

$= 4 \text{ V} - 2.739 \text{ V}$

$= \mathbf{1.261 \text{ V}}$

37. $I_D = k(V_{GS} - V_T)^2$

$\dfrac{I_D}{k} = (V_{GS} - V_T)^2$

$\sqrt{\dfrac{I_D}{k}} = V_{GS} - V_T$

$V_{GS} = V_T + \sqrt{\dfrac{I_D}{k}} = 5 \text{ V} + \sqrt{\dfrac{30 \text{ mA}}{0.06 \times 10^{-3}}}$

$= \mathbf{27.36 \text{ V}}$

38. Enhancement-type MOSFET:

$I_D = k(V_{GS} - V_T)^2$

$$\frac{dI_D}{dV_{GS}} = 2k(V_{GS} - V_T)\left[\underbrace{\frac{d}{dV_{GS}}(V_{GS} - V_T)}_{1}\right]$$

$$\frac{dI_D}{dV_{GS}} = \mathbf{2k(V_{GS} - V_T)}$$

Depletion-type MOSFET:

$I_D = I_{DSS}(1 - V_{GS}/V_P)^2$

$$\frac{dI_D}{dV_{GS}} = I_{DSS}\frac{d}{dV_{GS}}\left(1-\frac{V_{GS}}{V_P}\right)^2$$

$$= I_{DSS}\,2\underbrace{\left[1-\frac{V_{GS}}{V_P}\right]\frac{d}{dV_{GS}}\left[0-\frac{V_{GS}}{V_P}\right]}_{-\frac{1}{V_P}}$$

$$= 2I_{DSS}\left(1-\frac{V_{GS}}{V_P}\right)\left(-\frac{1}{V_P}\right)$$

$$= -\frac{2I_{DSS}}{V_P}\left(1-\frac{V_{GS}}{V_P}\right)$$

$$= -\frac{2I_{DSS}}{V_P}\left(\frac{V_P}{V_P}\right)\left(1-\frac{V_{GS}}{V_P}\right)$$

$$\frac{dI_D}{dV_{GS}} = \mathbf{\frac{2I_{DSS}}{V_P^2}(V_{GS}-V_P)}$$

For both devices $\frac{dI_D}{dV_{GS}} = k_1(V_{GS} - K_2)$

revealing that the drain current of each will increase at about the same rate.

39. $I_D = k(V_{GS} - V_T)^2 = 0.45 \times 10^{-3}(V_{GS} - (-5\text{ V}))^2$
$= 0.45 \times 10^{-3}(V_{GS} + 5\text{ V})^2$
$V_{GS} = -5$ V, $I_D = 0$ mA; $V_{GS} = -6$ V, $I_D = 0.45$ mA; $V_{GS} = -7$ V, $I_D = 1.8$ mA;
$V_{GS} = -8$ V, $I_D = 4.05$ mA; $V_{GS} = -9$ V, $I_D = 7.2$ mA; $V_{GS} = -10$ V, $I_D = 11.25$ mA

41. –

42. (a) –

(b) For the "on" transistor: $R = \frac{V}{I} = \frac{0.1\text{ V}}{4\text{ mA}}$ = **25 ohms**

For the "off" transistor: $R = \frac{V}{I} = \frac{4.9\text{ V}}{0.5\ \mu\text{A}}$ = **9.8 MΩ**

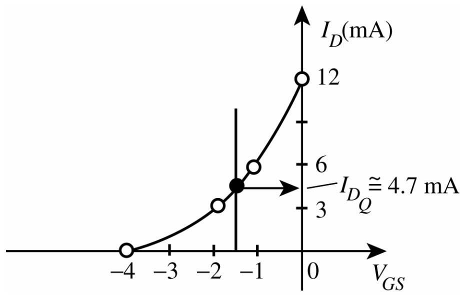
Absolutely, the high resistance of the "off" resistance will ensure V_o is very close to 5 V.

43. –

Chapter 7

1. (a) $V_{GS} = 0$ V, $I_D = I_{DSS} = 12$ mA
$V_{GS} = V_P = -4$ V, $I_D = 0$ mA
$V_{GS} = V_P/2 = -2$ V, $I_D = I_{DSS}/4 = 3$ mA
$V_{GS} = 0.3V_P = -1.2$ V, $I_D = I_{DSS}/2 = 6$ mA

(b)



(c) $I_{D_Q} \cong$ **4.7 mA**

$V_{DS_Q} = V_{DD} - I_{D_Q}R_D = 12\text{ V} - (4.7\text{ mA})(1.2\text{ k}\Omega)$
$= \mathbf{6.36\ V}$

(d) $I_{D_Q} = I_{DSS}(1 - V_{GS}/V_P)^2 = 12\text{ mA}(1 - (-1.5\text{ V})/(-4\text{ V}))^2$
$= \mathbf{4.69\ mA}$

$V_{DS_Q} = V_{DD} - I_{D_Q}R_D = 12\text{ V} - (4.69\text{ mA})(1.2\text{ k}\Omega)$
$= \mathbf{6.37\ V}$
excellent comparison

2. (a) $I_{D_Q} = I_{DSS}(1 - V_{GS}/V_P)^2$
$= 10\text{ mA}\left(1-(-3\text{ V})/(-4.5\text{ V})\right)^2$
$= 10\text{ mA}(0.333)^2$
$I_{D_Q} = \mathbf{1.11\ mA}$

(b) $V_{GS_Q} = \mathbf{-3\ V}$

(c) $V_{DS} = V_{DD} - I_D(R_D + R_S)$
$= 16\text{ V} - (1.11\text{ mA})(2.2\text{ k}\Omega)$
$= 16\text{ V} - 2.444\text{ V}$
$= \mathbf{13.56\ V}$
$V_D = V_{DS} = \mathbf{13.56\ V}$
$V_G = V_{GS_Q} = \mathbf{-3\ V}$
$V_S = \mathbf{0\ V}$

3. (a) $I_{D_Q} = \frac{V_{DD} - V_D}{R_D} = \frac{14 \text{ V} - 9 \text{ V}}{1.6 \text{ k}\Omega} = \mathbf{3.125 \text{ mA}}$

(b) $V_{DS} = V_D - V_S = 9 \text{ V} - 0 \text{ V} = \mathbf{9 \text{ V}}$

(c) $I_D = I_{DSS}(1 - V_{GS}/V_P)^2 \Rightarrow V_{GS} = V_P\left(1 - \sqrt{\frac{I_D}{I_{DSS}}}\right)$

$V_{GS} = (-4 \text{ V})\left(1 - \sqrt{\frac{3.125 \text{ mA}}{8 \text{ mA}}}\right)$

$= -1.5 \text{ V}$

$\therefore V_{GG} = \mathbf{1.5 \text{ V}}$

4. $V_{GS_Q} = 0 \text{ V}, I_D = I_{DSS} = 5 \text{ mA}$

$V_D = V_{DD} - I_D R_D$
$= 20 \text{ V} - (5 \text{ mA})(2.2 \text{ k}\Omega)$
$= 20 \text{ V} - 11 \text{ V}$
$= \mathbf{9 \text{ V}}$

5. $V_{GS} = V_P = -4 \text{ V}$

$\therefore I_{D_Q} = 0 \text{ mA}$

and $V_D = V_{DD} - I_{D_Q} R_D = 18 \text{ V} - (0)(2 \text{ k}\Omega)$

$= \mathbf{18 \text{ V}}$

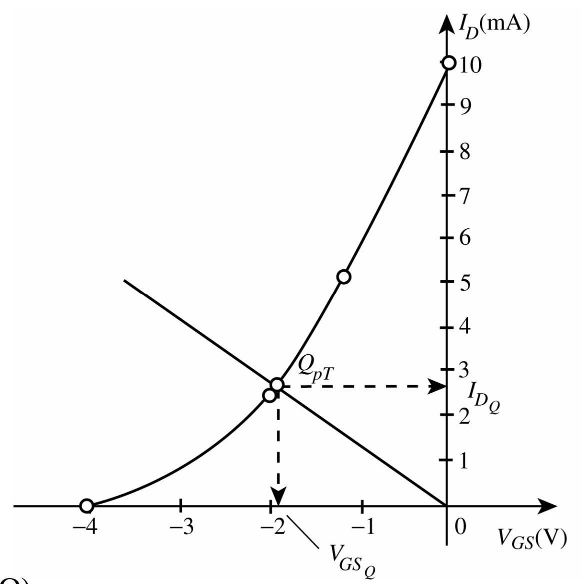
6. (a)(b) $V_{GS} = 0 \text{ V}, I_D = 10 \text{ mA}$

$V_{GS} = V_P = -4 \text{ V}, I_D = 0 \text{ mA}$

$V_{GS} = \frac{V_P}{2} = -2 \text{ V}, I_D = 2.5 \text{ mA}$

$V_{GS} = 0.3V_P = -1.2 \text{ V}, I_D = 5 \text{ mA}$

$V_{GS} = -I_D R_S$
$I_D = 5 \text{ mA}$:
$V_{GS} = -(5 \text{ mA})(0.75 \text{ k}\Omega)$
$= -3.75 \text{ V}$



(c) $I_{D_Q} \cong \mathbf{2.7 \text{ mA}}$

$V_{GS_Q} \cong \mathbf{-1.9 \text{ V}}$

(d) $V_{DS} = V_{DD} - I_D(R_D + R_S)$
$= 18 \text{ V} - (2.7 \text{ mA})(1.5 \text{ k}\Omega + 0.75 \text{ k}\Omega)$
$= \mathbf{11.93 \text{ V}}$

$V_D = V_{DD} - I_D R_D$
$= 18 \text{ V} - (2.7 \text{ mA})(1.5 \text{ k}\Omega)$
$= \mathbf{13.95 \text{ V}}$

$V_G = \mathbf{0 \text{ V}}$

$V_S = I_S R_S = I_D R_S$
$= (2.7 \text{ mA})(0.75 \text{ k}\Omega)$
$= \mathbf{2.03 \text{ V}}$

7. $I_D = I_{DSS}(1 - V_{GS}/V_P)^2 = I_{DSS}\left(1 + \frac{2I_D R_S}{V_P} + \frac{I_D^2 R_S^2}{V_P^2}\right)$

$$\left(\frac{I_{DSS} R_S^2}{V_P^2}\right) I_D^2 + \left(\frac{2I_{DSS} R_S}{V_P} - 1\right) I_D + I_{DSS} = 0$$

Substituting: $351.56 I_D^2 - 4.75 I_D + 10 \text{ mA} = 0$

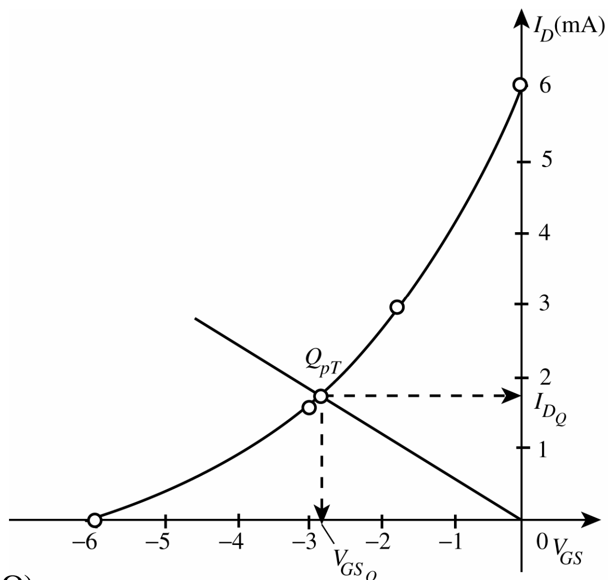
$I_D = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} = 10.91$ mA (crossed out), 2.60 mA

I_{D_Q} = **2.6 mA** (exact match #6)

$V_{GS} = -I_D R_S = -(2.60 \text{ mA})(0.75 \text{ k}\Omega)$
= **−1.95 V** vs. −2 V (#6)

8. $V_{GS} = 0$ V, $I_D = I_{DSS} = 6$ mA
$V_{GS} = V_P = -6$ V, $I_D = 0$ mA
$V_{GS} = \frac{V_P}{2} = -3$ V, $I_D = 1.5$ mA

$V_{GS} = 0.3V_P = -1.8$ V, $I_D = 3$ mA
$V_{GS} = -I_D R_S$
$I_D = 2$ mA:
$V_{GS} = -(2 \text{ mA})(1.6 \text{ k}\Omega)$
= −3.2 V



(a) I_{D_Q} = **1.7 mA**
V_{GS_Q} = **−2.8 V**

(b) $V_{DS} = V_{DD} - I_D(R_D + R_S)$
= 12 V − (1.7 mA)(2.2 kΩ + 1.6 kΩ)
= **5.54 V**
$V_D = V_{DD} - I_D R_D$
= 12 V − (1.7 mA)(2.2 kΩ)
= **8.26 V**
V_G = **0 V**
$V_S = I_S R_S = I_D R_S$
= (1.7 mA)(1.6 kΩ)
= **2.72 V** (vs. 2.8 V from $V_S = (V_{GS_Q})$)

9. (a) $I_{D_Q} = I_S = \frac{V_S}{R_S} = \frac{1.7 \text{ V}}{0.51 \text{ k}\Omega}$ = **3.33 mA**

(b) $V_{GS_Q} = -I_{D_Q} R_S = -(3.33 \text{ mA})(0.51 \text{ k}\Omega)$
≅ **−1.7 V**

(c) $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$
$3.33 \text{ mA} = I_{DSS}(1 - (-1.7 \text{ V})/(-4 \text{ V}))^2$
$3.33 \text{ mA} = I_{DSS}(0.331)$
$I_{DSS} =$ **10.06 mA**

(d) $V_D = V_{DD} - I_{D_Q} R_D$
$= 18 \text{ V} - (3.33 \text{ mA})(2 \text{ k}\Omega) = 18 \text{ V} - 6.66 \text{ V}$
= **11.34 V**

(e) $V_{DS} = V_D - V_S = 11.34 \text{ V} - 1.7 \text{ V}$
= **9.64 V**

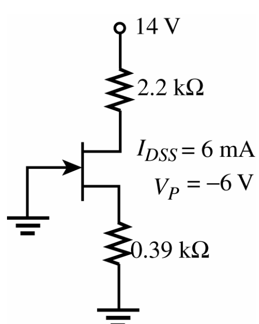
10. (a) $V_{GS} = 0 \text{ V}$
$\therefore I_D = I_{DSS} =$ **4.5 mA**

(b) $V_{DS} = V_{DD} - I_D(R_D + R_S)$
$= 20 \text{ V} - (4.5 \text{ mA})(2.2 \text{ k}\Omega + 0.68 \text{ k}\Omega)$
$= 20 \text{ V} - 12.96$
= **7.04 V**

(c) $V_D = V_{DD} - I_D R_D$
$= 20 \text{ V} - (4.5 \text{ mA})(2.2 \text{ k}\Omega)$
= **10.1 V**

(d) $V_S = I_S R_S = I_D R_S$
$= (4.5 \text{ mA})(0.68 \text{ k}\Omega)$
= **3.06 V**

11. Network redrawn:



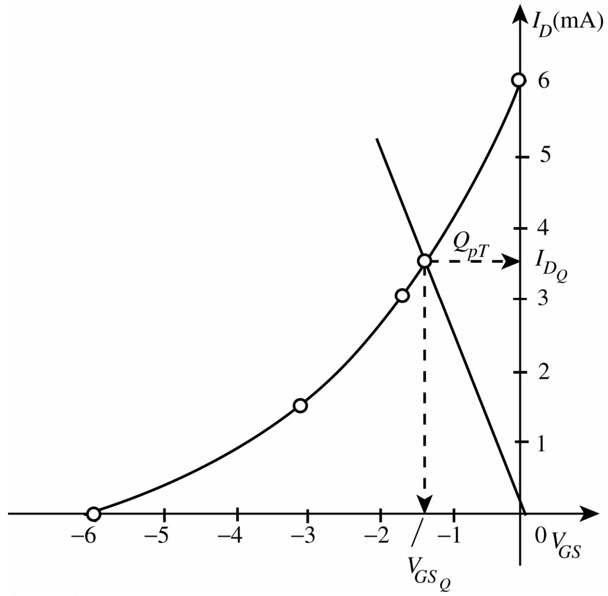
$V_{GS} = 0 \text{ V}, I_D = I_{DSS} = 6 \text{ mA}$
$V_{GS} = V_P = -6 \text{ V}, I_D = 0 \text{ mA}$
$V_{GS} = \frac{V_P}{2} = -3 \text{ V}, I_D = 1.5 \text{ mA}$
$V_{GS} = 0.3V_P = -1.8 \text{ V}, I_D = 3 \text{ mA}$
$V_{GS} = -I_D R_S = -I_D(0.39 \text{ k}\Omega)$
For $I_D = 5 \text{ mA}, V_{GS} = -1.95 \text{ V}$

From graph $I_{D_Q} \cong$ **3.55 mA**

$V_{GS_Q} \cong$ **−1.4 V**

$V_S = -\left(V_{GS_Q}\right) = -(-1.4 \text{ V})$

$= $ **+1.4 V**



12. (a) $V_G = \dfrac{R_2}{R_1 + R_2} V_{DD} = \dfrac{110 \text{ k}\Omega(20 \text{ V})}{910 \text{ k}\Omega + 110 \text{ k}\Omega}$

$= $ **2.16 V**

$V_{GS} = 0$ V, $I_D = I_{DSS} = 10$ mA

$V_{GS} = V_P = -3.5$ V, $I_D = 0$ mA

$V_{GS} = \dfrac{V_P}{2} = -1.75$ V, $I_D = 2.5$ mA

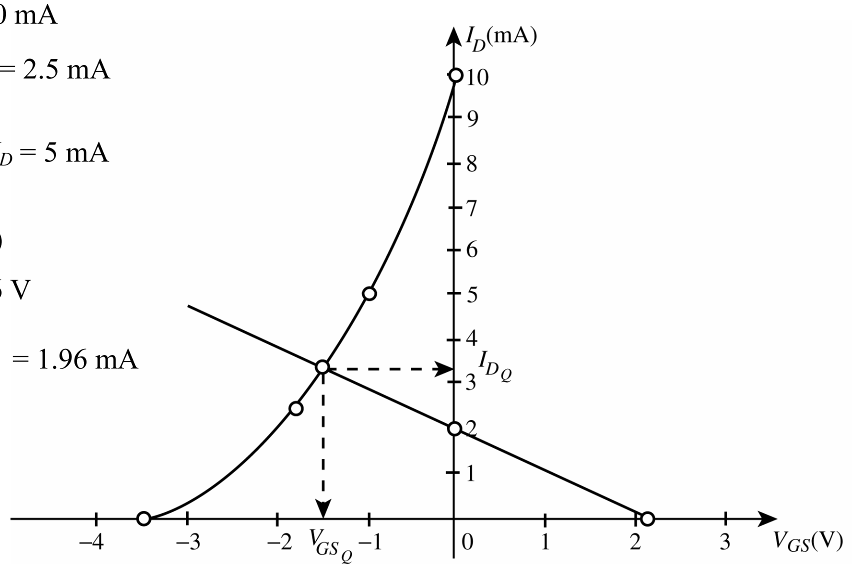
$V_{GS} = 0.3V_P = -1.05$ V, $I_D = 5$ mA

$V_{GS_Q} = V_G - I_D R_S$

$V_{GS_Q} = 2.16 - I_D(1.1 \text{ k}\Omega)$

$I_D = 0$: $V_{GS_Q} = V_G = 2.16$ V

$V_{GS_Q} = 0$ V, $I_D = \dfrac{2.16 \text{ V}}{1.1 \text{ k}\Omega} = 1.96$ mA



(b) $I_{D_Q} \cong$ **3.3 mA**

$V_{GS_Q} \cong$ **−1.5 V**

(c) $V_D = V_{DD} - I_{D_Q} R_D$

$= 20 \text{ V} - (3.3 \text{ mA})(2.2 \text{ k}\Omega)$

$= $ **12.74 V**

$V_S = I_S R_S = I_D R_S$

$= (3.3 \text{ mA})(1.1 \text{ k}\Omega)$

$= $ **3.63 V**

(d) $V_{DS_Q} = V_{DD} - I_{D_Q}(R_D + R_S)$

$= 20 \text{ V} - (3.3 \text{ mA})(2.2 \text{ k}\Omega + 1.1 \text{ k}\Omega)$

$= 20 \text{ V} - 10.89 \text{ V}$

$= $ **9.11 V**

13. (a) $I_D = I_{DSS} = 10$ mA, $V_P = -3.5$ V
$V_{GS} = 0$ V, $I_D = I_{DSS} = 10$ mA
$V_{GS} = V_P = -3.5$ V, $I_D = 0$ mA

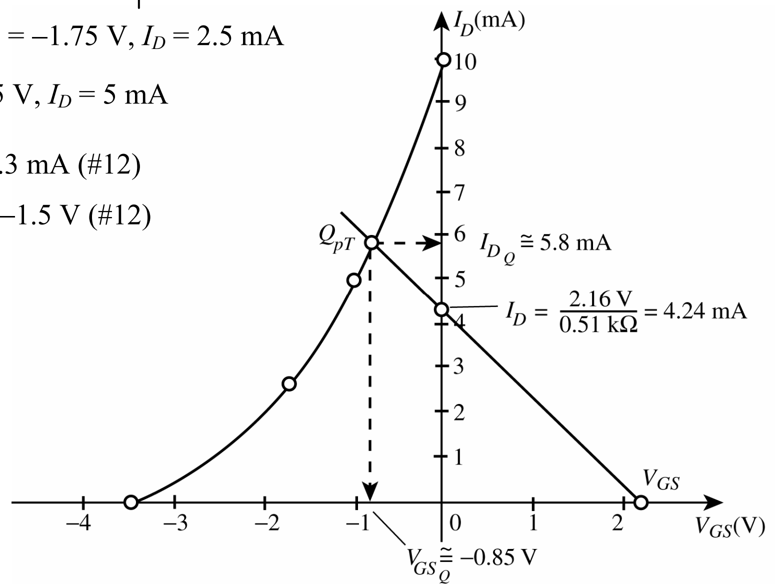
$$V_G = \frac{110\text{ k}\Omega(20\text{ V})}{110\text{ k}\Omega + 910\text{ k}\Omega} = \mathbf{2.16\ V}$$

$$V_{GS} = \frac{V_P}{2} = \frac{-3.5\text{ V}}{2} = -1.75\text{ V},\ I_D = 2.5\text{ mA}$$

$V_{GS} = 0.3V_P = -1.05$ V, $I_D = 5$ mA

$I_{D_Q} \cong$ **5.8 mA** vs. 3.3 mA (#12)

$V_{GS_Q} \cong$ **−0.85 V** vs. −1.5 V (#12)



(b) As R_S decreases, the intersection on the vertical axis increases. The maximum occurs at $I_D = I_{DSS} = 10$ mA.

$$\therefore R_{S_{\min}} = \frac{V_G}{I_{DSS}} = \frac{2.16\text{ V}}{10\text{ mA}} = \mathbf{216\ \Omega}$$

14. (a) $$I_D = \frac{V_{R_D}}{R_D} = \frac{V_{DD} - V_D}{R_D} = \frac{18\text{ V} - 9\text{ V}}{2\text{ k}\Omega} = \frac{9\text{ V}}{2\text{ k}\Omega} = \mathbf{4.5\ mA}$$

(b) $V_S = I_SR_S = I_DR_S = (4.5\text{ mA})(0.68\text{ k}\Omega)$
$= \mathbf{3.06\ V}$
$V_{DS} = V_{DD} - I_D(R_D + R_S)$
$= 18\text{ V} - (4.5\text{ mA})(2\text{ k}\Omega + 0.68\text{ k}\Omega)$
$= 18\text{ V} - 12.06\text{ V}$
$= \mathbf{5.94\ V}$

(c) $$V_G = \frac{R_2}{R_1 + R_2}V_{DD} = \frac{91\text{ k}\Omega(18\text{ V})}{750\text{ k}\Omega + 91\text{ k}\Omega} = \mathbf{1.95\ V}$$

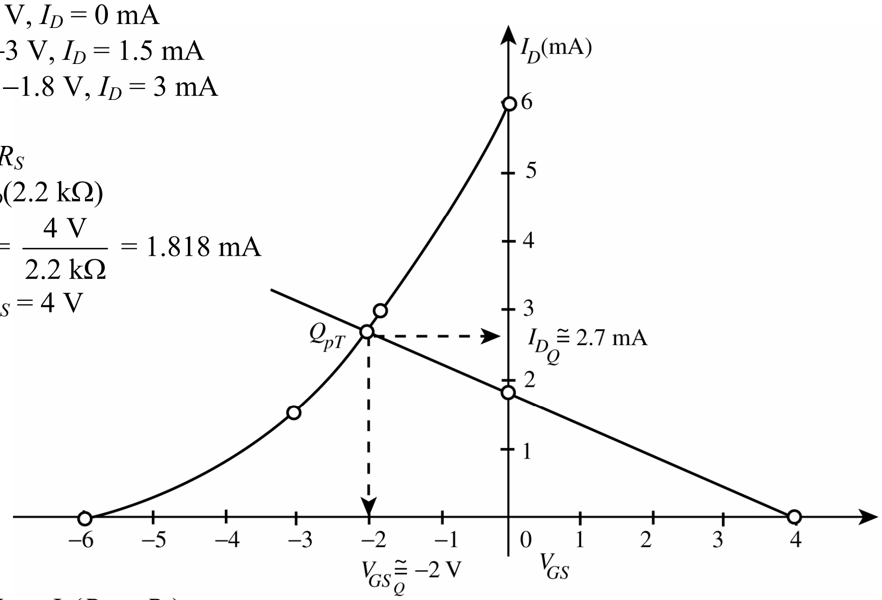
$V_{GS} = V_G - V_S = 1.95\text{ V} - 3.06\text{ V} = \mathbf{-1.11\ V}$

(d) $$V_P = \frac{V_{GS}}{1 - \sqrt{\dfrac{I_D}{I_{DSS}}}} = \frac{-1.11\text{ V}}{1 - \sqrt{\dfrac{4.5\text{ mA}}{8\text{ mA}}}} = \mathbf{-4.44\ V}$$
$= \mathbf{-1.48\ V}$

15. (a) $V_{GS} = 0$ V, $I_D = I_{DSS} = 6$ mA
$V_{GS} = V_P = -6$ V, $I_D = 0$ mA
$V_{GS} = V_P/2 = -3$ V, $I_D = 1.5$ mA
$V_{GS} = 0.3V_P = -1.8$ V, $I_D = 3$ mA

$V_{GS} = V_{SS} - I_D R_S$
$V_{GS} = 4\text{ V} - I_D(2.2\text{ k}\Omega)$
$V_{GS} = 0\text{ V}, I_D = \dfrac{4\text{ V}}{2.2\text{ k}\Omega} = 1.818\text{ mA}$
$I_D = 0$ mA, $V_{GS} = 4$ V

$I_{D_Q} \cong$ **2.7 mA**
$V_{GS_Q} \cong$ **−2 V**



(b) $V_{DS} = V_{DD} + V_{SS} - I_D(R_D + R_S)$
$= 16\text{ V} + 4\text{ V} - (2.7\text{ mA})(4.4\text{ k}\Omega)$
= **8.12 V**
$V_S = -V_{SS} + I_D R_S = -4\text{ V} + (2.7\text{ mA})(2.2\text{ k}\Omega)$
= **1.94 V**
or $V_S = -\left(V_{GS_Q}\right) = -(-2\text{ V}) =$ **+2 V**

16. (a) $I_D = \dfrac{V}{R} = \dfrac{V_{DD} + V_{SS} - V_{DS}}{R_D + R_S} = \dfrac{12\text{ V} + 3\text{ V} - 4\text{ V}}{3\text{ k}\Omega + 2\text{ k}\Omega} = \dfrac{11\text{ V}}{5\text{ k}\Omega} =$ **2.2 mA**

(b) $V_D = V_{DD} - I_D R_D = 12\text{ V} - (2.2\text{ mA})(3\text{ k}\Omega)$
= **5.4 V**
$V_S = I_S R_S + V_{SS} = I_D R_S + V_{SS}$
$= (2.2\text{ mA})(2\text{ k}\Omega) + (-3\text{ V})$
$= 4.4\text{ V} - 3\text{ V}$
= **1.4 V**

(c) $V_{GS} = V_G - V_S$
$= 0\text{ V} - 1.4\text{ V}$
= **−1.4 V**

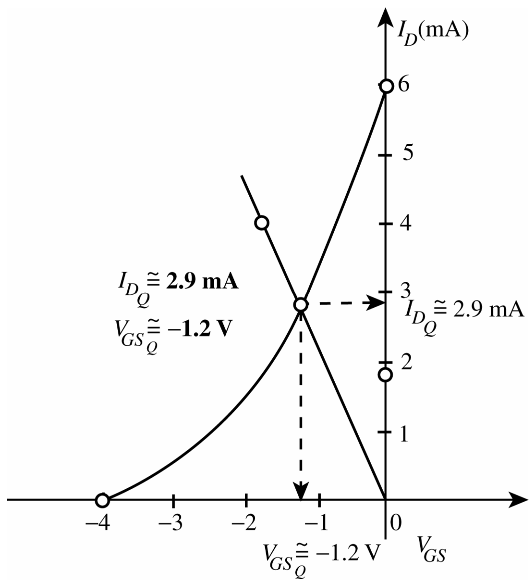
17. (a) $I_{D_Q} =$ **4 mA**

(b) $V_{D_Q} = 12\text{ V} - 4\text{ mA}(1.8\text{ k}\Omega) = 12\text{ V} - 7.2\text{ V} =$ **4.8 V**
$V_{DS_Q} =$ **4.8 V**

(c) $P_s = (12\text{ V})(4\text{ mA}) =$ **48 mW**
$P_d = (4.8\text{ V})(4\text{ mA}) =$ **19.2 mW**

18. $V_{GS} = 0$ V, $I_D = I_{DSS} = 6$ mA
$V_{GS} = V_P = -4$ V, $I_D = 0$ mA
$V_{GS} = V_P/2 = -2$ V, $I_D = I_{DSS}/4 = 1.5$ mA
$V_{GS} = 0.3V_P = -1.2$ V, $I_D = I_{DSS}/2 = 3$ mA

$V_{GS} = -I_DR_S = -I_D(0.43\text{ k}\Omega)$
$I_D = 4$ mA, $V_{GS} = -1.72$ V



(b) $V_{DS} = V_{DD} - I_D(R_D + R_S)$
$= 14\text{ V} - 2.9\text{ mA}(1.2\text{ k}\Omega + 0.43\text{ k}\Omega)$
$=$ **9.27 V**

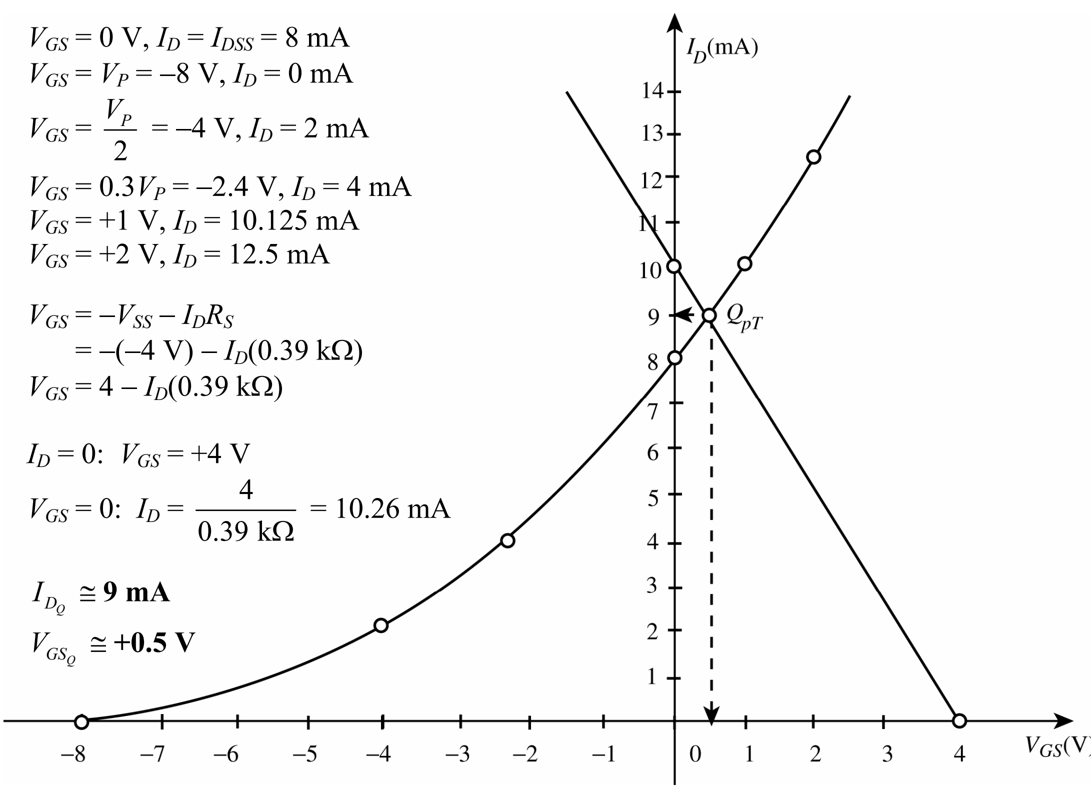
$V_D = V_{DD} - I_DR_D$
$= 14\text{ V} - (2.9\text{ mA})(1.2\text{ k}\Omega)$
$=$ **10.52 V**

19. (a) $V_{GS} = 0$ V, $I_D = I_{DSS} = 8$ mA
$V_{GS} = V_P = -8$ V, $I_D = 0$ mA
$V_{GS} = \dfrac{V_P}{2} = -4$ V, $I_D = 2$ mA
$V_{GS} = 0.3V_P = -2.4$ V, $I_D = 4$ mA
$V_{GS} = +1$ V, $I_D = 10.125$ mA
$V_{GS} = +2$ V, $I_D = 12.5$ mA

$V_{GS} = -V_{SS} - I_DR_S$
$= -(-4\text{ V}) - I_D(0.39\text{ k}\Omega)$
$V_{GS} = 4 - I_D(0.39\text{ k}\Omega)$

$I_D = 0$: $V_{GS} = +4$ V
$V_{GS} = 0$: $I_D = \dfrac{4}{0.39\text{ k}\Omega} = 10.26$ mA

$I_{D_Q} \cong$ **9 mA**
$V_{GS_Q} \cong$ **+0.5 V**



(b) $V_{DS} = V_{DD} - I_D(R_D + R_S) + V_{SS}$
$= 18\text{ V} - 9\text{ mA}(1.2\text{ k}\Omega + 0.39\text{ k}\Omega) + 4\text{ V}$
$= 22\text{ V} - 14.31\text{ V}$
$= \mathbf{7.69\text{ V}}$
$V_S = -\left(V_{GS_Q}\right) = \mathbf{-0.5\text{ V}}$

20. $I_D = k(V_{GS} - V_T)^2$

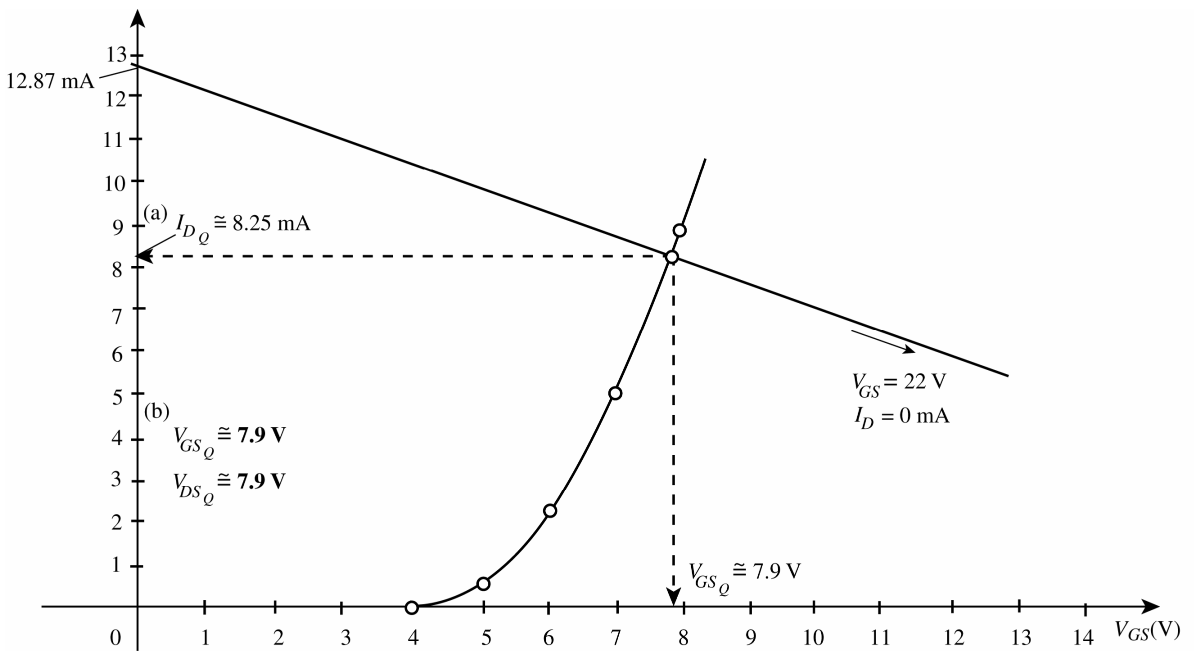
$$k = \frac{I_{D(\text{on})}}{\left(V_{GS(\text{on})} - V_{Th}\right)^2} = \frac{5\text{ mA}}{(7\text{ V} - 4\text{ V})^2} = \frac{5\text{ mA}}{9\text{ V}^2}$$

$K = 0.556 \times 10^{-3}\text{ A/V}^2$
and $I_D = \mathbf{0.556 \times 10^{-3}(V_{GS} - 4\text{ V})^2}$

$V_{DS} = V_{DD} - I_D(R_D + R_S)$

$$V_{DS} = 0\text{ V};\ I_D = \frac{V_{DD}}{R_D + R_S} = \frac{22\text{ V}}{1.2\text{ k}\Omega + 0.51\text{ k}\Omega} = 12.87\text{ mA}$$

$I_D = 0\text{ mA},\ V_{DS} = V_{DD} = 22\text{ V}$



(c) $V_D = V_{DD} - I_DR_D$
$= 22\text{ V} - (8.25\text{ mA})(1.2\text{ k}\Omega)$
$= \mathbf{12.1\text{ V}}$
$V_S = I_SR_S = I_DR_S$
$= (8.25\text{ mA})(0.51\text{ k}\Omega)$
$= \mathbf{4.21\text{ V}}$

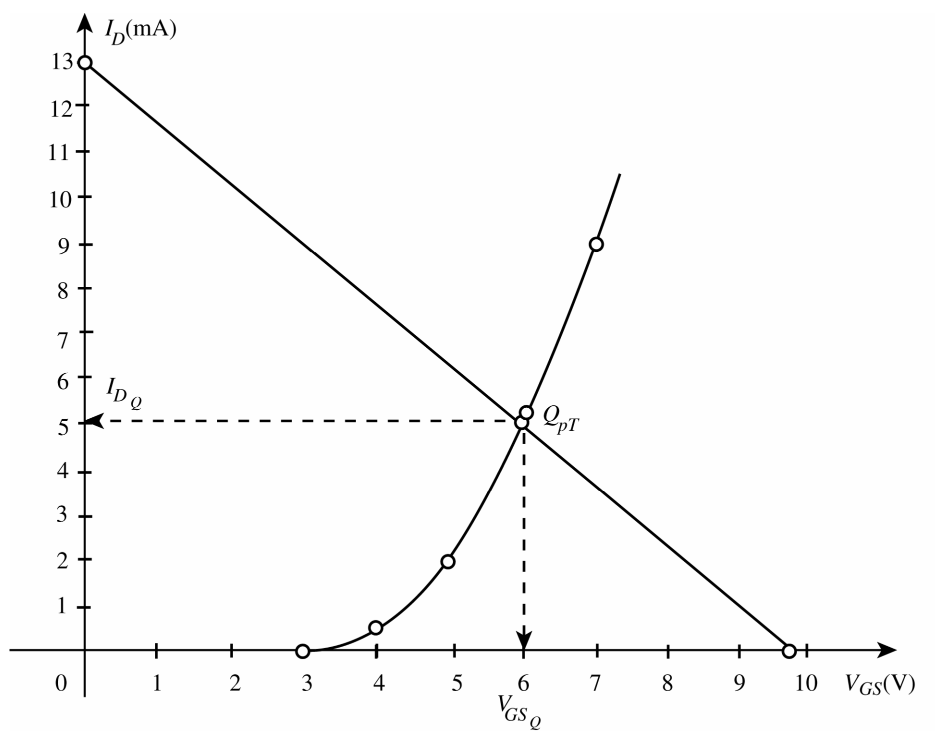
(d) $V_{DS} = V_D - V_S$
$= 12.1\text{ V} - 4.21\text{ V}$
$= \mathbf{7.89\text{ V}}$
vs. 7.9 V obtained graphically

21. (a) $V_G = \frac{R_2}{R_1 + R_2} V_{DD} = \frac{6.8\text{ M}\Omega}{10\text{ M}\Omega + 6.8\text{ M}\Omega}(24\text{ V}) = 9.71\text{ V}$

$V_{GS} = V_G - I_D R_S$
$V_{GS} = 9.71 - I_D(0.75\text{ k}\Omega)$
At $I_D = 0$ mA, $V_{GS} = 9.71$ V
At $V_{GS} = 0$ V, $I_D = \frac{9.71\text{ V}}{0.75\text{ k}\Omega} = 12.95$ mA

$$k = \frac{I_{D(\text{on})}}{\left(V_{GS(\text{on})} - V_{GS(Th)}\right)^2} = \frac{5\text{ mA}}{(6\text{ V} - 3\text{ V})^2} = \frac{5\text{ mA}}{(3\text{ V})^2}$$
$= 0.556 \times 10^{-3}\text{A/V}^2$
$\therefore I_D = \mathbf{0.556 \times 10^{-3}(V_{GS} - 3\text{ V})^2}$

V_{GS}	I_D
3 V	0 mA
4 V	0.556 mA
5 V	2.22 mA
6 V	5 mA
7 V	8.9 mA



$I_{D_Q} \cong \mathbf{5\text{ mA}}$
$V_{GS_Q} \cong \mathbf{6\text{ V}}$

(b) $V_D = V_{DD} - I_D R_D = 24\text{ V} - (5\text{ mA})(2.2\text{ k}\Omega)$

$= \mathbf{13\text{ V}}$

$V_S = I_S R_S = I_D R_S$

$= (5\text{ mA})(0.75\text{ k}\Omega)$

$= \mathbf{3.75\text{ V}}$

22. (a) $V_G = \dfrac{R_2}{R_1 + R_2} V_{CC} = \dfrac{18\text{ k}\Omega}{91\text{ k}\Omega + 18\text{ k}\Omega}(20\text{ V})$

$= \mathbf{3.3\text{ V}}$

(b) $V_{GS} = 0\text{ V}, I_D = I_{DSS} = 6\text{ mA}$

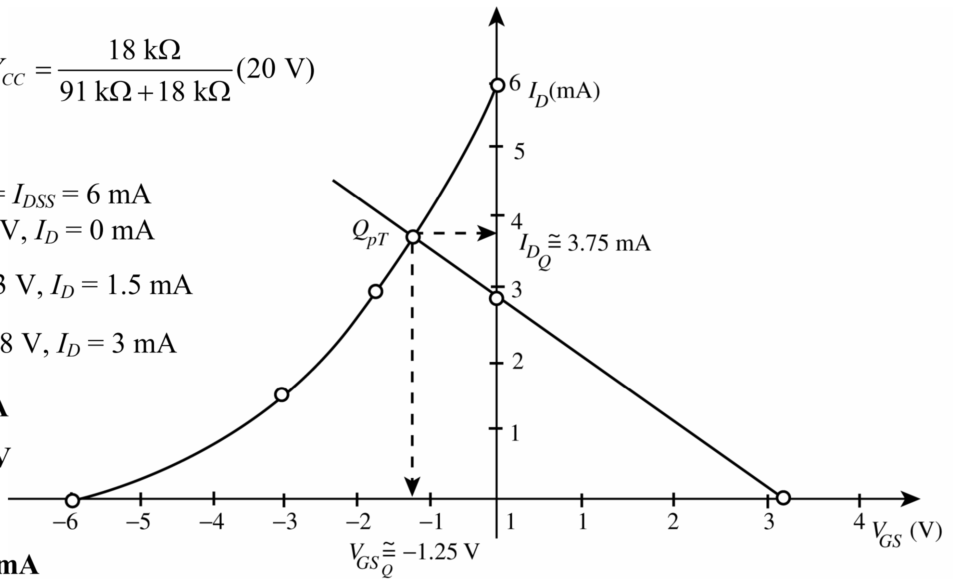
$V_{GS} = V_P = -6\text{ V}, I_D = 0\text{ mA}$

$V_{GS} = \dfrac{V_P}{2} = -3\text{ V}, I_D = 1.5\text{ mA}$

$V_{GS} = V_P = -1.8\text{ V}, I_D = 3\text{ mA}$

$I_{D_Q} \cong \mathbf{3.75\text{ mA}}$

$V_{GS_Q} \cong \mathbf{-1.25\text{ V}}$



(c) $I_E = I_D = \mathbf{3.75\text{ mA}}$

(d) $I_B = \dfrac{I_C}{\beta} = \dfrac{3.75\text{ mA}}{160} = \mathbf{23.44\ \mu A}$

(e) $V_D = V_E = V_B - V_{BE} = V_{CC} - I_B R_B - V_{BE} = 20\text{ V} - (23.44\ \mu\text{A})(330\text{ k}\Omega) - 0.7\text{ V}$

$= \mathbf{11.56\text{ V}}$

(f) $V_C = V_{CC} - I_C R_C = 20\text{ V} - (3.75\text{ mA})(1.1\text{ k}\Omega)$

$= \mathbf{15.88\text{ V}}$

23. Testing:

$\beta R_E \geq 10 R_2$

$(100)(1.2\text{ k}\Omega) \geq 10(10\text{ k}\Omega)$

$120\text{ k}\Omega > 100\text{ k}\Omega$ (satisfied)

(a) $V_B = V_G = \dfrac{R_2 V_{DD}}{R_1 + R_2} = \dfrac{10\text{ k}\Omega(16\text{ V})}{40\text{ k}\Omega + 10\text{ k}\Omega}$

$= \mathbf{3.2\text{ V}}$

(b) $V_E = V_B - V_{BE} = 3.2\text{ V} - 0.7\text{ V} = \mathbf{2.5\text{ V}}$

(c) $I_E = \dfrac{V_E}{R_E} = \dfrac{2.5\text{ V}}{1.2\text{ k}\Omega} = \mathbf{2.08\text{ mA}}$

$I_C \cong I_E = \mathbf{2.08\text{ mA}}$

$I_D = I_C = \mathbf{2.08\text{ mA}}$

(d) $I_B = \dfrac{I_C}{\beta} = \dfrac{2.08\text{ mA}}{100}$ = **20.8 μA**

(e) $V_C = V_G - V_{GS}$

$$V_{GS} = V_P\left(1 - \sqrt{\frac{I_D}{I_{DSS}}}\right)$$

$$= (-6\text{ V})\left(1 - \sqrt{\frac{2.08\text{ mA}}{6\text{ mA}}}\right)$$

$= -2.47$ V

$V_C = 3.2 - (-2.47\text{ V})$

= **5.67 V**

$V_S = V_C$ = **5.67 V**

$V_D = V_{DD} - I_DR_D$

= 16 V – (2.08 mA)(2.2 kΩ)

= **11.42 V**

(f) $V_{CE} = V_C - V_E = 5.67\text{ V} - 2.5\text{ V}$

= **3.17 V**

(g) $V_{DS} = V_D - V_S = 11.42\text{ V} - 5.67\text{ V}$

= **5.75 V**

24. $V_{GS} = V_P\left(1 - \sqrt{\dfrac{I_D}{I_{DSS}}}\right) = (-6\text{ V})\left(1 - \sqrt{\dfrac{4\text{ mA}}{8\text{ mA}}}\right)$

$= -1.75$ V

$V_{GS} = -I_DR_S$: $R_S = -\dfrac{V_{GS}}{I_D} = \dfrac{-(-1.75\text{ V})}{4\text{ mA}}$ = **0.44 kΩ**

$R_D = 3R_S = 3(0.44\text{ kΩ})$ = **1.32 kΩ**

Standard values: R_S = **0.43 kΩ**

R_D = **1.3 kΩ**

25. $V_{GS} = V_P\left(1 - \sqrt{\dfrac{I_D}{I_{DSS}}}\right) = (-4\text{ V})\left(1 - \sqrt{\dfrac{2.5\text{ mA}}{10\text{ mA}}}\right)$

= **–2 V**

$V_{GS} = V_G - V_S$

and $V_S = V_G - V_{GS} = 4\text{ V} - (-2\text{ V})$

= 6 V

$R_S = \dfrac{V_S}{I_D} = \dfrac{6\text{ V}}{2.5\text{ mA}}$ = **2.4 kΩ** (a standard value)

$R_D = 2.5R_S = 2.5(2.4\text{ kΩ}) = 6\text{ kΩ} \Rightarrow$ use **6.2 kΩ**

$V_G = \dfrac{R_2V_{DD}}{R_1 + R_2} \Rightarrow 4\text{ V} = \dfrac{R_2(24\text{ V})}{22\text{ MΩ} + R_2} \Rightarrow 88\text{ MΩ} + 4R_2 = 24R_2$

$20R_2 = 88$ MΩ

$R_2 = 4.4$ MΩ

Use R_2 = **4.3 MΩ**

26. $I_D = k(V_{GS} - V_T)^2$

$$\frac{I_D}{k} = (V_{GS} - V_T)^2$$

$$\sqrt{\frac{I_D}{k}} = V_{GS} - V_T$$

and $V_{GS} = V_T + \sqrt{\frac{I_D}{k}} = 4\text{ V} + \sqrt{\frac{6\text{ mA}}{0.5\times10^{-3}\text{ A/V}^2}} = 7.46\text{ V}$

$$R_D = \frac{V_{R_D}}{I_D} = \frac{V_{DD} - V_{DS}}{I_D} = \frac{V_{DD} - V_{GS}}{I_D} = \frac{16\text{ V} - 7.46\text{ V}}{6\text{ mA}} = \frac{8.54\text{ V}}{6\text{ mA}}$$

$= 1.42\text{ k}\Omega$

Standard value: $R_D =$ **0.75 kΩ**

$R_G =$ **10 MΩ**

27. (a) $I_D = I_S = \frac{V_S}{R_S} = \frac{4\text{ V}}{1\text{ k}\Omega} = 4\text{ mA}$

$V_{DS} = V_{DD} - I_D(R_D + R_S) = 12\text{ V} - (4\text{ mA})(2\text{ k}\Omega + 1\text{ k}\Omega)$
$= 12\text{ V} - (4\text{ mA})(3\text{ k}\Omega)$
$= 12\text{ V} - 12\text{ V}$
$= 0\text{ V}$

JFET in saturation!

(b) $V_S = 0$ V reveals that the JFET is nonconducting and the JFET is either defective or an open-circuit exists in the output circuit. V_S is at the same potential as the grounded side of the 1 kΩ resistor.

(c) Typically, the voltage across the 1 MΩ resistor is ≅ 0 V. The fact that the voltage across the 1 MΩ resistor is equal to V_{DD} suggests that there is a short-circuit connection from gate to drain with $I_D = 0$ mA. Either the JFET is defective or an improper circuit connection was made.

28. $V_G = \frac{75\text{ k}\Omega(20\text{ V})}{75\text{ k}\Omega + 330\text{ k}\Omega} = 3.7\text{ V}$ (seems correct!)

$V_{GS} = 3.7\text{ V} - 6.25\text{ V} = -2.55\text{ V}$ (possibly okay)

$I_D = I_{DSS}(1 - V_{GS}/V_P)^2$
$= 10\text{ mA}(1 - (-2.55\text{ V})/(-6\text{ V}))^2$
$= 3.3\text{ mA}$ (reasonable)

However, $I_S = \frac{V_S}{R_S} = \frac{6.25\text{ V}}{1\text{ k}\Omega} = 6.25\text{ mA} \neq 3.3\text{ mA}$

$V_{R_D} = I_D R_D = I_S R_D = (6.25\text{ mA})(2.2\text{ k}\Omega)$
$= 13.75\text{ V}$

and $V_{R_S} + V_{R_D} = 6.25\text{ V} + 13.75\text{ V}$
$=$ **20 V** $= V_{DD}$

$\therefore V_{DS} = 0\text{ V}$

1. Possible short-circuit from D-S.
2. Actual I_{DSS} and/or V_P may be larger in magnitude than specified.

29. $I_D = I_S = \dfrac{V_S}{R_S} = \dfrac{6.25\text{ V}}{1\text{ k}\Omega} = 6.25\text{ mA}$

$V_{DS} = V_{DD} - I_D(R_D + R_S)$
$= 20\text{ V} - (6.25\text{ mA})(2.2\text{ k}\Omega + 1\text{ k}\Omega)$
$= 20\text{ V} - 20\text{ V}$
$= 0\text{ V}$ (saturation condition)

$V_G = \dfrac{R_2 V_{DD}}{R_1 + R_2} = \dfrac{75\text{ k}\Omega(20\text{ V})}{330\text{ k}\Omega + 75\text{ k}\Omega} = 3.7\text{ V}$ (as it should be)

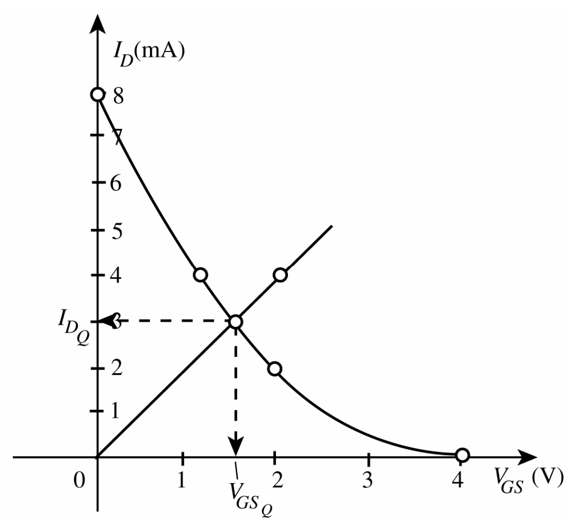
$V_{GS} = V_G - V_S = 3.7\text{ V} - 6.25\text{ V} = -2.55\text{ V}$

$I_D = I_{DSS}\left(1 - \dfrac{V_{GS}}{V_P}\right)^2 = 10\text{ mA}(1 - (-2.55\text{ V})/(6\text{ V}))^2$
$= 3.3\text{ mA} \neq 6.25\text{ mA}$

In all probability, an open-circuit exists between the voltage divider network and the gate terminal of the JFET with the transistor exhibiting saturation conditions.

30. (a) $V_{GS} = 0\text{ V}, I_D = I_{DSS} = 8\text{ mA}$
$V_{GS} = V_P = +4\text{ V}, I_D = 0\text{ mA}$
$V_{GS} = \dfrac{V_P}{2} = +2\text{ V}, I_D = 2\text{ mA}$
$V_{GS} = 0.3V_P = 1.2\text{ V}, I_D = 4\text{ mA}$

$V_{GS} = I_D R_S$
$I_D = 4\text{ mA}$;
$V_{GS} = (4\text{ mA})(0.51\text{ k}\Omega)$
$= 2.04\text{ V}$
I_{D_Q} = **3 mA**, V_{GS_Q} = **1.55 V**



(b) $V_{DS} = V_{DD} + I_D(R_D + R_S)$
$= -18\text{ V} + (3\text{ mA})(2.71\text{ k}\Omega)$
$= $ **–9.87 V**

(c) $V_D = V_{DD} - I_D R_D$
$= -18\text{ V} - (3\text{ mA})(2.2\text{ k}\Omega)$
$= $ **–11.4 V**

31. $k = \dfrac{I_{D(\text{on})}}{\left(V_{GS(\text{on})} - V_{GS(Th)}\right)^2} = \dfrac{4\text{ mA}}{\left(-7\text{ V} - (-3\text{ V})\right)^2} = \dfrac{4\text{ mA}}{(-4\text{ V})^2}$

$= 0.25 \times 10^{-3}\text{ A/V}^2$

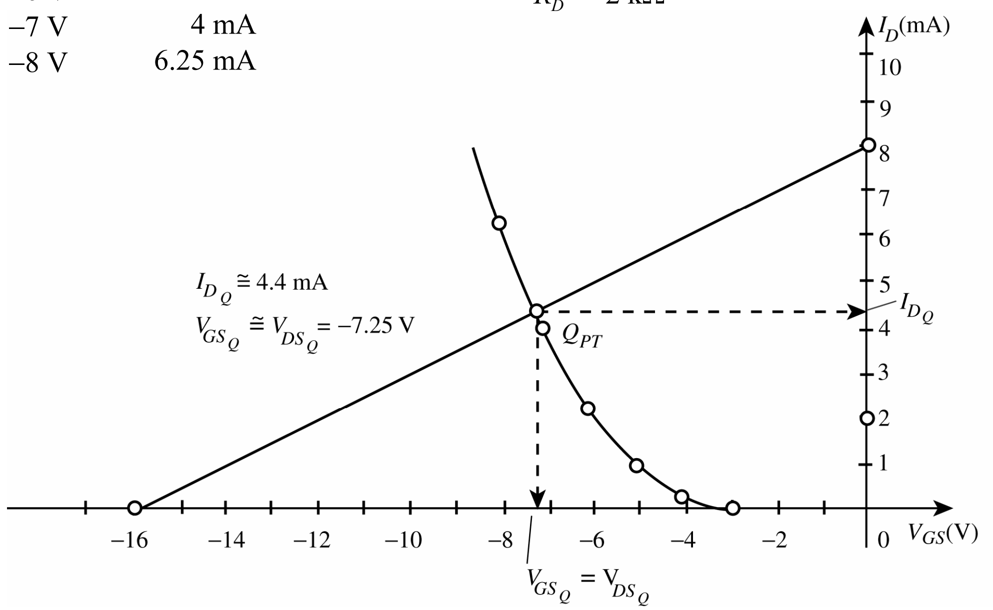
$I_D = \mathbf{0.25 \times 10^{-3}(V_{GS} + 3\text{ V})^2}$

V_{GS}	I_D
–3 V	0 mA
–4 V	0.25 mA
–5 V	1 mA
–6 V	2.25 mA
–7 V	4 mA
–8 V	6.25 mA

$V_{GS} = V_{DS} = V_{DD} + I_D R_D$

At $I_D = 0$ mA, $V_{GS} = V_{DD} = -16$ V

At $V_{GS} = 0$ V, $I_D = \dfrac{V_{DD}}{R_D} = \dfrac{16\text{ V}}{2\text{ k}\Omega} = 8$ mA



(b) $V_{DS} = V_{GS} = \mathbf{-7.25\text{ V}}$

(c) $V_D = V_{DS} = \mathbf{-7.25\text{ V}}$

or $V_{DS} = V_{DD} + I_D R_D$

$= -16\text{ V} + (4.4\text{ mA})(2\text{ k}\Omega)$

$= -16\text{ V} + 8.8\text{ V}$

$V_{DS} = \mathbf{-7.2\text{ V}} = V_D$

32. $\dfrac{V_{GS}}{|V_P|} = \dfrac{-1.5\text{ V}}{4\text{ V}} = -0.375$

Find –0.375 on the horizontal axis.

Then move vertically to the $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$ curve.

Finally, move horizontally from the intersection with the curve to the left to the I_D/I_{DSS} axis.

$\dfrac{I_D}{I_{DSS}} = 0.39$

and $I_D = 0.39(12\text{ mA}) = \mathbf{4.68\text{ mA}}$ vs. 4.69 mA (#1)

$V_{DS_Q} = V_{DD} - I_D R_D = 12\text{ V} - (4.68\text{ mA})(1.2\text{ k}\Omega)$

$= \mathbf{6.38\text{ V}}$ vs. 6.37 V (#1)

33. $m = \dfrac{|V_P|}{I_{DSS}R_S} = \dfrac{4\text{ V}}{(10\text{ mA})(0.75\text{ k}\Omega)}$

$= \mathbf{0.533}$

$M = m\dfrac{V_{GG}}{|V_P|} = \dfrac{0.533(0)}{4\text{ V}}$

$= \mathbf{0}$

Draw a straight line from $M = 0$ through $m = 0.533$ until it crosses the normalized curve of $I_D = I_{DSS}\left(1 - \dfrac{V_{GS}}{V_P}\right)^2$. At the intersection with the curve drop a line down to determine

$$\frac{V_{GS}}{|V_P|} = -0.49$$

so that $V_{GS_Q} = -0.49V_P = -0.49(4\text{ V})$

$= \mathbf{-1.96\ V}$ (vs. −1.9 V #6)

If a horizontal line is drawn from the intersection to the left vertical axis we find

$$\frac{I_D}{I_{DSS}} = 0.27$$

and $I_D = 0.27(I_{DSS}) = 0.27(10\text{ mA}) =$ **2.7 mA**
(vs. 2.7 mA from #6)

(a) $V_{GS_Q} = \mathbf{-1.96\ V}$, $I_{D_Q} = \mathbf{2.7\ mA}$

(b) –

(c) –

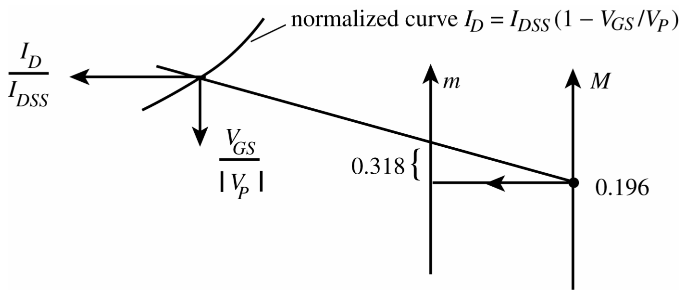
(d) $V_{DS} = V_{DD} - I_D(R_D + R_S) =$ **11.93 V** (like #6)
$V_D = V_{DD} - I_DR_D =$ **13.95 V** (like #6)
$V_G = 0$ V, $V_S = I_DR_S =$ **2.03 V** (like #6)

34. $V_{GG} = \dfrac{R_2V_{DD}}{R_1 + R_2} = \dfrac{110\text{ k}\Omega(20\text{ V})}{110\text{ k}\Omega + 910\text{ k}\Omega} = 2.16\text{ V}$

$m = \dfrac{|V_P|}{I_{DSS}R_S} = \dfrac{3.5\text{ V}}{(10\text{ mA})(1.1\text{ k}\Omega)} = 0.318$

$M = m \times \dfrac{V_{GG}}{|V_P|} = 0.318\dfrac{(2.16\text{ V})}{3.5} = 0.196$

Find 0.196 on the vertical axis labeled M and mark the location. Move horizontally to the vertical axis labeled m and then add $m = 0.318$ to the vertical height (≅ 1.318 in total)—mark the spot. Draw a straight line through the two points located above, as shown below.



Continue the line until it intersects the $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$ curve. At the intersection move horizontally to obtain the I_D/I_{DSS} ratio and move down vertically to obtain the $V_{GS}/|V_p|$ ratio.

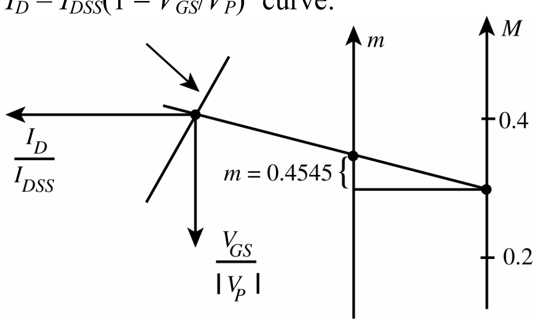
$$\frac{I_D}{I_{DSS}} = 0.33 \text{ and } I_{D_Q} = 0.33(10\text{ mA}) = \mathbf{3.3\ mA}$$
vs. 3.3 mA (#12)

$$\frac{V_{GS}}{|V_P|} = -0.425 \text{ and } V_{GS_Q} = -0.425(3.5\text{ V}) = \mathbf{-1.49\ V}$$
vs. 1.5 V (#12)

35. $m = \frac{|V_P|}{I_{DSS}R_S} = \frac{6\text{ V}}{(6\text{ mA})(2.2\text{ k}\Omega)} = \mathbf{0.4545}$

$M = m\frac{V_{GG}}{|V_P|} = 0.4545\frac{(4\text{ V})}{(6\text{ V})} = \mathbf{0.303}$

Find 0.303 on the vertical M axis.
Draw a horizontal line from $M = 0.303$ to the vertical m axis.
Add 0.4545 to the vertical location on the m axis defined by the horizontal line.
Draw a straight line between $M = 0.303$ and the point on the m axis resulting from the addition of $m = 0.4545$.
Continue the straight line as shown below until it crosses the normalized $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$ curve:



At the intersection drop a vertical line to determine

$$\frac{V_{GS}}{|V_P|} = -0.34$$

and $V_{GS_Q} = -0.34(6 \text{ V})$

$= \mathbf{-2.04\ V}$ (vs. –2 V from problem 15)

At the intersection draw a horizontal line to the I_D/I_{DSS} axis to determine

$$\frac{I_D}{I_{DSS}} = 0.46$$

and $I_{D_Q} = 0.46(6 \text{ mA})$

$= \mathbf{2.76\ mA}$ (vs. 2.7 mA from problem 15)

(a) I_{D_Q} = **2.76 mA**, V_{GS_Q} = **–2.04 V**

(b) $V_{DS} = V_{DD} + V_{SS} - I_D(R_D + R_S)$

$= 16 \text{ V} + 4 \text{ V} - (2.76 \text{ mA})(4.4 \text{ k}\Omega)$

$=$ **7.86 V** (vs. 8.12 V from problem 15)

$V_S = -V_{SS} + I_DR_S = -4 \text{ V} + (2.76 \text{ mA})(2.2 \text{ k}\Omega)$

$= -4 \text{ V} + 6.07 \text{ V}$

$=$ **2.07 V** (vs. 1.94 V from problem 15)

Chapter 8

1. $g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(15\text{ mA})}{|-5\text{ V}|}$ = **6 mS**

2. $g_{m0} = \dfrac{2I_{DSS}}{|V_P|} \Rightarrow |V_P| = \dfrac{2I_{DSS}}{g_{m0}} = \dfrac{2(12\text{ mA})}{10\text{ mS}}$ = 2.4 V

   V_P = **–2.4 V**

3. $g_{m0} = \dfrac{2I_{DSS}}{|V_P|} \Rightarrow I_{DSS} = \dfrac{(g_{mO})(|V_P|)}{2} = \dfrac{5\text{ mS}(3.5\text{ V})}{2}$ = **8.75 mA**

4. $g_m = g_{m0}\left(1 - \dfrac{V_{GS_Q}}{V_P}\right) = \dfrac{2(12\text{ mA})}{|-3\text{ V}|}\left(1 - \dfrac{-1\text{ V}}{-3\text{ V}}\right)$ = **5.3 mS**

5. $g_m = \dfrac{2I_{DSS}}{|V_P|}\left(1 - \dfrac{V_{GS_Q}}{V_P}\right)$

   $6\text{ mS} = \dfrac{2I_{DSS}}{2.5\text{ V}}\left(1 - \dfrac{-1\text{ V}}{-2.5\text{ V}}\right)$

   I_{DSS} = **12.5 mA**

6. $g_m = g_{m0}\sqrt{\dfrac{I_D}{I_{DSS}}} = \dfrac{2I_{DSS}}{|V_P|}\sqrt{\dfrac{I_{DSS}/4}{I_{DSS}}} = \dfrac{2(10\text{ mA})}{5\text{ V}}\sqrt{\dfrac{1}{4}}$

   $= \dfrac{20\text{ mA}}{5\text{ V}}\left(\dfrac{1}{2}\right)$ = **2 mS**

7. $g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(8\text{ mA})}{5\text{ V}}$ = 3.2 mS

   $g_m = g_{m0}\left(1 - \dfrac{V_{GS_Q}}{V_P}\right) = 3.2\text{ mS}\left(1 - \dfrac{V_P/4}{V_P}\right) = 3.2\text{ mS}\left(1 - \dfrac{1}{4}\right) = 3.2\text{ mS}\left(\dfrac{3}{4}\right)$

   = **2.4 mS**

8. (a) $g_m = y_{fs}$ = **4.5 mS**

   (b) $r_d = \dfrac{1}{y_{os}} = \dfrac{1}{25\mu\text{S}}$ = **40 kΩ**

9. $g_m = y_{fs}$ = 4.5 mS

   $r_d = \dfrac{1}{y_{os}} = \dfrac{1}{25\mu\text{S}}$ = 40 kΩ

   $Z_o = r_d$ = **40 kΩ**

   A_v(FET) = $-g_m r_d$ = –(4.5 mS)(40 kΩ) = **–180**

10. $A_v = -g_m r_d \Rightarrow g_m = \dfrac{-A_v}{r_d} = -\dfrac{(-200)}{(100\text{ k}\Omega)}$ = **2 mS**

11. (a) $g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(10\text{ mA})}{5\text{ V}}$ = **4 mS**

(b) $g_m = \dfrac{\Delta I_D}{\Delta V_{GS}} = \dfrac{6.4\text{ mA} - 3.6\text{ mA}}{2\text{ V} - 1\text{ V}}$ = **2.8 mS**

(c) Eq. 8.6: $g_m = g_{m0}\left(1 - \dfrac{V_{GS_Q}}{V_P}\right) = 4\text{ mS}\left(1 - \dfrac{-1.5\text{ V}}{-5\text{ V}}\right)$ = **2.8 mS**

(d) $g_m = \dfrac{\Delta I_D}{\Delta V_{GS}} = \dfrac{3.6\text{ mA} - 1.6\text{ mA}}{3\text{ V} - 2\text{ V}}$ = **2 mS**

(e) $g_m = g_{m0}\left(1 - \dfrac{V_{GS_Q}}{V_P}\right) = 4\text{ mS}\left(1 - \dfrac{-2.5\text{ V}}{-5\text{ V}}\right)$ = **2 mS**

12. (a) $r_d = \left.\dfrac{\Delta V_{DS}}{\Delta I_D}\right|_{V_{GS}\text{ constant}} = \dfrac{(15\text{ V} - 5\text{ V})}{(9.1\text{ mA} - 8.8\text{ mA})} = \dfrac{10\text{ V}}{0.3\text{ mA}}$ = **33.33 kΩ**

(b) At V_{DS} = 10 V, I_D = 9 mA on V_{GS} = 0 V curve

$\therefore g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(9\text{ mA})}{4\text{ V}}$ = **4.5 mS**

13. From 2N4220 data:

$g_m = y_{fs} = 750\ \mu\text{S}$ = **0.75 mS**

$r_d = \dfrac{1}{y_{os}} = \dfrac{1}{10\mu\text{S}}$ = **100 kΩ**

14. (a) g_m (@ V_{GS} = –6 V) = **0**, g_m (@ V_{GS} = 0 V) = $g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(8\text{ mA})}{6\text{ V}}$ = **2.67 mS**

(b) g_m (@ I_D = 0 mA) = **0**, g_m (@ $I_D = I_{DSS}$ = 8 mA) = g_{m0} = **2.67 mS**

15. $g_m = y_{fs}$ = **5.6 mS**, $r_d = \dfrac{1}{y_{os}} = \dfrac{1}{15\ \mu\text{S}}$ = **66.67 kΩ**

16. $g_m = \dfrac{2I_{DSS}}{|V_P|}\left(1 - \dfrac{V_{GS_Q}}{V_P}\right) = \dfrac{2(10\text{ mA})}{4\text{ V}}\left(1 - \dfrac{-2\text{ V}}{-4\text{ V}}\right)$ = **2.5 mS**

$r_d = \dfrac{1}{y_{os}} = \dfrac{1}{25\ \mu\text{S}}$ = **40 kΩ**

17. Graphically, $V_{GS_Q} = -1.5$ V

$$g_m = \frac{2I_{DSS}}{|V_P|}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = \frac{2(10 \text{ mA})}{4 \text{ V}}\left(1 - \frac{-1.5 \text{ V}}{-4 \text{ V}}\right) = 3.125 \text{ mS}$$

$Z_i = R_G =$ **1 MΩ**

$Z_o = R_D \parallel r_d = 1.8$ kΩ || 40 kΩ = **1.72 kΩ**

$A_v = -g_m(R_D \parallel r_d) = -(3.125 \text{ mS})(1.72 \text{ k}\Omega)$

= **–5.375**

18. $V_{GS_Q} = -1.5$ V

$$g_m = \frac{2I_{DSS}}{|V_P|}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = \frac{2(12 \text{ mA})}{6 \text{ V}}\left(1 - \frac{-1.5 \text{ V}}{-6 \text{ V}}\right) = 3 \text{ mS}$$

$Z_i = R_G =$ **1 MΩ**

$Z_o = R_D \parallel r_d,\ r_d = \dfrac{1}{y_{os}} = \dfrac{1}{40\ \mu\text{S}} = 25$ kΩ

= 1.8 kΩ || 25 kΩ

= **1.68 kΩ**

$A_v = -g_m(R_D \parallel r_d) = -(3 \text{ mS})(1.68 \text{ k}\Omega) =$ **–5.04**

19. $g_m = y_{fs} = 3000\ \mu$S = 3 mS

$r_d = \dfrac{1}{y_{os}} = \dfrac{1}{50\ \mu\text{S}} = 20$ kΩ

$Z_i = R_G =$ **10 MΩ**

$Z_o = r_d \parallel R_D = 20$ kΩ|| 3.3 kΩ = **2.83 kΩ**

$A_v = -g_m(r_d \parallel R_D)$

= –(3 mS)(2.83 kΩ)

= **–8.49**

20. $V_{GS_Q} = 0$ V, $g_m = g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(6 \text{ mA})}{6 \text{ V}} = 2$ mS, $r_d = \dfrac{1}{y_{os}} = \dfrac{1}{40\ \mu\text{S}} = 25$ kΩ

$Z_i =$ **1 MΩ**

$Z_o = r_d \parallel R_D = 25$ kΩ || 2 kΩ = **1.852 kΩ**

$A_v = -g_m(r_d \parallel R_D) = -(2 \text{ mS})(1.852 \text{ k}\Omega) \cong$ **–3.7**

21. $g_m = 3$ mS, $r_d = 20$ kΩ

$Z_i =$ **10 MΩ**

$$Z_o = \frac{R_D}{1 + g_m R_S + \dfrac{R_D + R_S}{r_d}} = \frac{3.3\text{ k}\Omega}{1 + (3\text{ mS})(1.1\text{ k}\Omega) + \dfrac{3.3\text{ k}\Omega + 1.1\text{ k}\Omega}{20\text{ k}\Omega}}$$

$$= \frac{3.3\text{ k}\Omega}{1 + 3.3 + 0.22} = \frac{3.3\text{ k}\Omega}{4.52} = \mathbf{730\ \Omega}$$

$$A_v = \frac{-g_m R_D}{1 + g_m R_S + \dfrac{R_D + R_S}{r_d}} = \frac{-(3\text{ mS})(3.3\text{ k}\Omega)}{1 + (3\text{ mS})(1.1\text{ k}\Omega) + \dfrac{3.3\text{ k}\Omega + 1.1\text{ k}\Omega}{20\text{ k}\Omega}}$$

$$= \frac{-9.9}{1 + 3.3 + 0.22} = -\frac{9.9}{4.52} = \mathbf{-2.19}$$

22. $g_m = y_{fs} = 3000\ \mu$S = 3 mS

$$r_d = \frac{1}{y_{os}} = \frac{1}{10\ \mu\text{S}} = 100\text{ k}\Omega$$

$Z_i = R_G =$ **10 MΩ** (the same)

$Z_o = r_d \| R_D = 100$ kΩ $\|$ 3.3 kΩ = **3.195 kΩ** (higher)

$A_v = -g_m(r_d \| R_D)$

= –(3 mS)(3.195 kΩ)

= **–9.59** (higher)

23. $V_{GS_Q} = -0.95$ V

$$g_m = \frac{2I_{DSS}}{V_P}\left(1 - \frac{V_{GS_Q}}{V_P}\right)$$

$$= \frac{2(12\text{ mA})}{3\text{ V}}\left(1 - \frac{-0.95\text{ V}}{-3\text{ V}}\right)$$

= 5.47 mS

$Z_i = 82$ MΩ $\|$ 11 MΩ = **9.7 MΩ**

$Z_o = r_d \| R_D = 100$ kΩ $\|$ 2 kΩ = **1.96 kΩ**

$A_v = -g_m(r_d \| R_D) = -(5.47$ mS)(1.96 kΩ) = **–10.72**

$V_o = A_v V_i = (-10.72)(20$ mV) = **–214.4 mV**

24. $V_{GS_Q} = -0.95$ V (as before), $g_m = 5.47$ mS (as before)

$Z_i =$ **9.7 MΩ** as before

$$Z_o = \frac{R_D}{1 + g_m R_S + \dfrac{R_D + R_S}{r_d}}$$

but $r_d \geq 10(R_D + R_S)$

$$\therefore Z_o = \frac{R_D}{1+g_mR_S} = \frac{2\text{ k}\Omega}{1+(5.47\text{ mS})(0.61\text{ k}\Omega)} = \frac{2\text{ k}\Omega}{1+3.337} = \frac{2\text{ k}\Omega}{4.337}$$

= **461.1 Ω**

$$A_v = \frac{-g_mR_D}{1+g_mR_S} \quad \text{since } r_d \geq 10(R_D + R_S)$$

$$= \frac{-(5.47\text{ mS})(2\text{ k}\Omega)}{4.337\text{ (from above)}} = -\frac{10.94}{4.337} = \mathbf{-2.52} \text{ (a big reduction)}$$

$V_o = A_vV_i$ = (–2.52)(20 mV) = **–50.40 mV** (compared to –214.4 mV earlier)

25. V_{GS_Q} = –0.95 V, g_m (problem 23) = 5.47 mS

Z_i (the same) = **9.7 MΩ**
Z_o (reduced) = $r_d \parallel R_D$ = 20 kΩ || 2 kΩ = **1.82 kΩ**
A_v (reduced) = $-g_m(r_d \parallel R_D)$ = –(5.47 mS)(1.82 kΩ) = **–9.94**
V_o (reduced) = A_vV_i = (–9.94)(20 mV) = **–198.8 mV**

26. V_{GS_Q} = –0.95 V (as before), g_m = 5.47 mS (as before)

Z_i = **9.7 MΩ** as before

$$Z_o = \frac{R_D}{1+g_mR_S + \dfrac{R_D+R_S}{r_d}} \quad \text{since } r_d < 10(R_D + R_S)$$

$$= \frac{2\text{ k}\Omega}{1+(5.47\text{ mS})(0.61\text{ k}\Omega)+\dfrac{2\text{ k}\Omega+0.61\text{ k}\Omega}{20\text{ k}\Omega}}$$

$$= \frac{2\text{ k}\Omega}{1+3.33+0.13} = \frac{2\text{ k}\Omega}{4.46}$$

= **448.4 Ω** (slightly less than 461.1 Ω obtained in problem 24)

$$A_v = \frac{-g_mR_D}{1+g_mR_S + \dfrac{R_D+R_S}{r_d}}$$

$$= \frac{-(5.47\text{ mS})(2\text{ k}\Omega)}{1+(5.47\text{ mS})(0.61\text{ k}\Omega)+\dfrac{2\text{ k}\Omega+0.61\text{ k}\Omega}{20\text{ k}\Omega}}$$

$$= \frac{-10.94}{1+3.33+0.13} = \frac{-10.94}{4.46} = \mathbf{-2.45} \text{ slightly less than } -2.52 \text{ obtained in problem 24)}$$

27. $V_{GS_Q} = -2.85\text{ V},\ g_m = \dfrac{2I_{DSS}}{V_P}\left(1-\dfrac{V_{GS_Q}}{V_P}\right) = \dfrac{2(9\text{ mA})}{4.5\text{ V}}\left(1-\dfrac{-2.85\text{ V}}{-4.5\text{ V}}\right) = 1.47\text{ mS}$

$Z_i = R_G$ = **10 MΩ**

$$Z_o = r_d \parallel R_S \parallel 1/g_m = 40\text{ k}\Omega \parallel 2.2\text{ k}\Omega \parallel \underbrace{1/1.47\text{ mS}}_{680.27\ \Omega} = \mathbf{512.9\ \Omega}$$

$$A_v = \frac{g_m(r_d \parallel R_S)}{1+g_m(r_d \parallel R_S)} = \frac{(1.47\text{ mS})(40\text{ k}\Omega \parallel 2.2\text{ k}\Omega)}{1+(1.47\text{ mS})(40\text{ k}\Omega \parallel 2.2\text{ k}\Omega)} = \frac{3.065}{1+3.065}$$

= **0.754**

28. $V_{GS_Q} = -2.85$ V, $g_m = 1.47$ mS

Z_i = **10 MΩ** (as in problem 27)

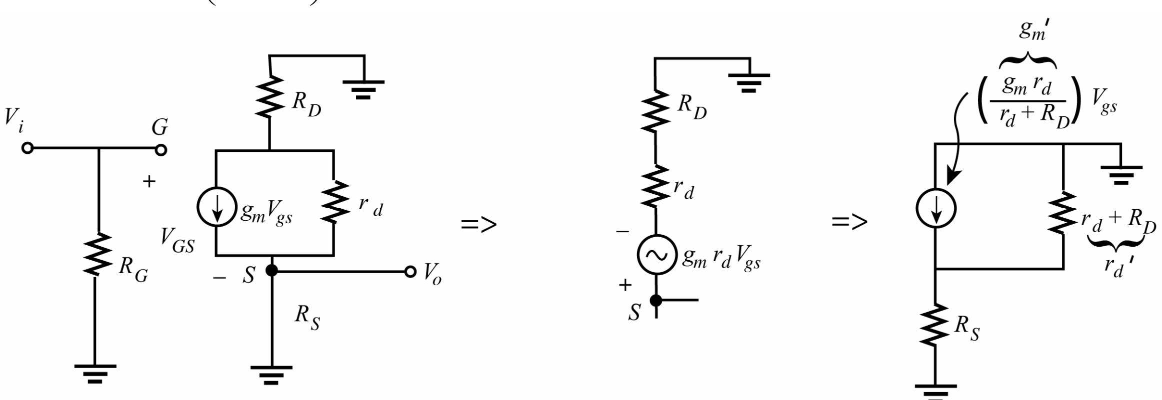
$Z_o = r_d \parallel R_S \parallel 1/g_m = \underbrace{20\text{ k}\Omega \parallel 2.2\text{ k}\Omega}_{1.982\text{ k}\Omega} \parallel 680.27\ \Omega$ = **506.4 Ω** < 512.9 Ω (#27)

$$A_v = \frac{g_m(r_d \| R_S)}{1 + g_m(r_d \| R_S)} = \frac{1.47\text{ mS}(20\text{ k}\Omega \| 2.2\text{ k}\Omega)}{1 + 1.47\text{ mS}(20\text{ k}\Omega \| 2.2\text{ k}\Omega)} = \frac{2.914}{1 + 2.914}$$

= **0.745** < 0.754 (#27)

29. $V_{GS_Q} = -3.8$ V

$$g_m = \frac{2I_{DSS}}{V_P}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = \frac{2(6\text{ mA})}{6\text{ V}}\left(1 - \frac{-3.8\text{ V}}{-6\text{ V}}\right) = 0.733\text{ mS}$$



The network now has the format examined in the text and

$Z_i = R_G$ = **10 MΩ** $\qquad r_d' = r_d + R_D = 30\text{ k}\Omega + 3.3\text{ k}\Omega = 33.3\text{ k}\Omega$

$$Z_o = r_d' \parallel R_S \parallel 1/g_m' = \qquad g_m' = \frac{g_m r_d}{r_d + R_D} = \frac{(0.733\text{ mS})(30\text{ k}\Omega)}{30\text{ k}\Omega + 3.3\text{ k}\Omega} = \frac{21.99}{33.3\text{ k}\Omega} = 0.66\text{ mS}$$

$= 33.3\text{ k}\Omega \parallel 3.3\text{ k}\Omega \parallel 1/0.66\text{ mS}$

$= 3\text{ k}\Omega \parallel 1.52\text{ k}\Omega$

≅ **1 kΩ**

$$A_v = \frac{g_m'(r_d' \| R_S)}{1 + g_m'(r_d' \| R_S)} = \frac{0.66\text{ mS}(3\text{ k}\Omega)}{1 + 0.66\text{ mS}(3\text{ k}\Omega)} = \frac{1.98}{1 + 1.98} = \frac{1.98}{2.98}$$

= **0.66**

30. $V_{GS_Q} = -1.75$ V, $g_m = 2.14$ mS

$r_d \geq 10R_D$, $\therefore Z_i \cong R_S \parallel 1/g_m = 1.5\text{ k}\Omega \parallel 1/2.14\text{ mS}$

$= 1.5\text{ k}\Omega \parallel 467.29\ \Omega$

= **356.3 Ω**

$r_d \geq 10R_D$, $\therefore Z_o \cong R_D$ = **3.3 kΩ**

$r_d \geq 10R_D$, $\therefore A_v \cong g_m R_D = (2.14\text{ mS})(3.3\text{ k}\Omega)$ = **7.06**

$V_o = A_v V_i = (7.06)(0.1\text{ mV})$ = **0.706 mV**

31. $V_{GS_Q} = -1.75\text{ V},\ g_m = \dfrac{2I_{DSS}}{V_P}\left(1-\dfrac{V_{GS_Q}}{V_P}\right) = \dfrac{2(8\text{ mA})}{2.8\text{ V}}\left(1-\dfrac{-1.75\text{ V}}{-2.8\text{ V}}\right)$ = 2.14 mS

$$Z_i = R_S \parallel \left[\frac{r_d + R_D}{1+g_m r_d}\right] = 1.5\text{ k}\Omega \parallel \left[\frac{25\text{ k}\Omega + 3.3\text{ k}\Omega}{1+(2.14\text{ mS})(25\text{ k}\Omega)}\right] = 1.5\text{ k}\Omega \parallel \frac{28.3\text{ k}\Omega}{54.5}$$

$= 1.5\text{ k}\Omega \parallel 0.52\text{ k}\Omega =$ **386.1 Ω**

$Z_o = R_D \parallel r_d = 3.3\text{ k}\Omega \parallel 25\text{ k}\Omega =$ **2.92 kΩ**

$$A_v = \frac{g_m R_D + R_D/r_d}{1+R_D/r_d} = \frac{(2.14\text{ mS})(3.3\text{ k}\Omega) + 3.3\text{ k}\Omega/25\text{ k}\Omega}{1+3.3\text{ k}\Omega/25\text{ k}\Omega}$$

$$= \frac{7.062+0.132}{1+0.132} = \frac{7.194}{1.132} = 6.36$$

$V_o = A_v V_i = (6.36)(0.1\text{ mV}) =$ **0.636 mV**

32. $V_{GS_Q} \cong -1.2\text{ V},\ g_m = 2.63\text{ mS}$

$r_d \geq 10R_D,\ \therefore$ $Z_i \cong R_S \parallel 1/g_m = 1\text{ k}\Omega \parallel 1/2.63\text{ mS} = 1\text{ k}\Omega \parallel 380.2\ \Omega =$ **275.5 Ω**

$Z_o \cong R_D =$ **2.2 kΩ**

$A_v \cong g_m R_D = (2.63\text{ mS})(2.2\text{ k}\Omega) =$ **5.79**

33. $r_d = \dfrac{1}{y_{os}} = \dfrac{1}{20\ \mu\text{S}} = 50\text{ k}\Omega,\ V_{GS_Q} = 0\text{ V}$

$$g_m = g_{m0} = \frac{2I_{DSS}}{V_P} = \frac{2(8\text{ mA})}{3} = 5.33\text{ mS}$$

$A_v = -g_m R_D = -(5.33\text{ mS})(1.1\text{ k}\Omega) = -5.863$

$V_o = A_v V_i = (-5.863)(2\text{ mV}) =$ **11.73 mV**

34. $V_{GS_Q} = -0.75\text{ V},\ g_m = 5.4\text{ mS}$

$Z_i =$ **10 MΩ**

$r_o \geq 10R_D,\ \therefore$ $Z_o \cong R_D =$ **1.8 kΩ**

$r_o \geq 10R_D,\ \therefore$ $A_v \cong -g_m R_D = -(5.4\text{ mS})(1.8\text{ k}\Omega)$

= **–9.72**

35. $Z_i =$ **10 MΩ**

$Z_o = r_d \parallel R_D = 25\text{ k}\Omega \parallel 1.8\text{ k}\Omega =$ **1.68 kΩ**

$A_v = -g_m(r_d \parallel R_D)$

$$g_m = \frac{2I_{DSS}}{V_P}\left(1-\frac{V_{GS_Q}}{V_P}\right) = \frac{2(12\text{ mA})}{3.5\text{ V}}\left(1-\frac{-0.75\text{ V}}{-3.5\text{ V}}\right) = 5.4\text{ mS}$$

$A_v = -(5.4\text{ mS})(1.68\text{ k}\Omega)$

= **–9.07**

36. $g_m = y_{fs} = 6000\ \mu\text{S} = 6\text{ mS}$

$$r_d = \frac{1}{y_{os}} = \frac{1}{35\ \mu\text{S}} = 28.57\text{ k}\Omega$$

$$\begin{aligned} r_d \le 10R_D,\ \therefore A_v &= -g_m(r_d \parallel R_D) \\ &= -(6\text{ mS})(\underbrace{28.57\text{ k}\Omega \parallel 6.8\text{ k}\Omega}_{5.49\text{ k}\Omega}) \\ &= \mathbf{-32.94} \end{aligned}$$

$$\begin{aligned} V_o = A_vV_i &= (-32.94)(4\text{ mV}) \\ &= \mathbf{-131.76\ mV} \end{aligned}$$

37. $Z_i = 10\text{ M}\Omega \parallel 91\text{ M}\Omega \cong \mathbf{9\ M\Omega}$

$$g_m = \frac{2I_{DSS}}{V_P}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = \frac{2(12\text{ mA})}{3\text{ V}}\left(1 - \frac{-1.45\text{ V}}{-3\text{ V}}\right) = 4.13\text{ mS}$$

$$\begin{aligned} Z_o = r_d \parallel R_S \parallel 1/g_m &= 45\text{ k}\Omega \parallel 1.1\text{ k}\Omega \parallel 1/4.13\text{ mS} \\ &= 1.074\text{ k}\Omega \parallel 242.1\ \Omega \\ &= \mathbf{197.6\ \Omega} \end{aligned}$$

$$\begin{aligned} A_v = \frac{g_m(r_d \| R_S)}{1 + g_m(r_d \| R_S)} &= \frac{(4.13\text{ mS})(45\text{ k}\Omega \| 1.1\text{ k}\Omega)}{1 + (4.13\text{ mS})(45\text{ k}\Omega \| 1.1\text{ k}\Omega)} \\ &= \frac{(4.13\text{ mS})(1.074\text{ k}\Omega)}{1 + (4.13\text{ mS})(1.074\text{ k}\Omega)} = \frac{4.436}{1 + 4.436} \\ &= \mathbf{0.816} \end{aligned}$$

38.
$$\begin{aligned} g_m &= 2k\left(V_{GS_Q} - V_{GS(Th)}\right) \\ &= 2(0.3 \times 10^{-3})(8\text{ V} - 3\text{ V}) \\ &= \mathbf{3\ mS} \end{aligned}$$

39. $V_{GS_Q} = 6.7\text{ V}$

$$g_m = 2k\left(V_{GS_Q} - V_T\right) = 2(0.3 \times 10^{-3})(6.7\text{ V} - 3\text{ V}) = 2.22\text{ mS}$$

$$\begin{aligned} Z_i &= \frac{R_F + r_d \| R_D}{1 + g_m(r_d \| R_D)} = \frac{10\text{ M}\Omega + 100\text{ k}\Omega \| 2.2\text{ k}\Omega}{1 + (2.22\text{ mS})(100\text{ k}\Omega \| 2.2\text{ k}\Omega)} \\ &= \frac{10\text{ M}\Omega + 2.15\text{ k}\Omega}{1 + 2.22\text{ mS}(2.15\text{ k}\Omega)} \cong \mathbf{1.73\ M\Omega} \end{aligned}$$

$Z_o = R_F \parallel r_d \parallel R_D = 10\text{ M}\Omega \parallel 100\text{ k}\Omega \parallel 2.2\text{ k}\Omega = \mathbf{2.15\ k\Omega}$

$A_v = -g_m(R_F \parallel r_d \parallel R_D) = -2.22\text{ mS}(2.15\text{ k}\Omega) = \mathbf{-4.77}$

40. $g_m = 2k\left(V_{GS_Q} - V_T\right) = 2(0.2 \times 10^{-3})(6.7\text{ V} - 3\text{ V})$
$= 1.48\text{ mS}$

$$Z_i = \frac{R_F + r_d \| R_D}{1 + g_m(r_d \| R_D)} = \frac{10\text{ M}\Omega + 100\text{ k}\Omega \| 2.2\text{ k}\Omega}{1 + (1.48\text{ mS})(100\text{ k}\Omega \| 2.2\text{ k}\Omega)}$$
$$= \frac{10\text{ M}\Omega + 2.15\text{ k}\Omega}{1 + (1.48\text{ mS})(2.15\text{ k}\Omega)} = \mathbf{2.39\text{ M}\Omega} > 1.73\text{ M}\Omega \text{ (\#39)}$$

$Z_o = R_F \| r_d \| R_D =$ **$2.15\text{ k}\Omega$** $= 2.15\text{ k}\Omega$ (#39)
$A_v = -g_m(R_F \| r_d \| R_D) = -(1.48\text{ mS})(2.15\text{ k}\Omega)$
$=$ **-3.182** < -4.77 (#39)

41. $V_{GS_Q} = 5.7\text{ V}$, $g_m = 2k\left(V_{GS_Q} - V_T\right) = 2(0.3 \times 10^{-3})(5.7\text{ V} - 3.5\text{ V})$
$= 1.32\text{ mS}$

$$r_d = \frac{1}{30\ \mu\text{S}} = 33.33\text{ k}\Omega$$

$A_v = -g_m(R_F \| r_d \| R_D) = -1.32\text{ mS}(22\text{ M}\Omega \| 33.33\text{ k}\Omega \| 10\text{ k}\Omega)$
$= -10.15$
$V_o = A_vV_i = (-10.15)(20\text{ mV}) =$ **-203 mV**

42. $I_D = k(V_{GS} - V_T)^2$

$$\therefore k = \frac{I_{D(\text{on})}}{(V_{GS(\text{on})} - V_T)^2} = \frac{4\text{ mA}}{(7\text{ V} - 4\text{ V})^2} = 0.444 \times 10^{-3}$$

$g_m = 2k(V_{GS_Q} - V_{GS(Th)}) = 2(0.444 \times 10^{-3})(7\text{ V} - 4\text{ V})$
$= 2.66\text{ mS}$

$$A_v = -g_m(R_F \| r_d \| R_D) = -(2.66\text{ mS})(\underbrace{22\text{ M}\Omega \| \underbrace{50\text{ k}\Omega \| 10\text{ k}\Omega}_{8.33\text{ k}\Omega}}_{\cong 8.33\text{ k}\Omega}) = -22.16$$

$V_o = A_vV_i = (-22.16)(4\text{ mV}) =$ **-88.64 mV**

43. $V_{GS_Q} = 4.8\text{ V}$, $g_m = 2k\left(V_{GS_Q} - V_{GS_{(Th)}}\right) = 2(0.4 \times 10^{-3})(4.8\text{ V} - 3\text{ V}) = 1.44\text{ mS}$
$A_v = -g_m(r_d \| R_D) = -(1.44\text{ mS})(40\text{ k}\Omega \| 3.3\text{ k}\Omega) = -4.39$
$V_o = A_vV_i = (-4.39)(0.8\text{ mV}) =$ **-3.51 mV**

44. $r_d = \dfrac{1}{y_{os}} = \dfrac{1}{25\ \mu\text{S}} = 40\text{ k}\Omega$

$V_{GS_Q} = 0\text{ V},\ \therefore g_m = g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(8\text{ mA})}{2.5\text{ V}} = 6.4\text{ mS}$

$|A_v| = g_m(r_d \parallel R_D)$

$8 = (6.4\text{ mS})(40\text{ k}\Omega \parallel R_D)$

$\dfrac{8}{6.4\text{ mS}} = 1.25\text{ k}\Omega = \dfrac{40\text{ k}\Omega \cdot R_D}{40\text{ k}\Omega + R_D}$

and R_D = **1.29 kΩ**

Use R_D = **1.3 kΩ**

45. $V_{GS_Q} = \dfrac{1}{3}V_P = \dfrac{1}{3}(-3\text{ V}) = -1\text{ V}$

$I_{D_Q} = I_{DSS}\left(1 - \dfrac{V_{GS_Q}}{V_P}\right)^2 = 12\text{ mA}\left(1 - \dfrac{-1\text{ V}}{-3\text{ V}}\right)^2 = 5.33\text{ mA}$

$R_S = \dfrac{V_S}{I_{D_Q}} = \dfrac{1\text{ V}}{5.33\text{ mA}} = 187.62\ \Omega\ \therefore$ Use R_S = **180 Ω**

$g_m = \dfrac{2I_{DSS}}{V_P}\left(1 - \dfrac{V_{GS_Q}}{V_P}\right) = \dfrac{2(12\text{ mA})}{3\text{ V}}\left(1 - \dfrac{-1\text{ V}}{-3\text{ V}}\right) = 5.33\text{ mS}$

$A_v = -g_m(R_D \parallel r_d) = -10$

or $R_D \parallel 40\text{ k}\Omega = \dfrac{-10}{5.33\text{ mS}} = 1.876\text{ k}\Omega$

$\dfrac{R_D \cdot 40\text{ k}\Omega}{R_D + 40\text{ k}\Omega} = 1.876\text{ k}\Omega$

$40\text{ k}\Omega R_D = 1.876\text{ k}\Omega R_D + 75.04\text{ k}\Omega^2$

$38.124 R_D = 75.04\text{ k}\Omega$

$R_D = 1.97\text{ k}\Omega \Rightarrow R_D$ = **2 kΩ**

Chapter 9

1. (a) **3**, **1.699**, **−1.151**
   (b) **6.908**, **3.912**, **−0.347**
   (c) results differ by magnitude of 2.3

2. (a) $\log_{10} 2.2 \times 10^3 = \mathbf{3.3424}$

   (b) $\log_e (2.2 \times 10^3) = 2.3 \log_{10}(2.2 \times 10^3) = \mathbf{7.6962}$

   (c) $\log_e (2.2 \times 10^3) = \mathbf{7.6962}$

3. (a) same **13.98**
   (b) same **−13.01**
   (c) same **0.699**

4. (a) $\text{dB} = 10 \log_{10} \dfrac{P_o}{P_i} = 10 \log_{10} \dfrac{100 \text{ W}}{5 \text{ W}} = 10 \log_{10} 20 = 10(1.301)$

   $= \mathbf{13.01\ dB}$

   (b) $\text{dB} = 10 \log_{10} \dfrac{100 \text{ mW}}{5 \text{ mW}} = 10 \log_{10} 20 = 10(1.301)$

   $= \mathbf{13.01\ dB}$

   (c) $\text{dB} = 10 \log_{10} \dfrac{100\ \mu\text{W}}{20\ \mu\text{W}} = 10 \log_{10} 5 = 10(0.6987)$

   $= \mathbf{6.9897\ dB}$

5. $G_{\text{dBm}} = 10 \log_{10} \left.\dfrac{P_2}{1 \text{ mW}}\right|_{600\,\Omega} = 10 \log_{10} \left.\dfrac{25 \text{ W}}{1 \text{ mW}}\right|_{600\,\Omega}$

   $= \mathbf{43.98\ dBm}$

6. $G_{\text{dB}} = 20 \log_{10} \dfrac{V_2}{V_1} = 20 \log_{10} \dfrac{100 \text{ V}}{25 \text{ V}} = 20 \log_{10} 4 = 20(0.6021)$

   $= \mathbf{12.04\ dB}$

7. $G_{\text{dB}} = 20 \log_{10} \dfrac{V_2}{V_1} = 20 \log_{10} \dfrac{25 \text{ V}}{10 \text{ mV}} = 20 \log_{10} 2500$

   $= 20(3.398) = \mathbf{67.96\ dB}$

8. (a) Gain of stage 1 = A dB
   Gain of stage 2 = 2 A dB
   Gain of stage 3 = 2.7 A dB
   A + 2A +2.7A = 120
   A = **21.05 dB**

(b) Stage 1: $A_{v_1} = 21.05 \text{ dB} = 20 \log_{10} \frac{V_{o_1}}{V_{i_1}}$

$$\frac{21.05}{20} = 1.0526 = \log_{10} \frac{V_{o_1}}{V_{i_1}}$$

$$10^{1.0526} = \frac{V_{o_1}}{V_{i_1}}$$

and $\frac{V_{o_1}}{V_{i_1}} = \mathbf{11.288}$

Stage 2: $A_{v_2} = 42.1 \text{ dB} = 20 \log_{10} \frac{V_{o_2}}{V_{i_2}}$

$$2.105 = \log_{10} \frac{V_{o_2}}{V_{i_2}}$$

$$10^{2.105} = \frac{V_{o_2}}{V_{i_2}}$$

and $\frac{V_{o_2}}{V_{i_2}} = \mathbf{127.35}$

Stage 3: : $A_{v_3} = 56.835 \text{ dB} = 20 \log_{10} \frac{V_{o_3}}{V_{i_3}}$

$$2.8418 = \log_{10} \frac{V_{o_3}}{V_{i_3}}$$

$$10^{2.8418} = \frac{V_{o_3}}{V_{i_3}}$$

and $\frac{V_{o_3}}{V_{i_3}} = \mathbf{694.624}$

$A_{v_T} = A_{v_1} \cdot A_{v_2} \cdot A_{V_3} = (11.288)(127.35)(694.624) = \mathbf{99,8541.1}$

$A_T = 120 \text{ dB} \overset{?}{=} 20 \log_{10} 99,8541.1$

120 dB ≅ 119.99 dB (difference due to level of accuracy carried through calculations)

9. (a) $G_{dB} = 20 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{48 \text{ W}}{5 \ \mu\text{W}} = \mathbf{69.83 \text{ dB}}$

(b) $G_v = 20 \log_{10} \frac{V_o}{V_i} = 20 \log_{10} \frac{\sqrt{P_o R_o}}{V_i} = \frac{20 \log_{10} \sqrt{(48 \text{ W})(40 \text{ k}\Omega)}}{100 \text{ mV}}$

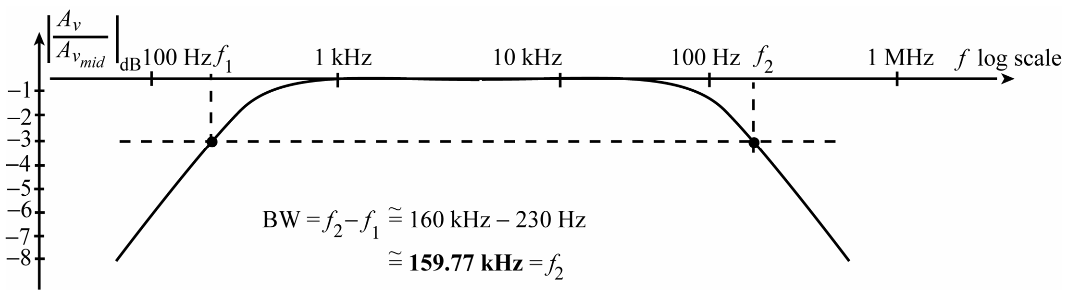
$= \mathbf{82.83 \text{ dB}}$

(c) $R_i = \frac{V_i^2}{P} = \frac{(100 \text{ mV})^2}{5\ \mu\text{W}}$ = **2 kΩ**

(d) $P_o = \frac{V_o^2}{R_o} \Rightarrow V_o = \sqrt{P_o R_o} = \sqrt{(48 \text{ W})(40 \text{ k}\Omega)}$ = **1385.64 V**

10. (a) Same shape except A_v = 190 is now level of 1. In fact, all levels of A_v are divided by 190 to obtain normalized plot.
0.707(190) = **134.33** defining cutoff frequencies
at low end $f_1 \cong$ **230 Hz** (remember this is a log scale)
at high end $f_2 \cong$ **160 kHz**

(b)



11. (a) $|A_v| = \left|\frac{V_o}{V_i}\right| = \frac{1}{\sqrt{1+(f_1/f)^2}}$ $f_l = \frac{1}{2\pi RC} = \frac{1}{2\pi(1.2 \text{ k}\Omega)(0.068\ \mu\text{F})}$
= 1950.43 Hz

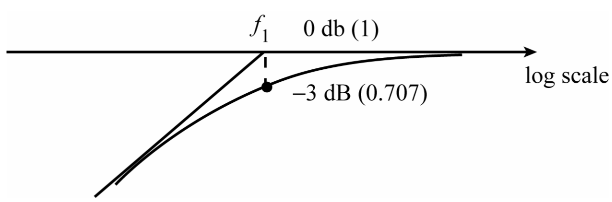
$$|A_v| = \frac{1}{\sqrt{1+\left(\frac{1950.43 \text{ Hz}}{f}\right)^2}}$$

(b)

		$A_{V_{dB}}$
100 Hz:	$\lvert A_v \rvert$ = 0.051	–25.8
1 kHz:	$\lvert A_v \rvert$ = 0.456	–6.81
2 kHz:	$\lvert A_v \rvert$ = 0.716	–2.90
5 kHz:	$\lvert A_v \rvert$ = 0.932	–0.615
10 kHz:	$\lvert A_v \rvert$ = 0.982	–0.162

(c) $f_1 \cong$ **1950 Hz**

(d)(e)

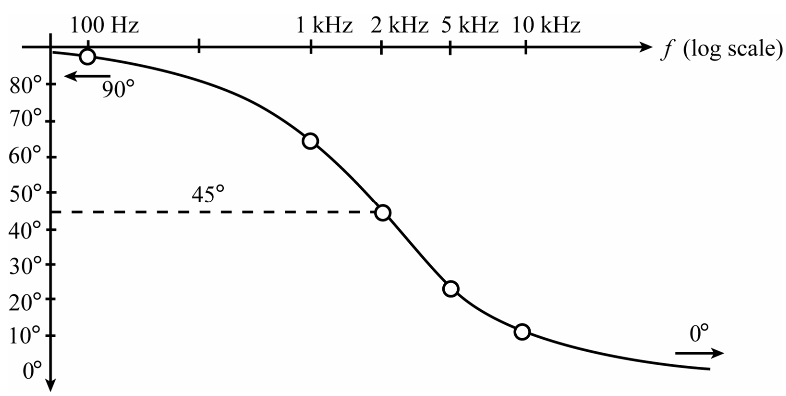


12. (a) $f_1 = \dfrac{1}{2\pi RC} = 1.95\text{ kHz}$

$\theta = \tan^{-1}\dfrac{f_1}{f} = \tan^{-1}\dfrac{1.95\text{ kHz}}{f}$

(b)

f	$\theta = \tan^{-1}\dfrac{1.95\text{ kHz}}{f}$
100 Hz	87.06°
1 kHz	62.85°
2 kHz	44.27°
5 kHz	21.3°
10 kHz	11.03°



(c) $f_1 = \dfrac{1}{2\pi RC} = 1.95\text{ kHz}$

(d) First find $\theta = 45°$ at $f_1 = 1.95$ kHz. Then sketch an approach to 90° at low frequencies and 0° at high frequencies. Use an expected shape for the curve noting that the greatest change in θ occurs near f_1. The resulting curve should be quite close to that plotted above.

13. (a) **10 kHz**

(b) **1 kHz**

(c) 20 kHz → 10 kHz → **5 kHz**

(d) 1 kHz → 10 kHz → **100 kHz**

14. From example 9.9, $r_e = 15.76\ \Omega$

$$A_v = \frac{-R_C \parallel R_L \parallel r_o}{r_e} = \frac{-4\text{ k}\Omega \parallel 2.2\text{ k}\Omega \parallel 40\text{ k}\Omega}{15.76\ \Omega}$$

$= -86.97$ (vs. -90 for Ex. 9.9)

f_{L_s}: r_o does not affect R_i $\therefore$ $f_{L_s} = \dfrac{1}{2\pi(R_s + R_i)C_S}$ the same $\cong$ **6.86 Hz**

$$f_{L_C} = \frac{1}{2\pi(R_o + R_L)C_C} = \frac{1}{2\pi(R_C \parallel r_o + R_L)C_C}$$

$R_C \parallel r_o = 4\text{ k}\Omega \parallel 40\text{ k}\Omega = 5.636\text{ k}\Omega$

$$f_{L_C} = \frac{1}{2\pi(5.636\text{ k}\Omega + 2\text{ k}\Omega)(1\ \mu\text{F})}$$

$=$ **28.23** Hz (vs. 25.68 Hz for Ex. 9.9)

f_{L_E}: R_e not affected by r_o, therefore, $f_{L_E} = \dfrac{1}{2\pi R_e C_E} \cong$ **327 Hz** is the same.

In total, the effect of r_o on the frequency response was to slightly reduce the mid-band gain.

15. (a) $\beta R_E \geq 10R_2$

$(120)(1.2\text{ k}\Omega) \geq 10(10\text{ k}\Omega)$

$144\text{ k}\Omega \geq 100\text{ k}\Omega$ (checks!)

$$V_B = \frac{10\text{ k}\Omega(14\text{ V})}{10\text{ k}\Omega + 68\text{ k}\Omega} = 1.795\text{ V}$$

$V_E = V_B - V_{BE} = 1.795\text{ V} - 0.7\text{ V}$

$= 1.095\text{ V}$

$$I_E = \frac{V_E}{R_E} = \frac{1.095\text{ V}}{1.2\text{ k}\Omega} = 0.913\text{ mA}$$

$$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{0.913\text{ mA}} = \mathbf{28.48\ \Omega}$$

(b) $$A_{V_{\text{mid}}} = -\frac{(R_L \parallel R_C)}{r_e} = \frac{-(3.3\text{ k}\Omega \parallel 5.6\text{ k}\Omega)}{28.48\ \Omega}$$

$=$ **−72.91**

(c) $Z_i = R_1 \parallel R_2 \parallel \beta r_e$

$$= 68\text{ k}\Omega \parallel 10\text{ k}\Omega \parallel \underbrace{(120)(28.48\ \Omega)}_{3.418\text{ k}\Omega}$$

$=$ **2.455 kΩ**

(d) $A_{v_s} = \dfrac{V_o}{V_s} = \dfrac{V_o}{V_i} \cdot \dfrac{V_i}{V_s}$

$$\frac{V_i}{V_s} = \frac{Z_i}{Z_i + R_s} = \frac{2.455\ \text{k}\Omega}{2.455\ \text{k}\Omega + 0.82\ \text{k}\Omega}$$
$$= 0.75$$
$$A_{v_s} = (-72.91)(0.75)$$
$$= \mathbf{-54.68}$$

(e) $f_{L_S} = \dfrac{1}{2\pi(R_s + R_i)C_s} = \dfrac{1}{2\pi(0.82\ \text{k}\Omega + 2.455\ \text{k}\Omega)(0.47\ \mu\text{F})}$

$$= \mathbf{103.4\ Hz}$$

$$f_{L_C} = \frac{1}{2\pi(R_o + R_L)C_C} = \frac{1}{2\pi(5.6\ \text{k}\Omega + 3.3\ \text{k}\Omega)(0.47\ \mu\text{F})}$$
$$= \mathbf{38.05\ Hz}$$

$$f_{L_E} = \frac{1}{2\pi R_e C_E} : R_e = R_E \parallel \left(\frac{R_s'}{\beta} + r_e\right)$$

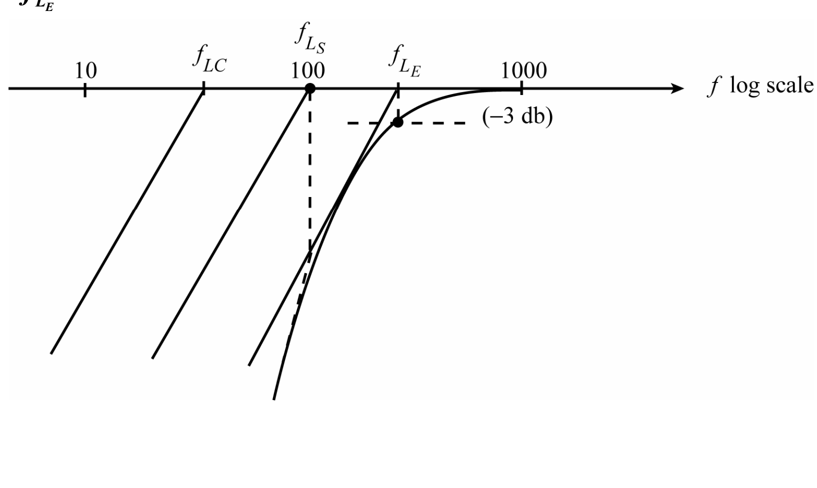
$$R_s' = R_s \parallel R_1 \parallel R_2 = 0.82\ \text{k}\Omega \parallel 68\ \text{k}\Omega \parallel 10\ \text{k}\Omega$$
$$= 749.51\ \Omega$$

$$R_e = 1.2\ \text{k}\Omega \parallel \left(\frac{749.51\ \Omega}{120} + 28.48\ \Omega\right)$$
$$= 1.2\ \text{k}\Omega \parallel 34.73\ \Omega$$
$$= 33.75\ \Omega$$

$$f_{L_E} = \frac{1}{2\pi R_e C_E} = \frac{1}{2\pi(33.75\ \Omega)(20\ \mu\text{F})}$$
$$= \mathbf{235.79\ Hz}$$

(f) $f_1 \cong \boldsymbol{f_{L_E}} = \mathbf{235.79\ Hz}$

(g)(h)



16. (a) $I_B = \dfrac{V_{CC} - V_{BE}}{R_B + (\beta+1)R_E} = \dfrac{20\text{ V} - 0.7\text{ V}}{470\text{ k}\Omega + (111)(0.91\text{ k}\Omega)} = \dfrac{19.3\text{ V}}{470\text{ k}\Omega + 101.01\text{ k}\Omega}$

$= 33.8\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (111)(33.8\ \mu\text{A})$

$= 3.752\text{ mA}$

$r_e = \dfrac{26\text{ mV}}{3.752\text{ mA}} = \mathbf{6.93\ \Omega}$

(b) $A_{v_{\text{mid}}} = \dfrac{V_o}{V_i} = \dfrac{-(R_C \parallel R_L)}{r_e} = \dfrac{-(3\text{ k}\Omega \parallel 4.7\text{ k}\Omega)}{6.93\ \Omega} = \dfrac{-1.831\text{ k}\Omega}{6.93\ \Omega}$

$= \mathbf{-264.24}$

(c) $Z_i = R_B \parallel \beta r_e = 470\text{ k}\Omega \parallel (110)(6.93\ \Omega) = 470\text{ k}\Omega \parallel 762.3\ \Omega$

$= \mathbf{761.07\ \Omega}$

(d) $A_{v_{s(\text{mid})}} = \dfrac{Z_i}{Z_i + R_s} A_{v_{\text{mid}}} = \dfrac{761.07\ \Omega}{761.07\ \Omega + 0.6\text{ k}\Omega}(-264.24)$

$= \mathbf{-147.76}$

(e) $f_{L_S} = \dfrac{1}{2\pi(R_S + Z_i)C_S} = \dfrac{1}{2\pi(600\ \Omega + 761.07\ \Omega)(1\ \mu\text{F})}$

$= \mathbf{116.93\ Hz}$

$f_{L_C} = \dfrac{1}{2\pi(R_o + R_L)C_C} = \dfrac{1}{2\pi(3\text{ k}\Omega + 4.7\text{ k}\Omega)(1\ \mu\text{F})}$

$= \mathbf{20.67\ Hz}$

$f_{L_E} = \dfrac{1}{2\pi R_e C_E}$

$= \dfrac{1}{2\pi(12.21\ \Omega)(6.8\ \mu\text{F})}$

$= \mathbf{1.917\ kHz}$

$R_e = R_E \parallel \left(\dfrac{R_s'}{\beta} + r_e\right)$

$= 0.91\text{ k}\Omega \parallel \left(\dfrac{R_s \parallel R_B}{\beta} + r_e\right)$

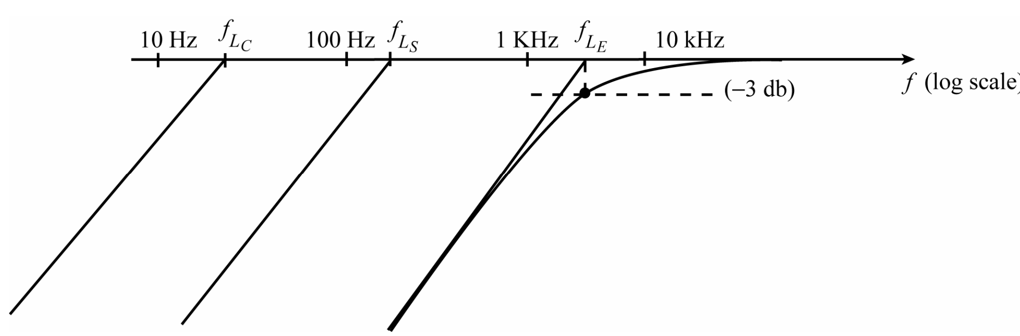
$= 0.91\text{ k}\Omega \parallel \left(\dfrac{0.6\text{ k}\Omega \parallel 470\text{ k}\Omega}{110} + 6.93\ \Omega\right)$

$= 910\ \Omega \parallel 12.38\ \Omega$

$= 12.21\ \Omega$

(f) $f_1 \cong f_{L_E} = \mathbf{1.917\ kHz}$

(g, h)



17. (a) $\beta R_E \geq 10R_2$

$(100)(2.2\text{ k}\Omega) \geq 10(30\text{ k}\Omega)$

$220\text{ k}\Omega \not\geq 300\text{ k}\Omega$ (No!)

$R_{Th} = R_1 \| R_2 = 120\text{ k}\Omega \| 30\text{ k}\Omega = 24\text{ k}\Omega$

$$E_{Th} = \frac{30\text{ k}\Omega(14\text{ V})}{30\text{ k}\Omega + 120\text{ k}\Omega} = 2.8\text{ V}$$

$$I_B = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta+1)R_E} = \frac{2.8\text{ V} - 0.7\text{ V}}{24\text{ k}\Omega + 222.2\text{ k}\Omega}$$

$= 8.53\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (101)(8.53\ \mu\text{A})$

$= 0.86\text{ mA}$

$$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{0.86\text{ mA}} = \mathbf{30.23\ \Omega}$$

(b)
$$A_{v_{\text{mid}}} = \frac{R_E \| R_L}{r_e + R_E \| R_L}$$

$$= \frac{2.2\text{ k}\Omega \| 8.2\text{ k}\Omega}{30.23\ \Omega + 2.2\text{ k}\Omega \| 8.2\text{ k}\Omega}$$

$= \mathbf{0.983}$

(c) $Z_i = R_1 \| R_2 \| \beta(r_e + R'_E)$ $\qquad R'_E = R_E \| R_L = 2.2\text{ k}\Omega \| 8.2\text{ k}\Omega = 1.735\text{ k}\Omega$

$= 120\text{ k}\Omega \| 30\text{ k}\Omega \| (100)(30.23\ \Omega + 1.735\text{ k}\Omega)$

$= \mathbf{21.13\ k\Omega}$

(d)
$$A_{v_s} = \frac{V_o}{V_s} = \frac{V_o}{V_i}\cdot\frac{V_i}{V_s} \qquad \frac{V_i}{V_s} = \frac{Z_i}{Z_i + R_s} = \frac{21.13\text{ k}\Omega}{21.13\text{ k}\Omega + 1\text{ k}\Omega} = 0.955$$

(e)
$$f_{L_S} = \frac{1}{2\pi(R_s + R_i)C_s}$$

$$= \frac{1}{2\pi(1\text{ k}\Omega + 21.13\text{ k}\Omega)(0.1\ \mu\text{F})}$$

$= \mathbf{71.92\ Hz}$

$$f_{L_C} = \frac{1}{2\pi(R_o + R_L)C_C}$$

$$R'_s = R_s \| R_1 \| R_2 = 1\text{ k}\Omega \| 120\text{ k}\Omega \| 30\text{ k}\Omega = 0.96\text{ k}\Omega$$

$$R_o = R_E \| \left(\frac{R'_s}{\beta} + r_e\right)$$

$$= (2.2\text{ k}\Omega) \| \left(\frac{0.96\text{ k}\Omega}{100} + 30.23\ \Omega\right)$$

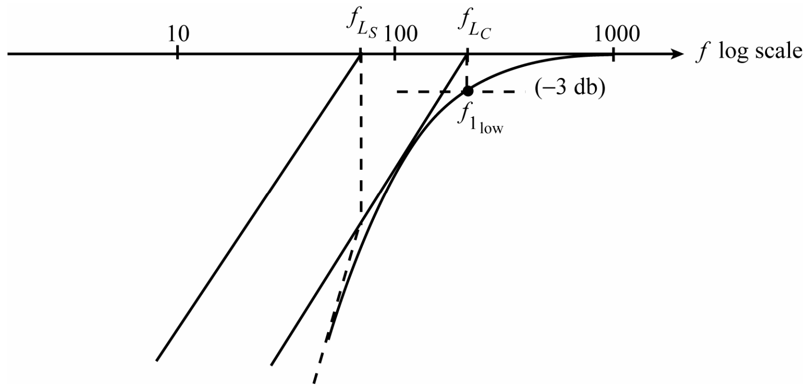
$= 39.12\ \Omega$

$$f_{L_C} = \frac{1}{2\pi(39.12\ \Omega + 8.2\text{ k}\Omega)(0.1\ \mu\text{F})}$$

$= \mathbf{193.16\ Hz}$

(f) $f_{1_{low}} \cong$ **193.16 Hz**

(g)(h)



18. (a) $I_E = \dfrac{V_{EE} - V_{EB}}{R_E} = \dfrac{4\text{ V} - 0.7\text{ V}}{1.2\text{ k}\Omega} = 2.75\text{ mA}$

$r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{2.75\text{ mA}} = 9.45\ \Omega$

(b) $A_{v_{mid}} = \dfrac{R_C \parallel R_L}{r_e} = \dfrac{3.3\text{ k}\Omega \parallel 4.7\text{ k}\Omega}{9.45\ \Omega}$

$= \mathbf{205.1}$

(c) $Z_i = R_E \parallel r_e = 1.2\text{ k}\Omega \parallel 9.45\ \Omega$

$= \mathbf{9.38\ \Omega}$

(d) $A_{v_{s(mid)}} = \dfrac{Z_i}{Z_i + R_s} A_{v_{mid}} = \dfrac{9.38\ \Omega(205.1)}{9.38\ \Omega + 100\ \Omega}$

$= \mathbf{17.59}$

(e) $f_{L_s} = \dfrac{1}{2\pi(R_s + Z_i)C_s} = \dfrac{1}{2\pi(100\ \Omega + 9.38\ \Omega)(10\ \mu\text{F})}$

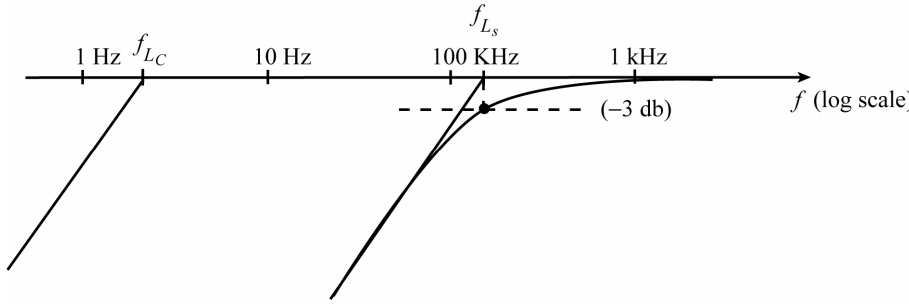
$=$ **145.5 Hz**

$f_{L_C} = \dfrac{1}{2\pi(R_o + R_L)C_E} = \dfrac{1}{2\pi(3.3\text{ k}\Omega + 4.7\text{ k}\Omega)(10\ \mu\text{F})}$

$=$ **1.989 Hz**

(f) $f = f_{L_s} \cong$ **145.5 Hz**

(g, h)



19. (a) $V_{GS} = -I_D R_S$

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2 \quad \Big\} \quad V_{GS_Q} \cong \mathbf{-2.45\ V}, \quad I_{D_Q} \cong \mathbf{2.1\ mA}$$

(b) $g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(6\text{ mA})}{6\text{ V}} = \mathbf{2\ mS}$

$$g_m = g_{m0}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = 2\text{ mS}\left(1 - \frac{(-2.45\text{ V})}{(-6\text{ V})}\right)$$
$$= \mathbf{1.18\ mS}$$

(c) $A_{v_{\text{mid}}} = -g_m(R_D \,||\, R_L)$

$$= -1.18\text{ mS}(3\text{ k}\Omega \,||\, 3.9\text{ k}\Omega) = -1.18\text{ mS}(1.6956\text{ k}\Omega)$$
$$= \mathbf{-2}$$

(d) $Z_i = R_G = \mathbf{1\ M\Omega}$

(e) $A_{v_s} = A_v = \mathbf{-2}$

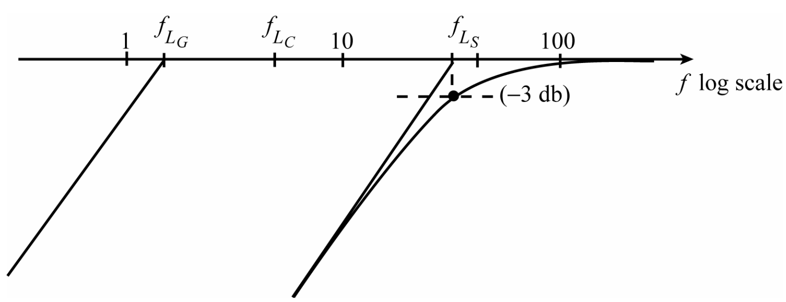
(f) $$f_{L_G} = \frac{1}{2\pi(R_{\text{sig}} + R_i)C_G} = \frac{1}{2\pi(1\text{ k}\Omega + 1\text{ M}\Omega)(0.1\ \mu\text{F})}$$
$$= \mathbf{1.59\ Hz}$$

$$f_{L_C} = \frac{1}{2\pi(R_o + R_L)C_C}$$
$$= \frac{1}{2\pi(3\text{ k}\Omega + 3.9\text{ k}\Omega)(4.7\ \mu\text{F})}$$
$$= \mathbf{4.91\ Hz}$$

$$f_{L_S} = \frac{1}{2\pi R_{\text{eq}} C_S} \qquad R_{\text{eq}} = R_S \,||\, \frac{1}{g_m} = 1.2\text{ k}\Omega \,||\, \frac{1}{1.18\text{ mS}} = 1.2\text{ k}\Omega \,||\, 847.46\ \Omega$$
$$= \frac{1}{2\pi(496.69\ \Omega)(10\ \mu\text{F})} \qquad = 496.69\ \Omega$$
$$= \mathbf{32.04\ Hz}$$

(g) $f_1 \cong f_{L_S} \cong \mathbf{32\ Hz}$

(h, i)



20. (a) same as problem 19

$V_{GS_Q} \cong \mathbf{-2.45\ V},\ I_{D_Q} \cong \mathbf{2.1\ mA}$

(b) g_{m0} = **2 mS**, g_m = **1.18 mS** (r_d has no effect!)

(c) $A_{v_{\text{mid}}} = -g_m (R_D \| R_L \| r_d)$
$= -1.18\text{ mS}(3\text{ k}\Omega \| 3.9\text{ k}\Omega \| 100\text{ k}\Omega)$
$= -1.18\text{ mS }(1.67\text{ k}\Omega)$
$= \mathbf{-1.971}$ (vs. –2 for problem 19)

(d) $Z_i = R_G$ = **1 MΩ** (the same)

(e) $$A_{v_{s(\text{mid})}} = \frac{Z_i}{Z_i + R_{\text{sig}}}(A_{v_{\text{mid}}}) = \frac{1\text{ M}\Omega}{1\text{ M}\Omega + 1\text{ k}\Omega}(-1.971)$$
$= \mathbf{-1.969}$ vs. –2 for problem 19

(f) f_{L_G} = **1.59 Hz** (no effect)

f_{L_C}: $R_o = R_D \| r_d = 3\text{ k}\Omega \| 100\text{ k}\Omega = 2.91\text{ k}\Omega$

$$f_{L_C} = \frac{1}{2\pi(R_o + R_L)C_C} = \frac{1}{2\pi(2.91\text{ k}\Omega + 3.9\text{ k}\Omega)(4.7\ \mu\text{F})}$$
= **4.97 Hz** vs. 4.91 Hz for problem 19

$$f_{L_S}:\ R_{\text{eq}} = \frac{R_S}{1 + R_S(1 + g_m r_d)/(r_d + (R_D \| R_L))}$$
$$= \frac{1.2\text{ k}\Omega}{1 + (1.2\text{ k}\Omega)(1 + (1.18\text{ mS})(100\text{ k}\Omega))/(100\text{ k}\Omega + 3\text{ k}\Omega \| 3.9\text{ k}\Omega)}$$
$$= \frac{1.2\text{ k}\Omega}{1 + 1.404}$$
$\cong 499.2\ \Omega$

$$f_{L_S} := \frac{1}{2\pi R_{\text{eq}} C_S} = \frac{1}{2\pi(499.2\ \Omega)(10\ \mu\text{F})}$$
= **31.88** Hz vs. 32.04 for problem 19.

Effect of r_d = 100 kΩ insignificant!

21. (a) $$V_G = \frac{68\text{ k}\Omega(20\text{ V})}{68\text{ k}\Omega + 220\text{ k}\Omega} = 4.72\text{ V}$$

$V_{GS} = V_G - I_D R_S$
$V_{GS} = 4.72\text{ V} - I_D(2.2\text{ k}\Omega)$
$I_D = I_{DSS}(1 - V_{GS}/V_P)^2$

$\Big\}$ $V_{GS_Q} \cong \mathbf{-2.55\ V}$, $I_{D_Q} \cong \mathbf{3.3\ mA}$

(b) $$g_{m0} = \frac{2I_{DSS}}{|V_P|} = \frac{2(10\text{ mA})}{6\text{ V}} = 3.33\text{ mS}$$

$$g_m = g_{m0}\left(1 - \frac{V_{GS}}{V_P}\right) = 3.33\text{ mS}\left(1 - \frac{(-2.55\text{ V})}{-6\text{ V}}\right)$$
= **1.91 mS**

(c) $A_{v_{\text{mid}}} = -g_m(R_D \parallel R_L)$

$= -(1.91 \text{ mS})(3.9 \text{ k}\Omega \parallel 5.6 \text{ k}\Omega)$

$= \mathbf{-4.39}$

(d) $Z_i = 68 \text{ k}\Omega \parallel 220 \text{ k}\Omega = \mathbf{51.94 \text{ k}\Omega}$

(e) $A_{v_{s(\text{mid})}} = \dfrac{V_o}{V_i} \cdot \dfrac{V_i}{V_s}$

$$\frac{V_i}{V_s} = \frac{Z_i}{Z_i + R_s} = \frac{51.94 \text{ k}\Omega}{51.94 \text{ k}\Omega + 1.5 \text{ k}\Omega} = 0.972$$

$A_{v_{s(\text{mid})}} = (-4.39)(0.972) = \mathbf{-4.27}$

(f) $$f_{L_G} = \frac{1}{2\pi(R_{\text{sig}} + R_i)C_G} = \frac{1}{2\pi(1.5 \text{ k}\Omega + 51.94 \text{ k}\Omega)(1\ \mu\text{F})}$$

$= \mathbf{2.98 \text{ Hz}}$

$$f_{L_C} = \frac{1}{2\pi(R_o + R_L)C_C} = \frac{1}{2\pi(3.9 \text{ k}\Omega + 5.6 \text{ k}\Omega)(6.8\ \mu\text{F})}$$

$= \mathbf{2.46 \text{ Hz}}$

$$f_{L_S} = \frac{1}{2\pi R_{\text{eq}} C_S}$$

$$= \frac{1}{2\pi(388.1\ \Omega)(10\ \mu\text{F})}$$

$= \mathbf{41 \text{ Hz}}$

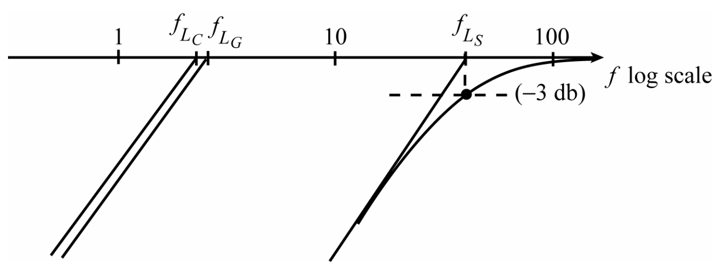
$R_{\text{eq}} = R_S \parallel \dfrac{1}{g_m} = 1.5 \text{ k}\Omega \parallel \dfrac{1}{1.91 \text{ mS}}$

$= 1.5 \text{ k}\Omega \parallel 523.56\ \Omega$

$= 388.1\ \Omega$

(g) $f_1 \cong f_{L_S} = \mathbf{41 \text{ Hz}}$

(h, i)



22. (a) $f_{H_i} = \dfrac{1}{2\pi R_{Th_1} C_i}$

$= \dfrac{1}{2\pi(614.56\ \Omega)(931.92\ \text{pF})}$

$=$ **277.89 kHz**

$R_{Th_1} = R_s \parallel R_1 \parallel R_2 \parallel R_i$

$= \underbrace{0.82\ \text{k}\Omega \parallel 68\ \text{k}\Omega}_{0.81\ \text{k}\Omega} \parallel \underbrace{10\ \text{k}\Omega \parallel 3.418\ \text{k}\Omega}_{2.547\ \text{k}\Omega}$

$= 614.56\ \Omega$

$C_i = C_{W_1} + C_{be} + C_{bc}(1 - A_v)$

$= 5\ \text{pF} + 40\ \text{pF} + 12\ \text{pF}(1 - (-72.91))$

$= 931.92\ \text{pF}$ ↑Prob. 15

$f_{H_o} = \dfrac{1}{2\pi R_{Th_2} C_o}$

$= \dfrac{1}{2\pi(2.08\ \text{k}\Omega)(28\ \text{pF})}$

$=$ **2.73 MHz**

$R_{Th_2} = R_C \parallel R_L = 5.6\ \text{k}\Omega \parallel 3.3\ \text{k}\Omega$

$= 2.08\ \text{k}\Omega$

$C_o = C_{W_o} + C_{ce} + C_{M_o}$

$= 8\ \text{pF} + 8\ \text{pF} + 12\ \text{pF}$

$= 28\ \text{pF}$

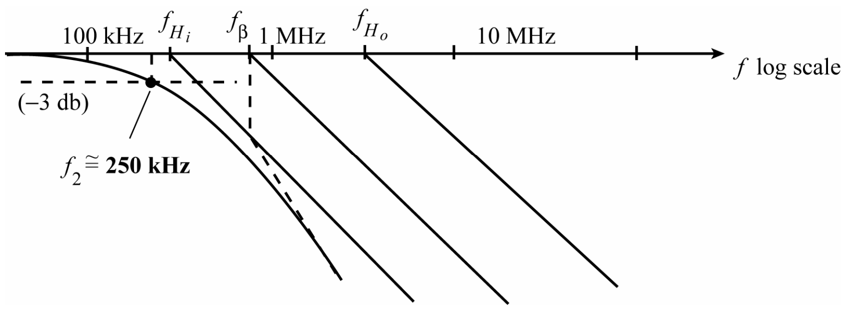
(b) $f_\beta \cong \dfrac{1}{2\pi\beta_{\text{mid}} r_e (C_{be} + C_{bc})} = \dfrac{1}{2\pi(120)(28.48\ \Omega)(40\ \text{pF} + 12\ \text{pF})}$

$=$ **895.56 kHz** ↑ Prob. 15

$f_T = \beta f_\beta = (120)(895.56\ \text{kHz})$

$=$ **107.47 MHz**

(c)



23. (a) $f_{H_i} = \dfrac{1}{2\pi R_{Th_1} C_i}$

$R_{Th_1} = R_s \parallel R_B \parallel R_i$

R_i: $I_B = \dfrac{V_{CC} - V_{BE}}{R_B + (\beta + 1)R_E} = \dfrac{20\ \text{V} - 0.7\ \text{V}}{470\ \text{k}\Omega + (111)(0.91\ \text{k}\Omega)}$

$= 33.8\ \mu\text{A}$

$I_E = (\beta + 1)I_B = (110 + 1)(33.8\ \mu\text{A})$

$= 3.75\ \text{mA}$

$r_e = \dfrac{26\ \text{mV}}{I_E} = \dfrac{26\ \text{mV}}{3.75\ \text{mA}} = 6.93\ \Omega$

$R_i = \beta r_e = (110)(6.93\ \Omega)$

$= 762.3\ \Omega$

$R_{Th_1} = R_s \parallel R_B \parallel R_i = 0.6\ \text{k}\Omega \parallel 470\ \text{k}\Omega \parallel 762.3\ \Omega$

$= 335.50\ \Omega$

$$f_{H_i} = \frac{1}{2\pi(335.50\ \Omega)(C_i)}$$

C_i: $C_i = C_{W_i} + C_{be} + (1 - A_v)C_{bc}$

A_v: $A_{v_{\text{mid}}} = \frac{-(R_L \parallel R_C)}{r_e} = \frac{-(4.7\ \text{k}\Omega \parallel 3\ \text{k}\Omega)}{6.93\ \Omega}$

$= -264.2$

$C_i = 7\ \text{pF} + 20\ \text{pF} + (1 - (-264.2)6\ \text{pF}$

$= 1.62\ \text{nF}$

$$f_{H_i} = \frac{1}{2\pi(335.50\ \Omega)(1.62\ \text{nF})}$$

$\cong$ **293 kHz**

$$f_{H_o} = \frac{1}{2\pi R_{Th_2} C_o}$$

$R_{Th_2} = R_C \parallel R_L = 3\ \text{k}\Omega \parallel\ 4.7\ \text{k}\Omega = 1.831\ \text{k}\Omega$

$C_o = C_{W_o} + C_{ce} + \underbrace{C_{M_o}}_{\cong C_f = C_{bc}}$

$= 11\ \text{pF} + 10\ \text{pF} + 6\ \text{pF}$

$= 27\ \text{pF}$

$$f_{H_o} = \frac{1}{2\pi(1.831\ \text{k}\Omega)(27\ \text{pF})}$$

$=$ **3.22 MHz**

(b) $f_\beta = \frac{1}{2\pi\beta_{\text{mid}} r_e (C_{be} + C_{bc})}$

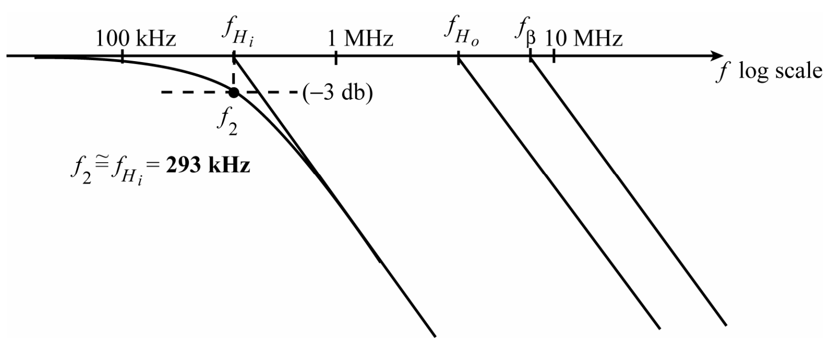
$= \frac{1}{2\pi(110)(6.93\ \Omega)(20\ \text{pF} + 6\ \text{pF})}$

$=$ **8.03 MHz**

$f_T = \beta_{\text{mid}} f_\beta = (110)(8.03\ \text{MHz})$

$=$ **883.3 MHz**

(c)



24. (a)

$$f_{H_i} = \frac{1}{2\pi R_{Th_1} C_i} = \frac{1}{2\pi(955\ \Omega)(58\ \text{pF})} = 2.87\ \text{MHz}$$

$R_{Th_1} = R_s \,\|\, R_1 \,\|\, R_2 \,\|\, Z_b$

$Z_b = \beta r_e + (\beta + 1)(R_E \,\|\, R_L)$
$= (100)(30.23\ \Omega) + (101)(2.2\ \text{k}\Omega \,\|\, 8.2\ \text{k}\Omega)$
$= 3.023\ \text{k}\Omega + 175.2\ \text{k}\Omega$
$= 178.2\ \text{k}\Omega$

$R_{Th_1} = 1\ \text{k}\Omega \,\|\, 120\ \text{k}\Omega \,\|\, 30\ \text{k}\Omega \,\|\, 178.2\ \text{k}\Omega$
$= 955\ \Omega$

$C_i = C_{W_i} + C_{be} + C_{bc}$ (No Miller effect)
$= 8\ \text{pF} + 30\ \text{pF} + 20\ \text{pF}$
$= 58\ \text{pF}$

$$f_{H_o} = \frac{1}{2\pi R_{Th_2} C_o} = \frac{1}{2\pi(38.94\ \Omega)(32\ \text{pF})} = \mathbf{127.72\ MHz}$$

$$R_{Th_2} = R_E \,\|\, R_L \,\|\, \left(r_e + \frac{\overbrace{R_1 \,\|\, R_2 \,\|\, R_3}^{24\ \text{k}\Omega}}{\beta}\right)$$

$$= 2.2\ \text{k}\Omega \,\|\, 8.2\ \text{k}\Omega \,\|\, \left(30.23\ \Omega + \frac{24\ \text{k}\Omega \,\|\, 1\ \text{k}\Omega}{100}\right)$$

$= 1.735\ \text{k}\Omega \,\|\, (30.23\ \Omega + 9.6\ \Omega)$
$= 1.735\ \text{k}\Omega \,\|\, 39.83\ \Omega$
$= 38.94\ \Omega$

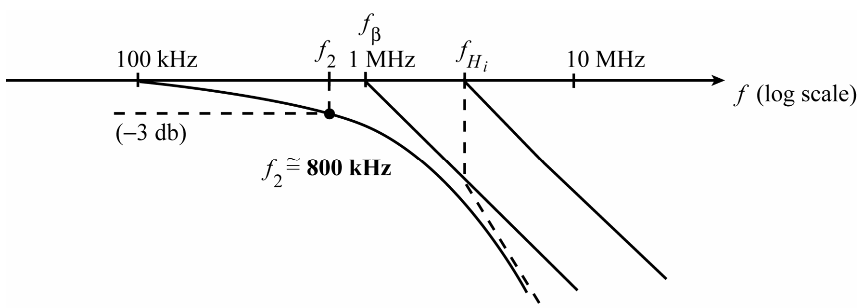
$C_o = C_{W_o} + C_{ce}$
$= 10\ \text{pF} + 12\ \text{pF}$
$= 32\ \text{pF}$

(b)

$$f_\beta = \frac{1}{2\pi\beta_{\text{mid}} r_e (C_{be} + C_{bc})} = \frac{1}{2\pi(100)(30.23\ \Omega)(30\ \text{pF} + 20\ \text{pF})} = \mathbf{1.05\ MHz}$$

$f_T = \beta_{\text{mid}} f_\beta = 100(1.05\ \text{MHz}) = \mathbf{105\ MHz}$

(c)



25. (a) $f_{H_i} = \dfrac{1}{2\pi R_{Th_1} C_i}$

$R_{Th_1} = R_s \parallel R_E \parallel R_i$

R_i: $I_E = \dfrac{V_{EE} - V_{BE}}{R_E} = \dfrac{4\text{ V} - 0.7\text{ V}}{1.2\text{ k}\Omega} = 2.75\text{ mA}$

$r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{2.75\text{ mA}} = 9.45\ \Omega$

$R_i = R_E \parallel r_e = 1.2\text{ k}\Omega \parallel 9.45\ \Omega$
$= 9.38\ \Omega$

C_i: $C_i = C_{W_i} + C_{be}$ (no Miller cap-noninverting!)
$= 8\text{ pF} + 24\text{ pF}$
$= 32\text{ pF}$

$R_i = 0.1\text{ k}\Omega \parallel 1.2\text{ k}\Omega \parallel 9.38\ \Omega = 8.52\ \Omega$

$f_{H_i} = \dfrac{1}{2\pi(8.52\ \Omega)(32\text{ pF})} \cong$ **584 MHz**

$f_{H_o} = \dfrac{1}{2\pi R_{Th_2} C_o}$ $\qquad R_{Th_2} = R_C \parallel R_L = 3.3\text{ k}\Omega \parallel 4.7\text{ k}\Omega = 1.94\text{ k}\Omega$

$C_o = C_{W_o} + C_{bc} +$ (no Miller)
$= 10\text{ pF} + 18\text{ pF}$
$= 28\text{ pF}$

$f_{H_o} = \dfrac{1}{2\pi(1.94\text{ k}\Omega)(28\text{ pF})}$
= **2.93 MHz**

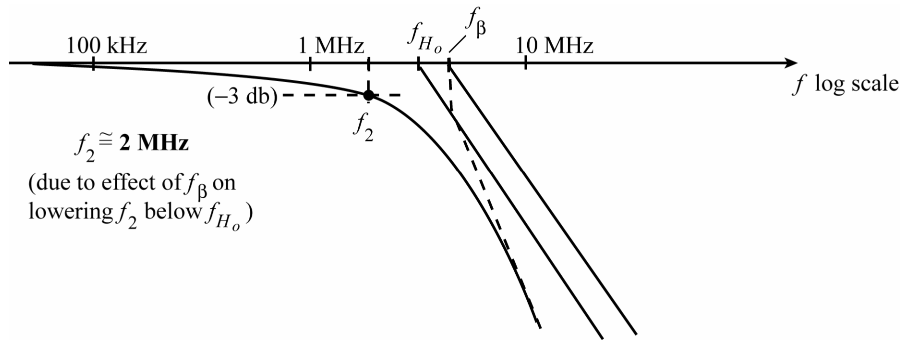
(b) $f_\beta = \dfrac{1}{2\pi\beta_{\text{mid}} r_e (C_{be} + C_{bc})}$

$= \dfrac{1}{2\pi(80)(9.45\ \Omega)(24\text{ pF} + 18\text{ pF})}$

= **5.01 MHz**

$f_T = \beta_{\text{mid}} f_\beta = (80)(5.01\text{ MHz})$
= **400.8 MHz**

(c)



26. (a) From problem 19 g_{m0} = **2 mS**, g_m = **1.18 mS**

(b) From problem 19 $A_{v_{\text{mid}}} \cong A_{v_{s\,(\text{mid})}} = \mathbf{-2}$

(c)
$$f_{H_i} = \frac{1}{2\pi R_{Th_1} C_i}$$

$$f_{H_i} = \frac{1}{2\pi(999\ \Omega)(21\ \text{pF})}$$

= **7.59 MHz**

$R_{Th_1} = R_{\text{sig}} \parallel R_G$
$= 1\ \text{k}\Omega \parallel 1\ \text{M}\Omega$
$= 999\ \Omega$

$C_i = C_{W_i} + C_{gs} + C_{M_i}$

$C_{M_i} = (1 - A_v)C_{gd}$
$= (1 - (-2)4\ \text{pF}$
$= 12\ \text{pF}$

$C_i = 3\ \text{pF} + 6\ \text{pF} + 12\ \text{pF}$
$= 21\ \text{pF}$

$$f_{H_o} = \frac{1}{2\pi R_{Th_2} C_o}$$

$$= \frac{1}{2\pi(1.696\ \text{k}\Omega)(12\ \text{pF})}$$

= **7.82 MHz**

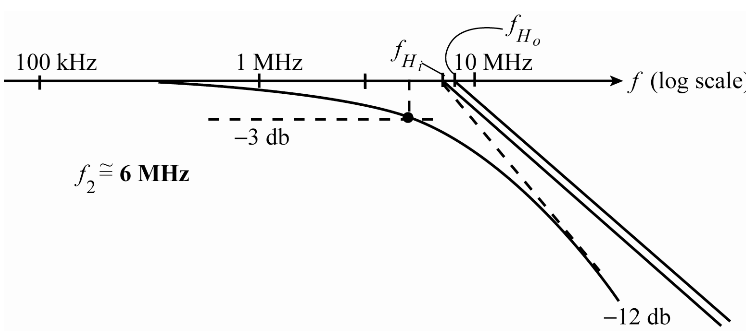
$R_{Th_2} = R_D \parallel R_L$
$= 3\ \text{k}\Omega \parallel 3.9\ \text{k}\Omega$
$= 1.696\ \text{k}\Omega$

$C_o = C_{W_o} + C_{ds} + C_{M_o}$

$$C_{M_o} = \left(1 - \frac{1}{-2}\right)4\ \text{pF}$$
$= (1.5)(4\ \text{pF})$
$= 6\ \text{pF}$

$C_o = 5\ \text{pF} + 1\ \text{pF} + 6\ \text{pF}$
$= 12\ \text{pF}$

(d)



27. (a) $$g_{m0} = \frac{2I_{DSS}}{|V_P|} = \frac{2(10\ \text{mA})}{6\ \text{V}} = \mathbf{3.33\ mS}$$

From problem #21 $V_{GS_Q} \cong$ **−2.55 V**, $I_{D_Q} \cong$ **3.3 mA**

$$g_m = g_{m0}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = 3.33\ \text{mS}\left(1 - \frac{-2.55\ \text{V}}{-6\ \text{V}}\right) = \mathbf{1.91\ mS}$$

(b) $A_{v_{\text{mid}}} = -g_m(R_D \parallel R_L)$

$= -(1.91 \text{ mS})(3.9 \text{ k}\Omega \parallel 5.6 \text{ k}\Omega)$

$= \mathbf{-4.39}$

$Z_i = 68 \text{ k}\Omega \parallel 220 \text{ k}\Omega = 51.94 \text{ k}\Omega$

$$\frac{V_i}{V_s} = \frac{Z_i}{Z_i + R_{\text{sig}}} = \frac{51.94 \text{ k}\Omega}{51.94 \text{ k}\Omega + 1.5 \text{ k}\Omega} = 0.972$$

$A_{v_{s\,(\text{mid})}} = (-4.39)(0.972)$

$= \mathbf{-4.27}$

(c) $f_{H_i} = \dfrac{1}{2\pi R_{Th_1} C_i}$ $\qquad R_{Th_1} = R_{\text{sig}} \parallel R_1 \parallel R_2$

$= 1.5 \text{ k}\Omega \parallel 51.94 \text{ k}\Omega$

$= 1.46 \text{ k}\Omega$

$C_i = C_{W_i} + C_{gs} + (1 - A_v)C_{gd}$

$= 4 \text{ pF} + 12 \text{ pF} + (1 - (-4.39))8 \text{ pF}$

$= 59.12 \text{ pF}$

$$f_{H_i} = \frac{1}{2\pi(1.46 \text{ k}\Omega)(59.12 \text{ pF})}$$

$= \mathbf{1.84\ MHz}$

$f_{H_o} = \dfrac{1}{2\pi R_{Th_2} C_o}$ $\qquad R_{Th_2} = R_D \parallel R_L = 3.9 \text{ k}\Omega \parallel 5.6 \text{ k}\Omega$

$= 2.3 \text{ k}\Omega$

$$C_o = C_{W_o} + C_{ds} + \left(1 - \frac{1}{A_v}\right)C_{gd}$$

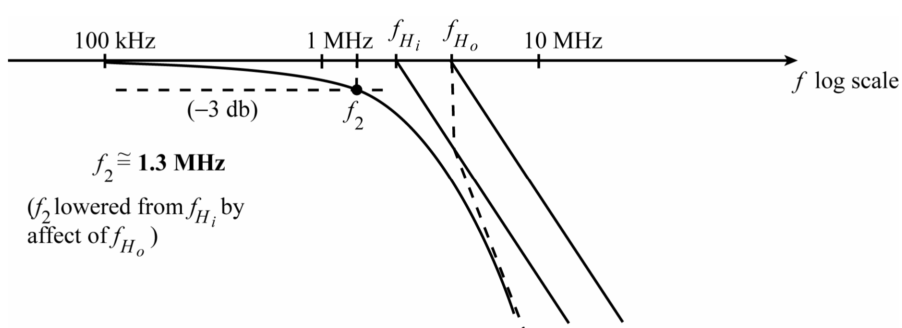
$$= 6 \text{ pF} + 3 \text{ pF} + \left(1 - \frac{1}{(-4.39)}\right)8 \text{ pF}$$

$= 18.82 \text{ pF}$

$$f_{H_o} = \frac{1}{2\pi(2.3 \text{ k}\Omega)(18.82 \text{ pF})}$$

$= \mathbf{3.68\ MHz}$

(d)



$f_2 \cong$ **1.3 MHz**

(f_2 lowered from f_{H_i} by affect of f_{H_o})

28. $A_{v_T} = A_{v_1} \cdot A_{v_2} \cdot A_{v_3} \cdot A_{v_4}$

$= A_v^{\,4}$

$= (20)^4$

$= \mathbf{16 \times 10^4}$

29. $f_2' = \left(\sqrt{2^{1/n} - 1}\right) f_2$

$= \left(\sqrt{\underbrace{2^{1/4}}_{1.18} - 1}\right)(2.5 \text{ MHz})$

$= 0.435(2.5 \text{ MHz})$

$= \mathbf{1.09 \text{ MHz}}$

30. $f_1' = \dfrac{f_1}{\sqrt{2^{1/n} - 1}} = \dfrac{40 \text{ Hz}}{\sqrt{2^{1/4} - 1}}$

$= \dfrac{40 \text{ Hz}}{0.435}$

$= \mathbf{91.96 \text{ Hz}}$

31. (a) $v = \dfrac{4}{\pi} V_m \left[\sin 2\pi f_s t + \dfrac{1}{3}\sin 2\pi(3f_s)t + \dfrac{1}{5}\sin 2\pi(5f_s)t + \dfrac{1}{7}\sin 2\pi(7f_s)t + \dfrac{1}{9}\sin 2\pi(9f_s)t + \ldots\right]$

$= 12.73 \times 10^{-3}(\sin 2\pi(100\times10^3)t + \dfrac{1}{3}\sin 2\pi(300\times10^3)t + \dfrac{1}{5}\sin 2\pi(500\times10^3)t + \dfrac{1}{7}\sin 2\pi(700\times10^3)t + \dfrac{1}{9}\sin 2\pi(900\times10^3)t)$

(b) $BW \cong \dfrac{0.35}{t_r}$

$\cong \dfrac{0.35}{0.7\ \mu\text{s}}$

$\cong 500$ kHz

At 90% or 81 mV, $t \cong 0.75\ \mu$s
At 10% or 9 mV, $t \cong 0.05\ \mu$s
$t_r \cong 0.75\ \mu\text{s} - 0.05\ \mu\text{s} = 0.7\ \mu\text{s}$

(c) $P = \dfrac{V - V'}{V} = \dfrac{90 \text{ mV} - 80 \text{ mV}}{90 \text{ mV}} = 0.111$

$f_{L_o} = \dfrac{P}{\pi} f_s = \dfrac{(0.111)(100 \text{ kHz})}{\pi} \cong \mathbf{3.53 \text{ kHz}}$

Chapter 10

1. $V_o = -\frac{R_F}{R_1}V_1 = -\frac{250\text{ k}\Omega}{20\text{ k}\Omega}(1.5\text{ V}) = \mathbf{-18.75\ V}$

2. $A_v = \frac{V_o}{V_i} = -\frac{R_F}{R_1}$

   For $R_1 = 10\text{ k}\Omega$:

   $A_v = -\frac{500\text{ k}\Omega}{10\text{ k}\Omega} = \mathbf{-50}$

   For $R_1 = 20\text{ k}\Omega$:

   $A_v = -\frac{500\text{ k}\Omega}{20\text{ k}\Omega} = \mathbf{-25}$

3. $V_o = -\frac{R_f}{R_1}V_1 = -\left(\frac{1\text{ M}\Omega}{20\text{ k}\Omega}\right)V_1 = 2\text{ V}$

   $V_1 = \frac{2\text{ V}}{-50} = \mathbf{-40\ mV}$

4. $V_o = -\frac{R_F}{R_1}V_1 = -\frac{200\text{ k}\Omega}{20\text{ k}\Omega}V_1 = -10\ V_1$

   For $V_1 = 0.1$ V:

   $V_o = -10(0.1\text{ V}) = \mathbf{-1\ V}$

   For $V_1 = 0.5$ V:

   $V_o = -10(0.5\text{ V}) = \mathbf{-5\ V}$

   } V_o ranges from **–1 V to –5 V**

5. $V_o = \left(1 + \frac{R_F}{R_1}\right)V_1 = \left(1 + \frac{360\text{ k}\Omega}{12\text{ k}\Omega}\right)(-0.3\text{ V})$

   $= 31(-0.3\text{ V}) = \mathbf{-9.3\ V}$

6. $V_o = \left(1 + \frac{R_F}{R_1}\right)V_1 = \left(1 + \frac{360\text{ k}\Omega}{12\text{ k}\Omega}\right)V_1 = 2.4\text{ V}$

   $V_1 = \frac{2.4\text{ V}}{31} = \mathbf{77.42\ mV}$

7. $V_o = \left(1 + \frac{R_F}{R_1}\right)V_1$

For $R_1 = 10\ \text{k}\Omega$:

$$V_o = \left(1 + \frac{200\ \text{k}\Omega}{10\ \text{k}\Omega}\right)(0.5\ \text{V}) = 21(0.5\ \text{V}) = \mathbf{10.5\ V}$$

For $R_1 = 20\ \text{k}\Omega$:

$$V_\text{o} = \left(1 + \frac{200\ \text{k}\Omega}{20\ \text{k}\Omega}\right)(0.5\ \text{V}) = 11(0.5\ \text{V}) = \mathbf{5.5\ V}$$

V_o ranges from 5.5 V to 10.5 V.

8. $V_o = -\left[\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3\right]$

$$= -\left[\frac{330\ \text{k}\Omega}{33\ \text{k}\Omega}(0.2\ \text{V}) + \frac{330\ \text{k}\Omega}{22\ \text{k}\Omega}(-0.5\ \text{V}) + \frac{330\ \text{k}\Omega}{12\ \text{k}\Omega}(0.8\ \text{V})\right]$$

$= -[10(0.2\ \text{V}) + 15(-0.5\ \text{V}) + 27.5(0.8\ \text{V})]$

$= -[2\ \text{V} + (-7.5\ \text{V}) + 2.2\ \text{V}]$

$= -[24\ \text{V} - 7.5\ \text{V}] = \mathbf{-16.5\ V}$

9. $V_o = -\left[\frac{R_F}{R_1}V_1 + \frac{R_F}{R_2}V_2 + \frac{R_F}{R_3}V_3\right]$

$$= -\left[\frac{68\ \text{k}\Omega}{33\ \text{k}\Omega}(0.2\ \text{V}) + \frac{68\ \text{k}\Omega}{22\ \text{k}\Omega}(-0.5\ \text{V}) + \frac{68\ \text{k}\Omega}{12\ \text{k}\Omega}(+0.8\ \text{V})\right]$$

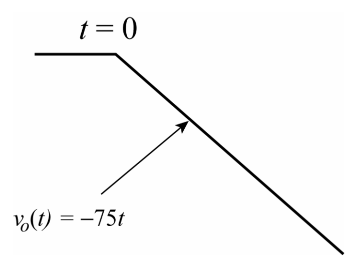
$= -[0.41\ \text{V} - 1.55\ \text{V} + 4.53\ \text{V}]$

$= \mathbf{-3.39\ V}$

10. $v_o(t) = -\frac{1}{RC}\int v_1(t)dt$

$$= -\frac{1}{(200\ \text{k}\Omega)(0.1\ \mu\text{F})}\int 1.5\ dt$$

$= -50(1.5t) = \mathbf{-75\mathit{t}}$



11. $V_o = V_1 = \mathbf{+0.5\ V}$

12. $V_o = -\frac{R_f}{R_1}V_1 = -\frac{100\ \text{k}\Omega}{20\ \text{k}\Omega}(1.5\ \text{V})$

$= -5(1.5\ \text{V}) = \mathbf{-7.5\ V}$

13. $V_2 = -\left[\frac{200\ \text{k}\Omega}{20\ \text{k}\Omega}\right](0.2\ \text{V}) = \mathbf{-2\ V}$

$V_3 = \left(1 + \frac{200\ \text{k}\Omega}{10\ \text{k}\Omega}\right)(0.2\ \text{V}) = \mathbf{+4.2\ V}$

14. $V_o = \left(1 + \frac{400\text{ k}\Omega}{20\text{ k}\Omega}\right)(0.1\text{ V}) \cdot \left(\frac{-100\text{ k}\Omega}{20\text{ k}\Omega}\right) + \left(-\frac{100\text{ k}\Omega}{10\text{ k}\Omega}\right)(0.1\text{ V})$

$= (2.1\text{ V})(-5) + (-10)(0.1\text{ V})$

$= -10.5\text{ V} - 1\text{ V} = \mathbf{-11.5\text{ V}}$

15. $V_o = -\left[\frac{600\text{ k}\Omega}{15\text{ k}\Omega}(25\text{ mV}) + \frac{600\text{ k}\Omega}{30\text{ k}\Omega}(-20\text{ mV})\right]\left(-\frac{300\text{ k}\Omega}{30\text{ k}\Omega}\right)$

$+\left[-\left(\frac{300\text{ k}\Omega}{15\text{ k}\Omega}\right)(-20\text{ mV})\right]$

$= -[40(25\text{ mV}) + (20)(-20\text{ mV})](-10) + (-20)(-20\text{ mV})$

$= -[1\text{ V} - 0.4\text{ V}](-10) + 0.4\text{ V}$

$= 6\text{ V} + 0.4\text{ V} = \mathbf{6.4\text{ V}}$

16. $V_o = \left(1 + \frac{R_f}{R_1}\right)V_{Io} + I_{Io}R_f$

$= \left(1 + \frac{200\text{ k}\Omega}{2\text{ k}\Omega}\right)(6\text{ mV}) + (120\text{ nA})(200\text{ k}\Omega)$

$= 101(6\text{ mV}) + 24\text{ mV}$

$= 606\text{ mV} + 24\text{ mV} = \mathbf{630\text{ mV}}$

17. $I_{IB}^{+} = I_{IB^{+}} + \frac{I_{Io}}{2} = 20\text{ nA} + \frac{4\text{ nA}}{2} = \mathbf{22\text{ nA}}$

$I_{IB}^{-} = I_{IB^{-}} - \frac{I_{Io}}{2} = 20\text{ nA} - \frac{4\text{ nA}}{2} = \mathbf{18\text{ nA}}$

18. $f_1 = 800\text{ kHz}$

$f_c = \frac{f_1}{A_{v_2}} = \frac{800\text{ kHz}}{150 \times 10^3} = \mathbf{5.3\text{ Hz}}$

19. $A_{CL} = \frac{SR}{\Delta V_i / \Delta t} = \frac{2.4\text{ V}/\mu\text{s}}{0.3\text{ V}/10\ \mu\text{s}} = \mathbf{80}$

20. $A_{CL} = \frac{R_f}{R_1} = \frac{200\text{ k}\Omega}{2\text{ k}\Omega} = 100$

$K = A_{CL}\,V_i = 100(50\text{ mV}) = 5\text{ V}$

$w_s \le \frac{SR}{K} = \frac{0.4\text{ V}/\mu\text{s}}{5\text{ V}} = \mathbf{80 \times 10^3\text{ rad/s}}$

$f_s = \frac{w_s}{2\pi} = \frac{80 \times 10^3}{2\pi} = \mathbf{12.73\text{ kHz}}$

21. V_{Io} = 1 mV, typical
I_{Io} = 20 nA, typical

$$V_o(\text{offset}) = \left(1 + \frac{R_f}{R_1}\right)V_{Io} + I_{Io}R_f$$
$$= \left(1 + \frac{200\text{ k}\Omega}{20\text{ k}\Omega}\right)(1\text{ mV}) + (200\text{ k}\Omega)(20\text{ nA})$$
$$= 101(1\text{ mV}) + 4000 \times 10^{-6}$$
$$= 101\text{ mV} + 4\text{ mV} = \mathbf{105\text{ mV}}$$

22. Typical characteristics for 741
R_o = 25 Ω, A = 200 K

(a) $A_{CL} = -\frac{R_f}{R_1} = -\frac{200\text{ k}\Omega}{2\text{ k}\Omega} = \mathbf{-100}$

(b) $Z_i = R_1 =$ **2 kΩ**

(c) $Z_o = \frac{R_o}{1+\beta A} = \frac{25\ \Omega}{1 + \frac{1}{100}(200{,}000)}$

$$= \frac{25\ \Omega}{2001} = \mathbf{0.0125\ \Omega}$$

23. $A_d = \frac{V_o}{V_d} = \frac{120\text{ mV}}{1\text{ mV}} = 120$

$A_c = \frac{V_o}{V_c} = \frac{20\ \mu\text{V}}{1\text{ mV}} = 20 \times 10^{-3}$

Gain (dB) = $20 \log \frac{A_d}{A_c} = 20 \log \frac{120}{20 \times 10^{-3}}$

$$= 20 \log(6 \times 10^3) = \mathbf{75.56\text{ dB}}$$

24. $V_d = V_{i1} - V_{i2} = 200\ \mu\text{V} - 140\ \mu\text{V} = 60\ \mu\text{V}$

$$V_c = \frac{V_{i1} + V_{i2}}{2} = \frac{(200\ \mu\text{V} + 140\ \mu\text{V})}{2} = 170\ \mu\text{V}$$

(a) $\text{CMRR} = \dfrac{A_d}{A_c} = 200$

$$A_c = \frac{A_d}{200} = \frac{6000}{200} = \mathbf{30}$$

(b) $\text{CMRR} = \dfrac{A_d}{A_c} = 10^5$

$$A_c = \frac{A_d}{10^5} = \frac{6000}{10^5} = 0.06 = \mathbf{60 \times 10^{-3}}$$

Using $V_o = A_d V_d \left[1 + \dfrac{1}{CMRR}\dfrac{V_c}{V_d}\right]$

(a) $V_o = 6000(60\ \mu\text{V})\left[1 + \dfrac{1}{200}\dfrac{170\ \mu\text{V}}{60\ \mu\text{V}}\right] = \mathbf{365.1\ mV}$

(b) $V_o = 6000(60\ \mu\text{V})\left[1 + \dfrac{1}{10^5}\dfrac{170\ \mu\text{V}}{60\ \mu\text{V}}\right] = \mathbf{360.01\ mV}$

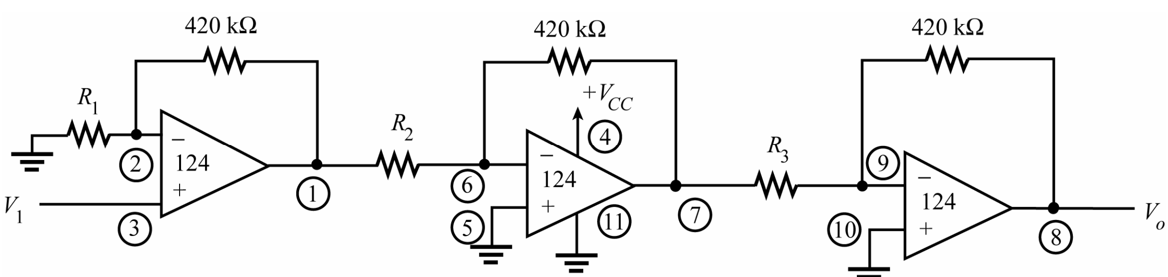
Chapter 11

1. $$V_o = -\frac{R_F}{R_1}V_1 = -\frac{180\text{ k}\Omega}{3.6\text{ k}\Omega}(3.5\text{ mV}) = \mathbf{-175\text{ mV}}$$

2. $$V_o = \left(1+\frac{R_F}{R_1}\right)V_1 = \left(1+\frac{750\text{ k}\Omega}{36\text{ k}\Omega}\right)(150\text{ mV, rms})$$
$$= \mathbf{3.275\text{ V}}\text{, rms } \angle 0°$$

3. $$V_o = \left(1+\frac{510\text{ k}\Omega}{18\text{ k}\Omega}\right)(20\ \mu\text{V})\left[-\frac{680\text{ k}\Omega}{22\text{ k}\Omega}\right]\left[-\frac{750\text{ k}\Omega}{33\text{ k}\Omega}\right]$$
$$= (29.33)(-30.91)(-22.73)(20\ \mu\text{V})$$
$$= \mathbf{412\text{ mV}}$$

4.



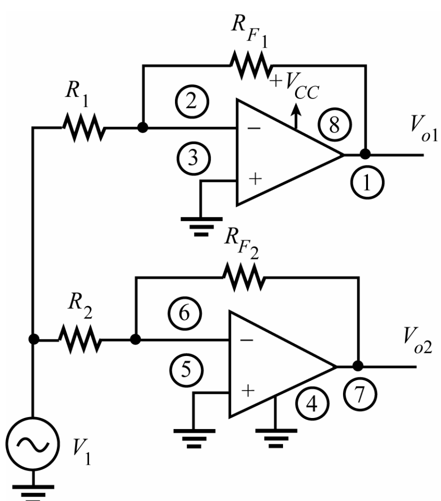
$$\left(1+\frac{420\text{ k}\Omega}{R_1}\right) = +15 \qquad -\frac{420\text{ k}\Omega}{R_2} = -22 \qquad \frac{420\text{ k}\Omega}{R_2} = -30$$

$$R_1 = \frac{420\text{ k}\Omega}{14} \qquad R_2 = \frac{420\text{ k}\Omega}{22} \qquad R_3 = \frac{420\text{ k}\Omega}{30}$$

$\mathbf{R_1 = 71.4\text{ k}\Omega}$ $\qquad$ $\mathbf{R_2 = 19.1\text{ k}\Omega}$ $\qquad$ $\mathbf{R_3 = 14\text{ k}\Omega}$

$$V_o = (+15)(-22)(-30)V_1 = 9000(80\ \mu\text{V}) = 792\text{ mV}$$
$$= \mathbf{0.792\text{ V}}$$

5.



$$V_{o1} = -\frac{R_{F1}}{R_1}V_1 = -\frac{150\text{ k}\Omega}{R_1}V_1$$
$$\frac{V_{o1}}{V_1} = A_{v_1} = -15 = -\frac{150\text{ k}\Omega}{R_1}$$
$$R_1 = \frac{150\text{ k}\Omega}{15} = \mathbf{10\text{ k}\Omega}$$

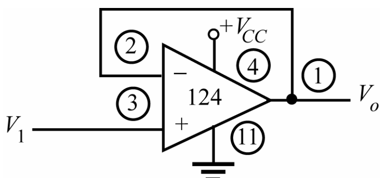
$$V_{o2} = -\frac{R_{F2}}{R_2}V_1 = -\frac{150\text{ k}\Omega}{R_2}V_1$$
$$\frac{V_{o2}}{V_1} = A_{v_2} = -30 = -\frac{150\text{ k}\Omega}{R_2}$$
$$R_2 = \frac{150\text{ k}\Omega}{30} = \mathbf{5\text{ k}\Omega}$$

6. $$V_o = -\left[\frac{R_F}{R_1}V_1 + \frac{R_F}{R_2}V_2\right] = -\left[\frac{470\text{ k}\Omega}{47\text{ k}\Omega}(40\text{ mV}) + \frac{470\text{ k}\Omega}{12\text{ k}\Omega}(20\text{ mV})\right]$$
$= -[400\text{ mV} + 783.3\text{ mV}] = \mathbf{-1.18\ V}$

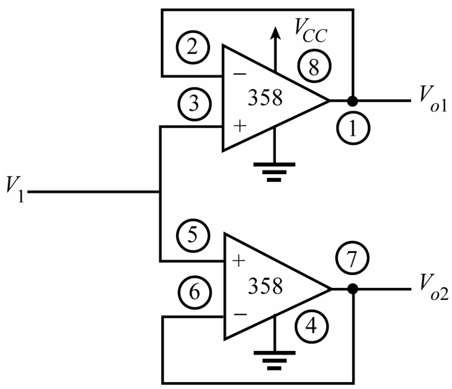
7. $$V_o = \left(\frac{10\text{ k}\Omega}{10\text{ k}\Omega + 10\text{ k}\Omega}\right)\left(\frac{150\text{ k}\Omega + 300\text{ k}\Omega}{150\text{ k}\Omega}\right)V_1 - \frac{300\text{ k}\Omega}{150\text{ k}\Omega}V_2$$
$= 0.5(3)(1\text{ V}) - 2(2\text{ V}) = 1.5\text{ V} - 4\text{ V} = \mathbf{-2.5\ V}$

8. $$V_o = -\left\{\left[\frac{330\text{ k}\Omega}{33\text{ k}\Omega}(12\text{ mV})\right]\left(\frac{470\text{ k}\Omega}{47\text{ k}\Omega}\right) + \frac{470\text{ k}\Omega}{47\text{ k}\Omega}(18\text{ mV})\right\}$$
$= -[(-120\text{ mV})(10) + 180\text{ mV}] = -[-1.2\text{ V} + 0.18\text{ V}]$
$= \mathbf{+1.02\ V}$

9.



10.



11. $$I_L = \frac{V_1}{R_1} = \frac{12\text{ V}}{2\text{ k}\Omega} = \mathbf{6\ mA}$$

12. $V_o = -I_1R_1 = -(2.5\text{ mA})(10\text{ k}\Omega) = \mathbf{-25\ V}$

13. $$\frac{I_o}{V_1} = \frac{R_F}{R_1}\left(\frac{1}{R_s}\right)$$
$$I_o = \frac{100\text{ k}\Omega}{200\text{ k}\Omega}\left(\frac{1}{10\ \Omega}\right)(10\text{ mV}) = \mathbf{0.5\ mA}$$

14. $$V_o = \left(1 + \frac{2R}{R_p}\right)[V_2 - V_1]$$
$$= \left(1 + \frac{2(5000)}{1000}\right)[1\text{ V} - 3\text{ V}] = \mathbf{-22\ V}$$

15. $f_{OH} = \dfrac{1}{2\pi R_1 C_1} = \dfrac{1}{2\pi(2.2\ \text{k}\Omega)(0.05\ \mu\text{F})}$

$= \mathbf{1.45\ kHz}$

16. $f_{OL} = \dfrac{1}{2\pi R_1 C_1} = \dfrac{1}{2\pi(20\ \text{k}\Omega)(0.02\ \mu\text{F})}$

$= \mathbf{397.9\ Hz}$

17. $f_{OL} = \dfrac{1}{2\pi R_1 C_1} = \dfrac{1}{2\pi(10\ \text{k}\Omega)(0.05\ \mu\text{F})}$ $= \mathbf{318.3\ Hz}$

$f_{OH} = \dfrac{1}{2\pi R_2 C_2} = \dfrac{1}{2\pi(20\ \text{k}\Omega)(0.02\ \mu\text{F})}$

$= \mathbf{397.9\ Hz}$

Chapter 12

1. $I_{B_Q} = \frac{V_{CC} - V_{BE}}{R_B} = \frac{18\text{ V} - 0.7\text{ V}}{1.2\text{ k}\Omega} = 14.42\text{ mA}$

$I_{C_Q} = \beta I_{B_Q} = 40(14.42\text{ mA}) = 576.67\text{ mA}$

$P_i = V_{CC}I_{dc} \cong V_{CC}I_{C_Q} = (18\text{ V})(576.67\text{ mA})$

$\cong \mathbf{10.4\ W}$

$I_C(\text{rms}) = \beta I_B(\text{rms})$

$= 40(5\text{ mA}) = 200\text{ mA}$

$P_o = I_C^2(\text{rms})R_C = (200\text{ mA})^2(16\ \Omega) = \mathbf{640\ mW}$

2. $I_{B_Q} = \frac{V_{CC} - V_{BE}}{R_B} = \frac{18\text{ V} - 0.7\text{ V}}{1.5\text{ k}\Omega} = 11.5\text{ mA}$

$I_{C_Q} = \beta I_{B_Q} = 40(11.5\text{ mA}) = 460\text{ mA}$

$P_i(\text{dc}) = V_{CC}I_{dc} = V_{CC}\left(I_{C_Q} + I_{B_Q}\right)$

$= 18\text{ V}(460\text{ mA} + 11.5\text{ mA})$

$= \mathbf{8.5\ W}$

$\left[P_i \approx V_{CC}I_{C_Q} = 18\text{ V}(460\text{ mA}) = 8.3\text{ W}\right]$

3. From problem 2: $I_{C_Q} = 460\text{ mA}$, $P_i = 8.3\text{ W}$.

For maximum efficiency of 25%:

$\%\eta = 100\% \times \frac{P_o}{P_i} = \frac{P_o}{8.3\text{ W}} \times 100\% = 25\%$

$P_o = 0.25(8.3\text{ W}) = \mathbf{21\ W}$

[If dc bias condition also is considered:

$V_C = V_{CC} - I_{C_Q}R_C = 18\text{ V} - (460\text{ mA})(16\ \Omega) = 10.64\text{ V}$

collector may vary ±7.36 V about Q-point, resulting in maximum output power:

$P_o = \frac{V_{CE}^2(P)}{2R_C} = \frac{(7.36\text{ V})^2}{2(16)} = \mathbf{1.69\ W}$

4. Assuming maximum efficiency of 25%
with P_o(max) = 1.5 W

$$\%\eta = \frac{P_o}{P_i} \times 100\%$$

$$P_i = \frac{1.5\text{ W}}{0.25} = 6\text{ W}$$

Assuming dc bias at mid-point, V_C = 9 V

$$I_{C_Q} = \frac{V_{CC} - V_C}{R_C} = \frac{18\text{ V} - 9\text{ V}}{16\ \Omega} = 0.5625\text{ A}$$

$$P_i(\text{dc}) = V_{CC} I_{C_Q} = (18\text{ V})(0.5625\text{ A}) = \mathbf{10.38\ W}$$

at this input:

$$\%\eta = \frac{P_o}{P_i} \times 100\% = \frac{1.5\text{ W}}{10.38\text{ W}} \times 100\% = \mathbf{14.45\%}$$

5. $$R_p = \left(\frac{N_1}{N_2}\right)^2 R_s = \left(\frac{25}{1}\right)^2 (4\ \Omega) = \mathbf{2.5\ k\Omega}$$

6. $R_2 = a^2 R_1$

$$a^2 = \frac{R_2}{R_1} = \frac{8\text{ k}\Omega}{8\ \Omega} = 1000$$

$$a = \sqrt{1000} = \mathbf{31.6}$$

7. $R_2 = a^2 R_1$

$8\text{ k}\Omega = a^2(4\ \Omega)$

$$a^2 = \frac{8\text{ k}\Omega}{4\ \Omega} = 2000$$

$$a = \sqrt{2000} = \mathbf{44.7}$$

8. (a) $P_{pri} = P_L = \mathbf{2\ W}$

(b) $P_L = \dfrac{V_L^2}{R_L}$

$$V_L = \sqrt{P_L R_L} = \sqrt{(2\text{ W})(16\ \Omega)} = \sqrt{32} = \mathbf{5.66\ V}$$

(c) $R_2 = a^2 R_1 = (3.87)^2(16\ \Omega) = \mathbf{239.6\ \Omega}$

$$P_{pri} = \frac{V_{pri}^2}{R_{pri}} = 2\text{ W}$$

$$V_{pri}^2 = (2\text{ W})(239.6\ \Omega)$$

$$V_{pri} = \sqrt{479.2} = \mathbf{21.89\ V}$$

[or, $V_{pri} = aV_L = (3.87)(5.66\text{ V}) = 21.9\text{ V}$]

(d) $P_L = I_L^2 R_L$

$$I_L = \sqrt{\frac{P_L}{R_L}} = \sqrt{\frac{2\text{ W}}{16\ \Omega}} = \mathbf{353.55\text{ mA}}$$

$$P_{pri} = 2\text{ W} = I_{pri}^2 R_{pri} = (239.6\ \Omega)\, I_{pri}^2$$

$$I_{pri} = \sqrt{\frac{2\text{ W}}{239.6\ \Omega}} = \mathbf{91.36\text{ mA}}$$

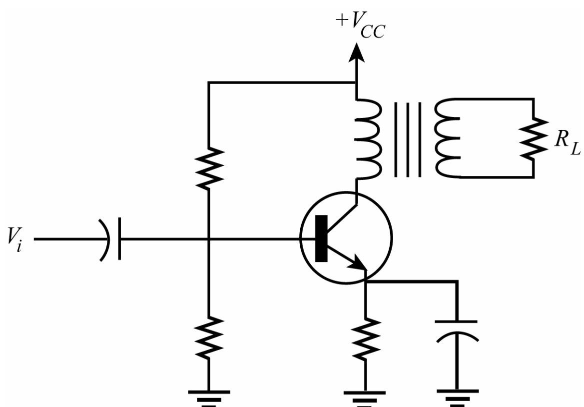
$$\text{or, } I_{pri} = \frac{I_L}{a} = \frac{353.55\text{ mA}}{3.87} = \mathbf{91.36\text{ mA}}$$

9. $I_{dc} = I_{C_Q} = 150\text{ mA}$

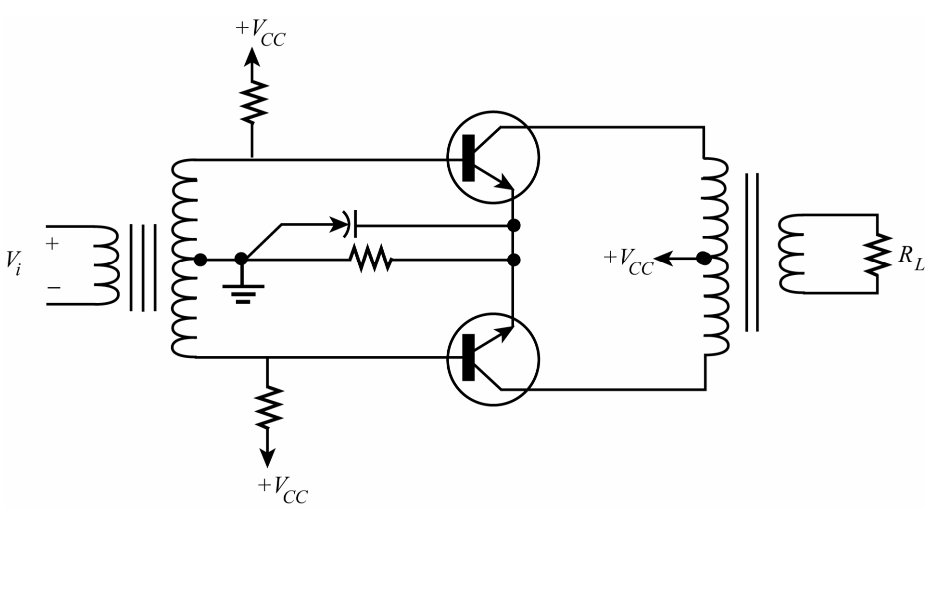
$$P_i = V_{CC} I_{C_Q} = (36\text{ V})(150\text{ mA}) = 5.4\text{ W}$$

$$\%\eta = \frac{P_o}{P_i} \times 100\% = \frac{2\text{ W}}{5.4\text{ W}} \times 100\% = \mathbf{37\%}$$

10.



11.



12. (a) $P_i = V_{CC}I_{dc}$ = (25 V)(1.75 A) = **43.77 W**

Where, $I_{dc} = \frac{2}{\pi}I_p = \frac{2}{\pi}\frac{V_p}{R_L} = \frac{2}{\pi}\cdot\frac{22\text{ V}}{8\ \Omega}$ = 1.75 A

(b) $P_o = \frac{V_p^2}{2R_L} = \frac{(22\text{ V})^2}{2(8\ \Omega)}$ = **30.25 W**

(c) $\%\eta = \frac{P_o}{P_i} \times 100\% = \frac{30.75\text{ W}}{43.77\text{ W}} \times 100\%$ = **69%**

13. (a) max $P_i = V_{CC}I_{dc}$

$= V_{CC}\cdot\left(\frac{2}{\pi}\cdot\frac{V_{CC}}{R_L}\right) = (25\text{ V})\left[\frac{2}{\pi}\cdot\frac{25\text{ V}}{8\ \Omega}\right]$

= **49.74 W**

(b) max $P_o = \frac{V_{CC}^2}{2R_L} = \frac{(25\text{ V})^2}{2(8\ \Omega)}$ = **39.06 W**

(c) max $\%\eta = \frac{\max P_o}{\max P_i} \times 100\% = \frac{39.06\text{ W}}{49.74\text{ W}} \times 100\%$

= **78.5%**

14. (a) $V_{L(\text{peak})}$ = 20 V

$P_i = V_{CC}I_{dc} = V_{CC}\left[\frac{2}{\pi}\cdot\frac{V_L}{R_L}\right]$

$= (22\text{ V})\left[\frac{2}{\pi}\cdot\frac{20\text{ V}}{4\ \Omega}\right]$ = 70 W

$P_o = \frac{V_L^2}{2R_L} = \frac{(20\text{ V})^2}{2(4\ \Omega)}$ = 50 W

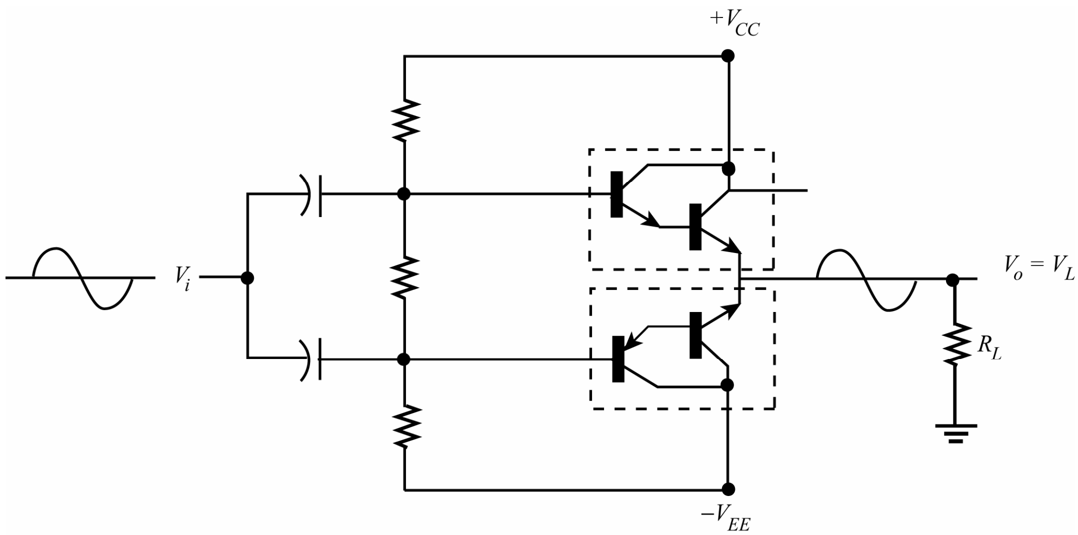
$\%\eta = \frac{P_o}{P_i} \times 100\% = \frac{50\text{ W}}{70\text{ W}} \times 100\%$ = **71.4%**

(b) $P_i = (22\text{ V})\left[\frac{2}{\pi}\cdot\frac{4\text{ V}}{4\ \Omega}\right]$ = 14 W

$P_o = \frac{(4)^2}{2(4)}$ = 2 W

$\%\eta = \frac{P_o}{P_i} \times 100\% = \frac{2\text{ W}}{14\text{ W}} \times 100\%$ = **14.3%**

15.



16. (a) max P_o(ac) for $V_{L_{\text{peak}}} = 30$ V:

$$\max P_o(\text{ac}) = \frac{V_L^2}{2R_L} = \frac{(30\text{ V})^2}{2(8\ \Omega)} = \mathbf{56.25\ W}$$

(b) $$\max P_i(\text{dc}) = V_{CC}I_{\text{dc}} = V_{CC}\left[\frac{2}{\pi}\cdot\frac{V_o}{R_L}\right] = V_{CC}\left[\frac{2}{\pi}\cdot\frac{30\text{ V}}{8\ \Omega}\right] = \mathbf{71.62\ W}$$

(c) $$\max \%\eta = \frac{\max P_o}{\max P_i}\times 100\% = \frac{56.25\text{ W}}{71.62\text{ W}}\times 100\%$$
$$= \mathbf{78.54\%}$$

(d) $$\max P_{Z_Q} = \frac{2}{\pi^2}\cdot\frac{V_{CC}^2}{R_L} = \frac{2}{\pi^2}\cdot\frac{(30)^2}{8} = \mathbf{22.8\ W}$$

17. (a) $$P_i(\text{dc}) = V_{CC}I_{\text{dc}} = V_{CC}\cdot\frac{2}{\pi}\left(\frac{V_o}{R_L}\right)$$
$$= 30\text{ V}\cdot\frac{2}{\pi}\left[\frac{\sqrt{2}\cdot 8}{8}\right] = \mathbf{27\ W}$$

(b) $$P_o(\text{ac}) = \frac{V_L^2(\text{rms})}{R_L} = \frac{(8\text{ V})^2}{8\ \Omega} = \mathbf{8\ W}$$

(c) $$\%\eta = \frac{P_o}{P_i}\times 100\% = \frac{8\text{ W}}{27\text{ W}}\times 100\% = \mathbf{29.6\%}$$

(d) $P_{2Q} = P_i - P_o = 27\text{ W} - 8\text{ W} = \mathbf{19\ W}$

18. (a) $P_o(\text{ac}) = \dfrac{V_L^2(\text{rms})}{R_L} = \dfrac{(18\text{ V})^2}{8\ \Omega}$ = **40.5 W**

(b) $P_i(\text{dc}) = V_{CC}I_{\text{dc}} = V_{CC}\left[\dfrac{2}{\pi}\cdot\dfrac{V_{L_{\text{peak}}}}{R_L}\right]$

$= (40\text{ V})\left[\dfrac{2}{\pi}\cdot\dfrac{18\sqrt{2}\text{ V}}{8\ \Omega}\right]$ = **81 W**

(c) $\%\eta = \dfrac{P_o}{P_i}\times 100\% = \dfrac{40.5\text{ W}}{81\text{ W}}\times 100\%$ = **50%**

(d) $P_{2_Q} = P_i - P_o = 81\text{ W} - 40.5\text{ W}$ = **40.5 W**

19. $\%D_2 = \left|\dfrac{A_2}{A_1}\right|\times 100\% = \left|\dfrac{0.3\text{ V}}{2.1\text{ V}}\right|\times 100\% \cong$ **14.3%**

$\%D_3 = \left|\dfrac{A_3}{A_1}\right|\times 100\% = \dfrac{0.1\text{ V}}{2.1\text{ V}}\times 100\% \cong$ **4.8%**

$\%D_4 = \left|\dfrac{A_4}{A_1}\right|\times 100\% = \dfrac{0.05\text{ V}}{2.1\text{ V}}\times 100\% \cong$ **2.4%**

20. $\%THD = \sqrt{D_2^2 + D_3^2 + D_4^2}\times 100\%$

$= \sqrt{(0.143)^2 + (0.048)^2 + (0.024)^2}\times 100\%$

= **15.3%**

21. $D_2 = \left|\dfrac{\frac{1}{2}\left(V_{CE_{\max}} + V_{CE_{\min}}\right)}{V_{CE_{\max}} - V_{CE_{\min}}}\right|\times 100\%$

$= \left|\dfrac{\frac{1}{2}(20\text{ V} + 2.4\text{ V}) - 10\text{ V}}{20\text{ V} - 2.4\text{ V}}\right|\times 100\%$

$= \dfrac{1.2\text{ V}}{17.6\text{ V}}\times 100\%$ = **6.8%**

22. $THD = \sqrt{D_2^2 + D_3^2 + D_4^2} = \sqrt{(0.15)^2 + (0.01)^2 + (0.05)^2}$

$\cong 0.16$

$P_1 = \dfrac{I_1^2 R_C}{2} = \dfrac{(3.3\text{ A})^2(4\ \Omega)}{2}$ = **21.8 W**

$P = (1 + THD^2)P_1 = [1 + (0.16)^2)]21.8\text{ W}$

= **22.36 W**

23. $P_D\,(150°\text{C}) = P_D(25°\text{C}) - (T_{150} - T_{25})$ (Derating Factor)

$= 100\text{ W} - (150°\text{C} - 25°\text{C})(0.6\text{ W/°C})$

$= 100\text{ W} - 125(0.6) = 100 - 75$

$=$ **25 W**

24. $$P_D = \frac{T_J - T_A}{\theta_{JC} + \theta_{CS} + \theta_{SA}} = \frac{200°\text{C} - 80°\text{C}}{0.5\text{ °C/W} + 0.8\text{ °C/W} + 1.5\text{ °C/W}}$$

$$= \frac{120°\text{C}}{2.8\text{ °C/W}} = \mathbf{42.9\ W}$$

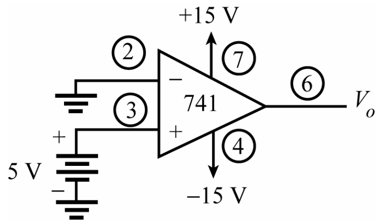
25. $$P_D = \frac{T_J - T_A}{\theta_{JA}}$$

$$= \frac{200°\text{C} - 80°\text{C}}{(40°\text{C/W})} = \frac{120°\text{C}}{40°\text{C/W}}$$

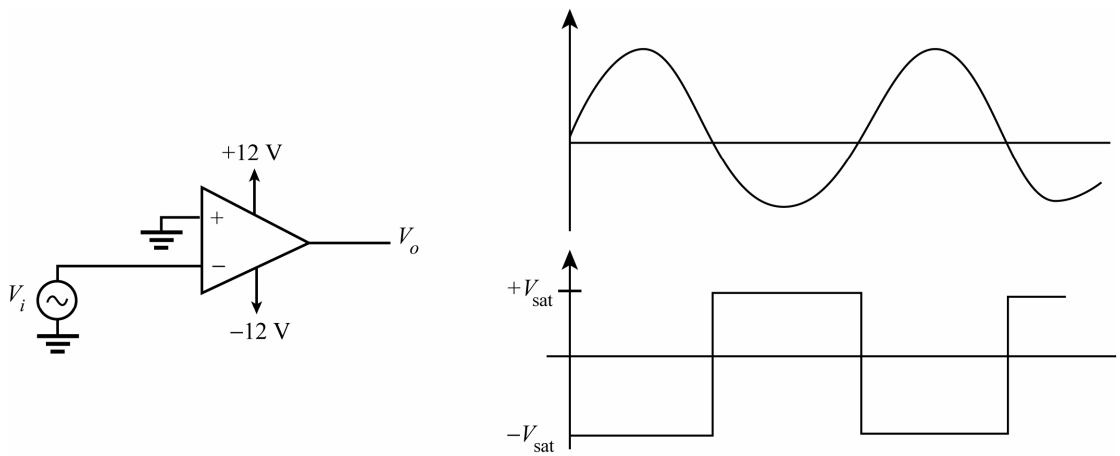
$=$ **3 W**

Chapter 13

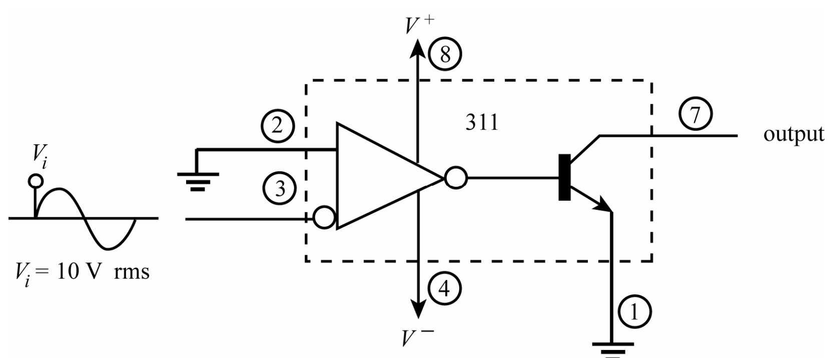
1.



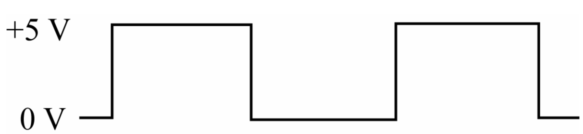
2.



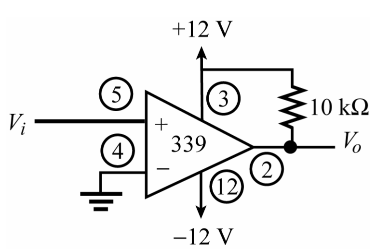
3.

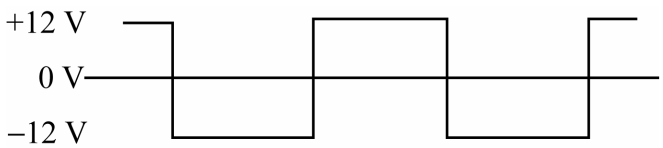


4.



5.



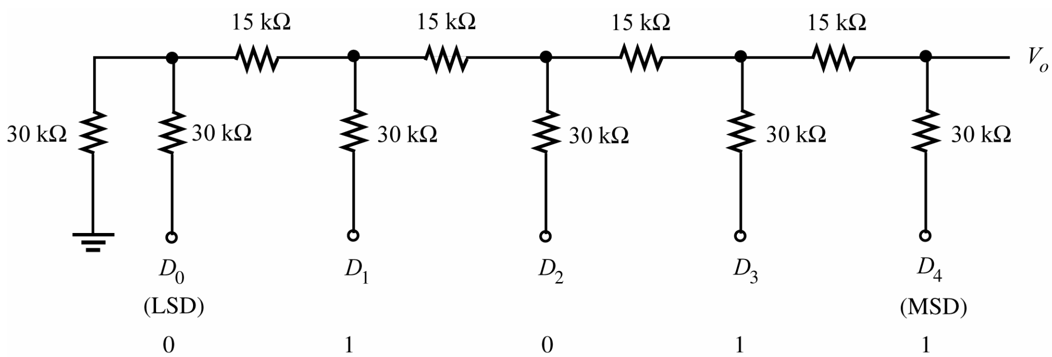
6. 

7. Circuit operates as a window detector.

Output goes *low* for input *above* $\frac{9.1\text{ k}\Omega}{9.1\text{ k}\Omega + 6.2\text{ k}\Omega}(+12\text{ V}) = \mathbf{7.1\ V}$

Output goes *low* for input *below* $\frac{1\text{ k}\Omega}{1\text{ k}\Omega + 6.2\text{ k}\Omega}(+12\text{ V}) = \mathbf{1.7\ V}$

Output is *high* for input between +1.7 V and +7.1 V.

8. 

9. $\frac{11010}{2^5}(16\text{ V}) = \frac{26}{32}(16\text{ V}) = \mathbf{13\ V}$

10. Resolution = $\frac{V_{REF}}{2^n} = \frac{10\text{ V}}{2^{12}} = \frac{10\text{ V}}{4096} = \mathbf{2.4\ mV/count}$

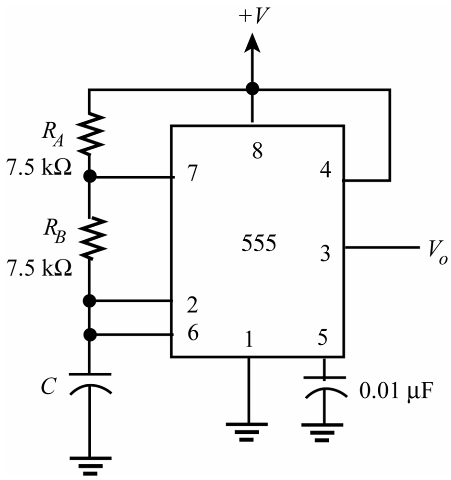
11. See section 13.3.

12. Maximum number of count steps = 2^{12} = **4096**

13. $2^{12} = 4096$ steps at $T = \frac{1}{f} = \frac{1}{20\text{ MHz}} = 50$ ns/count

Period = 4096 counts × $50\frac{\text{ns}}{\text{count}} = \mathbf{204.8\ \mu s}$

14.

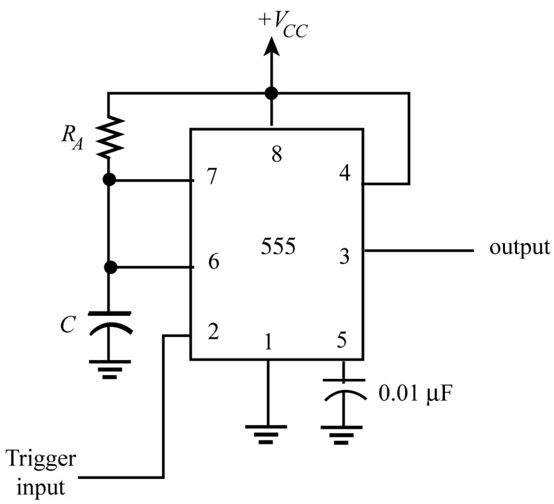


$$f = \frac{1.44}{(R_A + 2R_B)C} = 350 \text{ kHz}$$

$$C = \frac{1.44}{7.5 \text{ k}\Omega + 2(7.5 \text{ k}\Omega)(350 \text{ kHz})}$$

$\cong$ **183 pF**

15.



$T = 1.1\ R_A C$

$20\ \mu\text{s} = 1.1(7.5 \text{ k}\Omega)C$

$$C = \frac{20 \times 10^{-6}}{1.1(7.5 \times 10^{3})}$$

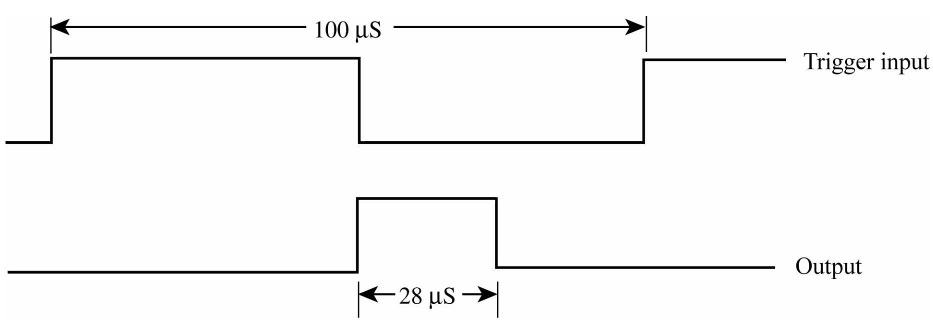
$= 2.4 \times 10^{-9}$

$= 2400 \times 10^{-12}$

= **2400 pF**

16. $T = \dfrac{1}{f} = \dfrac{1}{10 \text{ kHz}} = 100\ \mu\text{s}$

$T = 1.1\ R_A C = 1.1(5.1 \text{ k}\Omega)(5 \text{ nF}) =$ **28 μs**



17. $f_o = \dfrac{2}{R_1C_1}\left(\dfrac{V^+ - V_C}{V^+}\right)$

$V^+ = 12\text{ V}$

$V_C = \dfrac{R_3}{R_2 + R_3}(V^+) = \dfrac{11\text{ k}\Omega}{1.8\text{ k}\Omega + 11\text{ k}\Omega}(+12\text{ V}) = 10.3\text{ V}$

$f_o = \dfrac{2}{(4.7\text{ k}\Omega)(0.001\ \mu\text{F})}\left[\dfrac{12\text{ V} - 10.3\text{ V}}{12\text{ V}}\right]$

$= 60.3 \times 10^3 \cong$ **60 kHz**

18. With potentiometer set at top:

$V_C = \dfrac{R_3 + R_4}{R_2 + R_3 + R_4}V^+ = \dfrac{5\text{ k}\Omega + 18\text{ k}\Omega}{510\ \Omega + 5\text{ k}\Omega + 18\text{ k}\Omega}(12\text{ V}) = 11.74\text{ V}$

resulting in a lower cutoff frequency of

$f_o = \dfrac{2}{R_1C_1}\left(\dfrac{V^+ - V_C}{V^+}\right) = \dfrac{2}{(10 \times 10^3)(0.001\ \mu\text{F})}\left(\dfrac{12\text{ V} - 11.74\text{ V}}{12\text{ V}}\right)$

= **4.3 kHz**

With potentiometer set at bottom:

$V_C = \dfrac{R_4}{R_2 + R_3 + R_4}V^+ = \dfrac{18\text{ k}\Omega}{510\ \Omega + 5\text{ k}\Omega + 18\text{ k}\Omega}(12\text{ V})$

$= 9.19\text{ V}$

resulting in a higher cutoff frequency of

$f_o = \dfrac{2}{R_1C_1}\left(\dfrac{V^+ - V_C}{V^+}\right) = \dfrac{2}{(10\text{ k}\Omega)(0.001\ \mu\text{F})}\left[\dfrac{12\text{ V} - 9.19\text{ V}}{12\text{ V}}\right]$

= **61.2 kHz**

19. $V^+ = 12\text{ V}$

$V_C = \dfrac{R_3}{R_2 + R_3}V^+ = \dfrac{10\text{ k}\Omega}{1.5\text{ k}\Omega + 10\text{ k}\Omega}(12\text{ V}) = 10.4\text{ V}$

$f_o = \dfrac{2}{R_1C_1}\left(\dfrac{V^+ - V_C}{V^+}\right) = \dfrac{2}{10\text{ k}\Omega(C_1)}\left(\dfrac{12\text{ V} - 10.4\text{ V}}{12\text{ V}}\right)$

$= 200\text{ kHz}$

$C_1 = \dfrac{2}{10\text{ k}\Omega(200\text{ kHz})}(0.133)$

$= 133 \times 10^{-12} =$ **133 pF**

20. $f_o = \dfrac{0.3}{R_1C_1} = \dfrac{0.3}{(4.7\text{ k}\Omega)(0.001\ \mu\text{F})}$

= **63.8 kHz**

21. $C_1 = \dfrac{0.3}{R_1 f} = \dfrac{0.3}{(10\text{ k}\Omega)(100\text{ kHz})}$ = **300 pF**

22. $f_L = \pm\frac{8f_o}{V}$

$= \pm\frac{8(63.8\times10^3)}{6\text{ V}}$ $\left[f_o = \frac{0.3}{R_1C_1} = \frac{0.3}{4.7\text{ k}\Omega(0.001\ \mu\text{F})}\right]$

= **85.1 kHz** $= 63.8$ kHz

23. For current loop: mark = 20 mA
space = 0 mA

For $RS - 232\ C$: mark = −12 V
space = +12 V

24. A line (or lines) onto which data bits are connected.

25. Open-collector is active-LOW only.
Tri-state is active-HIGH or active-LOW.

Chapter 14

1. $A_f = \dfrac{A}{1+\beta A} = \dfrac{-2000}{1+\left(-\dfrac{1}{10}\right)(-2000)} = \dfrac{-2000}{201} = \mathbf{-9.95}$

2. $\dfrac{dA_f}{A_f} = \dfrac{1}{\beta A}\dfrac{dA}{A} = \dfrac{1}{\left(-\dfrac{1}{20}\right)(-1000)}(10\%) = \mathbf{0.2\%}$

3. $A_f = \dfrac{A}{1+\beta A} = \dfrac{-300}{1+\left(-\dfrac{1}{15}\right)(-300)} = \dfrac{-300}{21} = \mathbf{-14.3}$

$R_{if} = (1 + \beta A)R_i = 21(1.5\text{ k}\Omega) = \mathbf{31.5\text{ k}\Omega}$

$R_{of} = \dfrac{R_o}{1+\beta A} = \dfrac{50\text{ k}\Omega}{21} = \mathbf{2.4\text{ k}\Omega}$

4. $R_L = \dfrac{R_o R_D}{R_o + R_D} = 40\text{ k}\Omega \parallel 8\text{ k}\Omega = 6.7\text{ k}\Omega$

$A = -g_m R_L = -(5000 \times 10^{-6})(6.7 \times 10^{3}) = \mathbf{-33.5}$

$\beta = \dfrac{-R_2}{R_1 + R_2} = \dfrac{-200\text{ k}\Omega}{200\text{ k}\Omega + 800\text{ k}\Omega} = \mathbf{-0.2}$

$A_f = \dfrac{A}{1+\beta A} = \dfrac{-33.5}{1+(-0.2)(-33.5)} = \dfrac{-33.5}{7.7}$

$= \mathbf{-4.4}$

5. DC bias:

$I_B = \dfrac{V_{CC} - V_{BE}}{R_B + (\beta+1)R_E} = \dfrac{16\text{ V} - 0.7\text{ V}}{600\text{ k}\Omega + 76(1.2\text{ k}\Omega)}$

$= \dfrac{15.3\text{ V}}{691.2\text{ k}\Omega} = 22.1\ \mu\text{A}$

$I_E = (1 + \beta)I_B$

$= 76(22.1\ \mu\text{A}) = 1.68\text{ mA}$

$[V_{CE} = V_{CC} - I_C(R_C + R_E) = 16\text{ V} - 1.68\text{ mA}(4.7\text{ k}\Omega + 1.2\text{ k}\Omega) \cong 6.1\text{ V}]$

$r_e = \dfrac{26\text{ mV}}{I_E(\text{mA})} = \dfrac{26\text{ mV}}{1.68\text{ mA}} \cong 15.5\ \Omega$

$h_{ie} = (1 + \beta)r_e = 76(15.5\ \Omega) = \mathbf{1.18\text{ k}\Omega} = Z_i$

$Z_o = R_C = \mathbf{4.7\text{ k}\Omega}$

$A_v = \dfrac{-h_{fe}}{h_{ie} + R_E} = \dfrac{-75}{1.18\text{ k}\Omega + 1.2\text{ k}\Omega} = -31.5 \times 10^{-3}$

$\beta = R_E = -1.2 \times 10^3$

$(1 + \beta A) = 1 + (-1.2 \times 10^3)(-31.5 \times 10^{-3})$

$= 38.8$

$A_f = \dfrac{A_v}{1 + \beta A_v} = \dfrac{-31.5 \times 10^{-3}}{38.8} = 811.86 \times 10^{-6}$

$A_{v_f} = -A_f R_C = -(811.86 \times 10^{-6})(4.7 \times 10^3) = \mathbf{-3.82}$

$Z_{i_f} = (1 + \beta A_v)Z_i = (38.8)(1.18\text{ k}\Omega) = \mathbf{45.8\ k\Omega}$

$Z_{o_f} = (1 + \beta A_v)Z_o = (38.8)(4.7\text{ k}\Omega) = \mathbf{182.4\ k\Omega}$

without feedback (R_E bypassed):

$A_v = \dfrac{-R_C}{r_e} = -\dfrac{4.7\text{ k}\Omega}{15.5\ \Omega} = \mathbf{-303.2}$

6. $C = \dfrac{1}{2\pi Rf\sqrt{6}} = \dfrac{1}{2\pi(10 \times 10^3)(2.5 \times 10^3)\sqrt{6}}$

$= 2.6 \times 10^{-9} = \mathbf{2600\ pF} = 0.0026\ \mu\text{F}$

7. $f_o = \dfrac{1}{2\pi RC} \cdot \dfrac{1}{\sqrt{6 + 4\left(\dfrac{R_c}{R}\right)}}$

$= \dfrac{1}{2\pi(6 \times 10^3)(1500 \times 10^{-12})} \cdot \dfrac{1}{\sqrt{6 + 4(18 \times 10^3 / 6 \times 10^3)}}$

$= 4.17\text{ kHz} \cong \mathbf{4.2\ kHz}$

8. $f_o = \dfrac{1}{2\pi RC} = \dfrac{1}{2\pi(10 \times 10^3)(2400 \times 10^{-12})}$

$= \mathbf{6.6\ kHz}$

9. $C_{\text{eq}} = \dfrac{C_1 C_2}{C_1 + C_2} = \dfrac{(750\text{ pF})(2000\text{ pF})}{750\text{ pF} + 2000\text{ pF}} = 577\text{ pF}$

$f_o = \dfrac{1}{2\pi\sqrt{LC_{\text{eq}}}} = \dfrac{1}{2\pi\sqrt{40 \times 10^{-6})(577 \times 10^{-12})}}$

$= \mathbf{1.05\ MHz}$

10. $f_o = \dfrac{1}{2\pi\sqrt{LC_{\text{eq}}}}$, where $C_{\text{eq}} = \dfrac{C_1 C_2}{C_1 + C_2}$

$= \dfrac{(0.005\ \mu\text{F})(0.01\ \mu\text{F})}{0.005\ \mu\text{F} + 0.01\ \mu\text{F}}$

$= 3300\text{ pF}$

$= \dfrac{1}{2\pi\sqrt{(100\mu\text{H})(3300\text{ pF})}}$

$= \mathbf{277\ kHz}$

11. $f_o = \dfrac{1}{2\pi\sqrt{L_{eq}C}}$, $\quad L_{eq} = L_1 + L_2 + 2M = 1.5\text{ mH} + 1.5\text{ mH} + 2(0.5\text{ mH}) = 4\text{ mH}$

$$= \frac{1}{2\pi\sqrt{(4\times 10^{-3})(250\times 10^{-12})}}$$

= **159.2 kHz**

12. $f_o = \dfrac{1}{2\pi\sqrt{LC_{eq}}}$, $\quad$ where $L_{eq} = L_1 + L_2 + 2M = 750\ \mu\text{H} + 750\ \mu\text{H} + 2(150\ \mu\text{H}) = 1800\ \mu\text{H}$

$$= \frac{1}{2\pi\sqrt{(1800\,\mu\text{H})(150\text{ pF})}}$$

= 306.3 kHz

13. See Fig. 14.33a and Fig. 14.34.

14. $f_o = \dfrac{1}{R_T C_T \ln(1/(1-\eta))}$

for $\eta = 0.5$:

$$f_o \cong \frac{1.5}{R_T C_T}$$

(a) Using $R_T = 1\text{ k}\Omega$

$$C_T = \frac{1.5}{R_T f_o} = \frac{1.5}{(1\text{ k}\Omega)(1\text{ kHz})} = \mathbf{1.5\ \mu F}$$

(b) Using $R_T = 10\text{ k}\Omega$

$$C_T = \frac{1.5}{R_T f_o} = \frac{1.5}{(10\text{ k}\Omega)(150\text{ kHz})} = \mathbf{1000\ pF}$$

Chapter 15

1. ripple factor = $\dfrac{V_r\text{(rms)}}{V_{\text{dc}}} = \dfrac{2\text{ V}/\sqrt{2}}{50\text{ V}}$ = **0.028**

2. $\%VR = \dfrac{V_{NL} - V_{FL}}{V_{FL}} \times 100\% = \dfrac{28\text{ V} - 25\text{ V}}{25\text{ V}} \times 100\%$ = **12%**

3. $V_{\text{dc}} = 0.318V_m$
   $V_m = \dfrac{V_{\text{dc}}}{0.318} = \dfrac{20\text{ V}}{0.318} = 62.89\text{ V}$
   $V_r = 0.385V_m = 0.385(62.89\text{ V})$ = **24.2 V**

4. $V_{\text{dc}} = 0.636V_m$
   $V_m = \dfrac{V_{\text{dc}}}{0.636} = \dfrac{8\text{ V}}{0.636} = 12.6\text{ V}$
   $V_r = 0.308V_m = 0.308(12.6\text{ V})$ = **3.88 V**

5. $\%r = \dfrac{V_r\text{(rms)}}{V_{\text{dc}}} \times 100\%$
   $V_r\text{(rms)} = rV_{\text{dc}} = \dfrac{8.5}{100} \times 14.5\text{ V}$ = **1.2 V**

6. $V_{NL} = V_m = 18\text{ V}$
   $V_{FL} = 17\text{ V}$
   $\%VR = \dfrac{V_{NL} - V_{FL}}{V_{FL}} \times 100\% = \dfrac{18\text{ V} - 17\text{ V}}{17\text{ V}} \times 100\%$
   = **5.88%**

7. $V_m = 18\text{ V}$
   $C = 400\ \mu\text{F}$
   $I_L = 100\text{ mA}$

   $V_r = \dfrac{2.4I_{\text{dc}}}{C} = \dfrac{2.4(100)}{400} = 0.6\text{ V, rms}$
   $V_{\text{dc}} = V_m - \dfrac{4.17I_{\text{dc}}}{C}$
   $= 18\text{ V} - \dfrac{4.17(100)}{400}$ = **16.96 V**
   ≅ **17 V**

8. $V_r = \dfrac{2.4I_{\text{dc}}}{C} = \dfrac{2.4(120)}{200}$ = **1.44 V**

9. $C = 100\ \mu\text{F}$
   $\left.\begin{array}{l} V_{\text{dc}} = 12\text{ V} \\ R_L = 2.4\text{ k}\Omega \end{array}\right\} I_{\text{dc}} = \dfrac{V_{\text{dc}}}{R_L} = \dfrac{12\text{ V}}{2.4\text{ k}\Omega} = 5\text{ mA}$

   $V_r\text{(rms)} = \dfrac{2.4I_{\text{dc}}}{C} = \dfrac{2.4(5)}{100}$ = **0.12 V**

10. $C = \frac{2.4I_{dc}}{rV_{dc}} = \frac{2.4(150)}{(0.15)(24)}$ = **100 μF**

11. $C = 500\ \mu F$
$I_{dc} = 200$ mA
$R = 8\% = 0.08$

Using $r = \frac{2.4I_{dc}}{CV_{dc}}$

$$V_{dc} = \frac{2.4I_{dc}}{rC} = \frac{2.4(200)}{0.08(500)} = 12\text{ V}$$

$$V_m = V_{dc} + \frac{4.17I_{dc}}{C} = 12\text{ V} + \frac{(200)(4.17)}{500}$$
$$= 12\text{ V} + 1.7\text{ V} = \mathbf{13.7\ V}$$

12. $C = \frac{2.4I_{dc}}{V_r} = \frac{2.4(200)}{(0.07)}$ = **6857 μF**

13. $C = 120\ \mu F$
$I_{dc} = 80$ mA
$V_m = 25$ V

$$V_{dc} = V_m - \frac{4.17I_{dc}}{C} = 25\text{ V} - \frac{4.17(80)}{120}$$
$$= 22.2\text{ V}$$

$$\%r = \frac{2.4I_{dc}}{CV_{dc}} \times 100\% = \frac{2.4(80)}{(120)(22.2)} \times 100\%$$
$$= \mathbf{7.2\%}$$

14. $V_r' = \frac{r \cdot V_{dc}'}{100} = \frac{2(80)}{100}$ = **1.6 V, rms**

15. $V_r = 2$ V
$V_{dc} = 24$ V
***R* = 33 Ω, *C* = 120 μF**

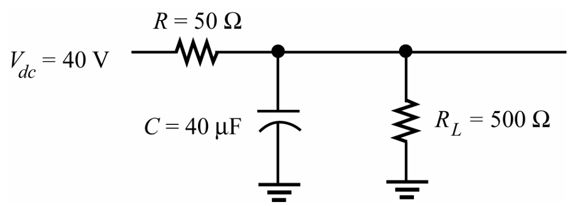
$$X_C = \frac{1.3}{C} = \frac{1.3}{120} = 10.8\ \Omega$$

$$V_r' = \frac{X_C}{R}V_r = \frac{10.8}{33}(2\text{ V}) = 0.65\text{ V}$$

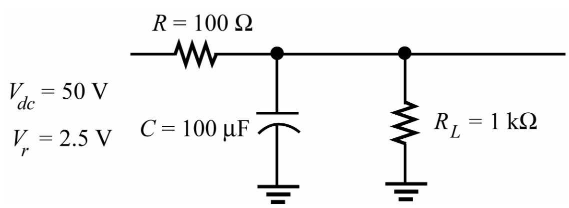
$$V_{dc}' = V_{dc} - I_{dc}R = 24\text{ V} - 33\ \Omega\ (100\ \text{mA})$$
$$= 20.7\text{ V}$$

$$\%r' = \frac{V_r'}{V_{dc}'} \times 100\% = \frac{0.65\text{ V}}{20.7\text{ V}} \times 100\% = \mathbf{3.1\%}$$

$$\%r = \frac{V_r}{V_{dc}} \times 100\% = \frac{2\text{ V}}{24\text{ V}} \times 100\%$$
$$= \mathbf{8.3\%}$$

16. 

$$V'_{\text{dc}} = \frac{R_L}{R+R_L}V_{\text{dc}}$$
$$= \frac{500}{50+500}(40\text{ V})$$
$$= 36.4\text{ V}$$
$$I_{\text{dc}} = \frac{V'_{\text{dc}}}{R_L} = \frac{36.4\text{ V}}{500\ \Omega} = \mathbf{72.8\ mA}$$

17. 

$$X_C = \frac{1.3}{C} = \frac{1.3}{100} = 13\ \Omega$$
$$V'_r = \frac{X_C}{R}V_r = \frac{13}{100}(2.5\text{ V})$$
$$= \mathbf{0.325\ V,\ rms}$$

18. $V_{NL} = 60$ V

$$V_{FL} = \frac{R_L}{R+R_L}V_{\text{dc}} = \frac{1\text{ k}\Omega}{100\ \Omega + 1\text{ k}\Omega}(50\text{ V}) = 45.46\text{ V}$$
$$\%VR = \frac{V_{NL}-V_{FL}}{V_{FL}}\times 100\% = \frac{50\text{ V}-45.46\text{ V}}{45.46\text{ V}}\times 100\%$$
$$= \mathbf{10\ \%}$$

19. $V_o = V_Z - V_{BE} = 8.3\text{ V} - 0.7\text{ V} = \mathbf{7.6\ V}$

$V_{CE} = V_i - V_o = 15\text{ V} - 7.6\text{ V} = 7.4\text{ V}$

$$I_R = \frac{V_i - V_Z}{R} = \frac{15\text{ V}-8.3\text{ V}}{1.8\text{ k}\Omega} = 3.7\text{ mA}$$
$$I_L = \frac{V_o}{R_L} = \frac{7.6\text{ V}}{2\text{ k}\Omega} = 3.8\text{ mA}$$
$$I_B = \frac{I_C}{\beta} = \frac{3.8\text{ mA}}{100} = 38\ \mu\text{A}$$

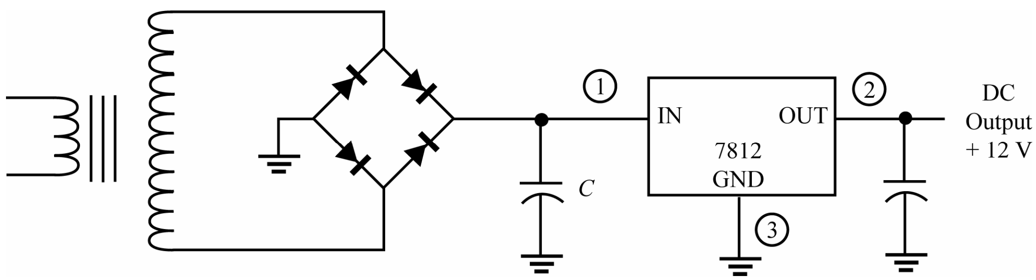
$I_Z = I_R - I_B = 3.7\text{ mA} - 38\ \mu\text{A} = \mathbf{3.66\ mA}$

20. $$V_o = \frac{R_1 + R_2}{R_2}(V_z + V_{BE_2})$$
$$= \frac{33\text{ k}\Omega + 22\text{ k}\Omega}{22\text{ k}\Omega}(10\text{ V} + 0.7\text{ V})$$
$$= \mathbf{26.75\ V}$$

21. $$V_o = \left(1 + \frac{R_1}{R_2}\right)V_Z = \left(1 + \frac{12\text{ k}\Omega}{8.2\text{ k}\Omega}\right)10\text{ V}$$
$$= \mathbf{24.6\ V}$$

22. $V_o = V_L = 10\text{ V} + 0.7\text{ V} = \mathbf{10.7\ V}$

23.



24. $I_L = 250\text{ mA}$

$V_m = V_r(\text{rms}) \cdot \sqrt{2} = \sqrt{2}\,(20\text{ V}) = 28.3\text{ V}$

$$V_{r_{\text{peak}}} = \sqrt{3}\,V_r(\text{rms}) = \sqrt{3}\left(\frac{2.4I_{\text{dc}}}{C}\right)$$
$$= \sqrt{3}\left(\frac{2.4(250)}{500}\right) = 2.1\text{ V}$$

$V_{\text{dc}} = V_m - V_{r_{\text{peak}}} = 28.3\text{ V} - 2.1\text{ V} = 26.2\text{ V}$

$V_i(\text{low}) = V_{\text{dc}} - V_{r_{\text{peak}}} = 26.2\text{ V} - 2.1\text{ V} = \mathbf{24.1\ V}$

25. To maintain $V_i(\text{min}) \geq 7.3\text{ V}$ (see Table 15.1)

$V_{r_{\text{peak}}} \leq V_m - V_i(\text{min}) = 12\text{ V} - 7.3\text{ V} = 4.7\text{ V}$

so that

$$V_r(\text{rms}) = \frac{V_{r_{\text{peak}}}}{\sqrt{3}} = \frac{4.7\text{ V}}{1.73} = 2.7\text{ V}$$

The maximum value of load current is then

$$I_{\text{dc}} = \frac{V_r(\text{rms})C}{2.4} = \frac{(2.7\text{ V})(200)}{2.4} = \mathbf{225\ mA}$$

26. $V_o = V_{\text{ref}}\left(1+\dfrac{R_2}{R_1}\right) + I_{\text{adj}}R_L$

$= 1.25\text{ V}\left(1+\dfrac{1.8\text{ k}\Omega}{240\ \Omega}\right) + 100\ \mu\text{A}(2.4\text{ k}\Omega)$

$= 1.25\text{ V}(8.5) + 0.24\text{ V}$

= **10.87 V**

27. $V_o = V_{\text{ref}}\left(1+\dfrac{R_2}{R_1}\right) + I_{\text{adj}}\,R_2$

$= 1.25\text{ V}\left(1+\dfrac{1.5\text{ k}\Omega}{220\ \Omega}\right) + 100\ \mu\text{A}(1.5\text{ k}\Omega)$

= **9.9 V**

Chapter 16

1. (a) The Schottky Barrier diode is constructed using an *n*-type semiconductor material and a metal contact to form the diode junction, while the conventional *p-n* junction diode uses both *p*- and *n*-type semiconductor materials to form the junction.

   (b) –

2. (a) In the forward-biased region the dynamic resistance is about the same as that for a *p-n* junction diode. Note that the slope of the curves in the forward-biased region is about the same at different levels of diode current.

   (b) In the reverse-biased region the reverse saturation current is larger in magnitude than for a *p-n* junction diode, and the Zener breakdown voltage is lower for the Schottky diode than for the conventional *p-n* junction diode.

3. $$\frac{\Delta I_R}{\Delta °C} = \frac{100\ \mu\text{A} - 0.5\ \mu\text{A}}{75°\ \text{C}} = 1.33\ \mu\text{A/°C}$$

   $$\Delta I_R = (1.33\ \mu\text{A/°C})\Delta\text{C} = (1.33\ \mu\text{A/°C})(25°\text{C}) = 33.25\mu\text{A}$$
   $$I_R = 0.5\mu\text{A} + 33.25\mu\text{A} = \mathbf{33.75\mu A}$$

4. $$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(1\ \text{MHz})(7\ \text{pF})} = \mathbf{22.7\ k\Omega}$$

   $$R_{DC} = \frac{V_F}{I_F} = \frac{400\ \text{mV}}{10\ \text{mA}} = \mathbf{40\ \Omega}$$

5. Temperature on linear scale
   T(1/2 power level of 100 mW) ≅ **95°C**

6. V_F a linear scale V_F (25°C) ≅ 380 mV = **0.38 V**

   At 125°C, V_F ≅ 280 mV

   $$\frac{\Delta V_F}{\Delta_T} = \frac{100\ \text{mV}}{100°\text{C}} = 1\ \text{mV/°C}$$

   ∴ At 100°C V_F = 280 mV + (1 mV/°C)(25°C)
   = 280 mV + 25 mV
   = 305 mV

   Increase temperature and V_F drops.

7. (a) $C_T(V_R) = \dfrac{C(0)}{\left(1+|V_R/V_T|\right)^n} = \dfrac{80\text{ pF}}{\left(1+\dfrac{4.2\text{ V}}{0.7\text{ V}}\right)^{1/3}}$

$= \dfrac{80\text{ pF}}{1.912} =$ **41.85 pF**

(b) $k = C_T(V_T + V_R)^n$

$= 41.85\text{ pF}(\underbrace{0.7\text{ V} + 4.2\text{ V})^{1/3}}_{1.698}$

$\cong \mathbf{71 \times 10^{-12}}$

8. (a) At –3 V, C = **40 pF**
At –12 V, C = **20 pF**
ΔC = 40 pF – 20 pF = **20 pF**

(b) At –8 V, $\dfrac{\Delta C}{\Delta V_R} = \dfrac{40\text{ pF}}{20\text{ V}}$ = **2 pF/V**

At –2 V, $\dfrac{\Delta C}{\Delta V_R} = \dfrac{60\text{ pF}}{9\text{ V}}$ = **6.67 pF/V**

$\dfrac{\Delta C}{\Delta V_R}$ increases at less negative values of V_R.

9. Ratio = $\dfrac{C_t(-1\text{ V})}{C_t(-8\text{ V})} = \dfrac{92\text{ pF}}{5.5\text{ pF}}$ = **16.73**

$\dfrac{C_t(-1.25\text{ V})}{C_t(-7\text{ V})}$ = **13**

10. $C_t \cong 15$ pF

$Q = \dfrac{1}{2\pi f R_s C_t} = \dfrac{1}{2\pi(10\text{ MHz})(3\ \Omega)(15\text{ pF})}$

= **354.61** vs **350** on chart

11. $TC_C = \dfrac{\Delta C}{C_o(T_1 - T_0)} \times 100\% \Rightarrow T_1 = \dfrac{\Delta C \times 100\%}{TC_C(C_o)} + T_o$

$= \dfrac{(0.11\text{ pF})(100)}{(0.02)(22\text{ pF})} + 25$

= **50°C**

12. V_R from –2 V to –8 V

$C_t(-2\text{ V}) = 60$ pF, $C_t(-8\text{ V}) = 6$ pF

Ratio = $\dfrac{C_t(-2\text{ V})}{C_t(-8\text{ V})} = \dfrac{60\text{ pF}}{6\text{ pF}}$ = **10**

13. $Q(-1\text{ V}) = 82$, $Q(-10\text{ V}) = 5000$

$$\text{Ratio} = \frac{Q(-10\text{ V})}{Q(-1\text{ V})} = \frac{5000}{82} = 60.98$$

$$BW = \frac{f_o}{Q} = \frac{10\times10^6\text{ Hz}}{82} = \mathbf{121.95\ kHz}$$

$$BW = \frac{f_o}{Q} = \frac{10\times10^6\text{ Hz}}{5000} = \mathbf{2\ kHz}$$

14. High-power diodes have a higher forward voltage drop than low-current devices due to larger *IR* drops across the bulk and contact resistances of the diode. The higher voltage drops result in higher power dissipation levels for the diodes, which in turn may require the use of heat sinks to draw the heat away from the body of the structure.

15. The primary difference between the standard *p-n* junction diode and the tunnel diode is that the tunnel diode is doped at a level from 100 to several thousand times the doping level of a *p-n* junction diode, thus producing a diode with a "negative resistance" region in its characteristic curve.

16. At 1 MHz: $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(1\times10^6\text{ Hz})(5\times10^{-12}\text{ F})}$

$= \mathbf{31.83\ k\Omega}$

At 100 MHz: $X_C = \dfrac{1}{2\pi(100\times10^6\text{ Hz})(5\times10^{-12}\text{ F})}$

$= \mathbf{318.3\ \Omega}$

At 1 MHz: $X_{L_s} = 2\pi fL = 2\pi(1\times10^6\text{ Hz})(6\times10^{-9}\text{ H})$

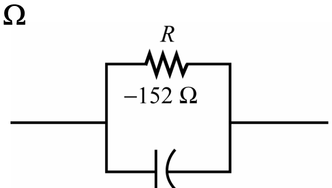
$= \mathbf{0.0337\ \Omega}$

At 100 MHz: $X_{L_s} = 2\pi(100\times10^6\text{ Hz})(6\times10^{-9}\text{ H})$

$= \mathbf{3.769\ \Omega}$

L_s effect is negligible!

R and *C* in parallel:
$f = 1$ MHz



$X_C = \dfrac{1}{2\pi fC} = 31.83\text{ k}\Omega$

$$Z_T = \frac{(152\ \Omega\angle180^\circ)(31.83\text{ k}\Omega\angle-90^\circ)}{-152\ \Omega - j31.83\text{ k}\Omega}$$

$= -152.05\ \Omega\angle0.27^\circ \cong -152\ \Omega\angle0^\circ$

$f = 100$ MHz

$$Z_T = \frac{(152\ \Omega\angle180^\circ)(318.3\angle-90^\circ)}{-152\ \Omega - j318.3}$$

$= -137.16\ \Omega\angle25.52 \neq -152\ \Omega\angle0^\circ$

At very high frequencies X_C has some impact!

17. The heavy doping greatly reduces the width of the depletion region resulting in lower levels of Zener voltage. Consequently, small levels of reverse voltage can result in a significant current levels.

18. At $V_T = 0.1$ V,

$I_F \cong 5.5$ mA

At $V_T = 0.3$ V

$I_F \cong 2.3$ mA

$$R = \frac{\Delta V}{\Delta I} = \frac{0.3\text{ V} - 0.1\text{ V}}{2.3\text{ mA} - 5.5\text{ mA}}$$

$$= \frac{0.2\text{ V}}{-3.2\text{ mA}} = \mathbf{-62.5\ \Omega}$$

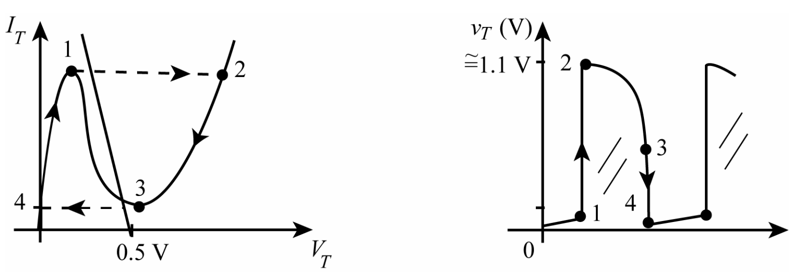
19. $$I_{\text{sat}} = \frac{E}{R} = \frac{2\text{ V}}{0.39\text{ k}\Omega} \cong 5.13\text{ mA}$$

From graph: Stable operating points: $I_T \cong$ **5 mA**, $V_T \cong$ **60 mV**

$I_T \cong$ **2.8 mA**, $V_T =$ **900 mV**

20. $$I_{\text{sat}} = \frac{E}{R} = \frac{0.5\text{ V}}{51\ \Omega} = 9.8\text{ mA}$$

Draw load line on characteristics.



21. $$f_s = \left(\frac{1}{2\pi\sqrt{LC}}\right)\sqrt{1 - \frac{R_l^2 C}{L}}$$

$$= \left(\frac{1}{2\pi\sqrt{(5\times10^{-3}\text{ H})(1\times10^{-6}\text{ F})}}\right)\sqrt{1 - \frac{(10\ \Omega)^2(1\times10^{-6}\text{ F})}{5\times10^{-3}\text{ H}}}$$

$= (2250.79\text{ Hz})(0.9899)$

$\cong$ **2228 Hz**

22. $$W = hf = h\frac{v}{\lambda} = \frac{(6.624\times10^{-34}\text{ J}\cdot\text{s})(3\times10^{8}\text{ m/s})}{(5000)(10^{-10}\text{ m})}$$

$= \mathbf{3.97 \times 10^{-19}}$ **J**

$$3.97\times10^{-19}\text{ J}\left[\frac{1\text{ eV}}{1.6\times10^{-19}\text{ J}}\right] = \mathbf{2.48\ eV}$$

23. (a) Visible spectrum: **3750 A → 7500**
(b) Silicon, peak relative response ≅ **8400 Å**
(c) BW = 10,300 Å − 6100 Å = **4200 Å**

24. $$\frac{4\times10^{-9}\ \text{W/m}^2}{1.609\times10^{-12}} = 2{,}486\,f_c$$
From the intersection of V_A = 30 V and 2,486 f_c we find
$I_\lambda \cong$ **440 μA**

25. (a) Silicon
(b) 1 Å = 10^{-10} m, $\dfrac{6\times10^{-7}\,\text{m}}{10^{-10}\,\text{m/Å}}$ ⇒ 6000 Å → **orange**

26. Note that V_λ is given and not V.
At the intersection of V_λ = 25 V and 3000f_c we find $I_\lambda \cong$ 500 μA and
$V_R = I_\lambda R = (500 \times 10^{-6}\text{ A})(100 \times 10^3\ \Omega)$ = **50 V**

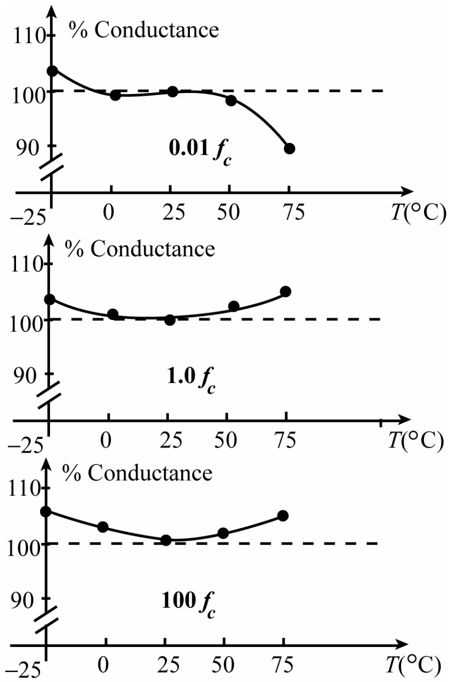
27. (a) Extending the curve:
0.1 kΩ → 1000f_c, 1 kΩ → 25f_c
$$\frac{\Delta R}{\Delta f_c} = \frac{(1-0.1)\times10^3\ \Omega}{(1000-25)f_c} = \mathbf{0.92\ \Omega/f_c \cong 0.9\ \Omega/f_c}$$

(b) 1 kΩ → 25f_c, 10 kΩ → 1.3f_c
$$\frac{\Delta R}{\Delta f_c} = \frac{(10-1)\times10^3\ \Omega}{(25-1.3)f_c} = \mathbf{379.75\ \Omega/f_c \cong 380\ \Omega/f_c}$$

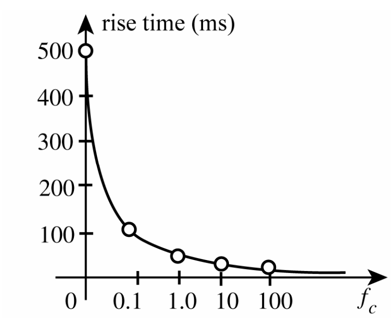
(c) 10 kΩ → 1.3f_c, 100 kΩ → 0.15f_c
$$\frac{\Delta R}{\Delta f_c} = \frac{(100-10)\times10^3}{(1.3-0.15)f_c} = \mathbf{78{,}260.87\ \Omega/f_c \cong 78\times10^3\ \Omega/f_c}$$
The greatest rate of change in resistance occurs in the low illumination region.

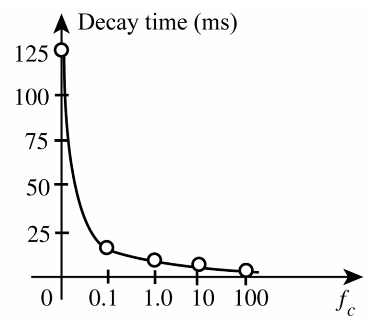
28. The "dark current" of a photodiode is the diode current level when no light is striking the diode. It is essentially the reverse saturation leakage current of the diode, comprised mainly of minority carriers.

29. 10f_c → $R \cong$ 2 kΩ
$$V_o = 6\text{ V} = \frac{(2\times10^3\ \Omega)V_i}{2\times10^3\ \Omega + 5\times10^3\ \Omega}$$
V_i = **21 V**

30. 

Except for low illumination levels ($0.01f_c$) the % conductance curves appear above the 100% level for the range of temperature. In addition, it is interesting to note that for other than the low illumination levels the % conductance is higher above and below room temperature (25°C). In general, the % conductance level is not adversely affected by temperature for the illumination levels examined.

31. (a) 

(b) 

(c) Increased levels of illumination result in reduced rise and decay times.

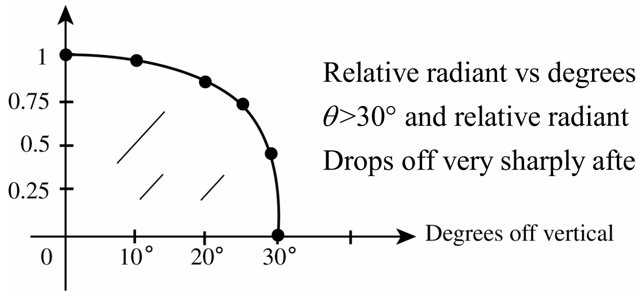
32. The highest % sensitivity occurs between 5250A and 5750A. Fig 16.20 reveals that the CdS unit would be most sensitive to *yellow*. The % sensitivity of the CdS unit of Fig. 16.30 is at the 30% level for the range 4800Å → 7000Å. This range includes green, yellow, and orange in Fig. 16.20.

33. (a) ≅ **5 mW** radiant flux

(b) ≅ 3.5 mW $\quad \dfrac{3.5\text{ mW}}{1.496\times10^{-13}\text{ W/lm}} = \mathbf{2.34\times10^{10}\ lms}$

34. (a) Relative radiant intensity ≅ **0.8**.

(b)



Relative radiant vs degrees off vertical
θ>30° and relative radiant intensity essentially zero-
Drops off very sharply after 25°!

35. At I_F = 60 mA, $\Phi \cong$ 4.4 mW
At 5°, relative radiant intensity = 0.8
(0.8)(4.4 mW) = **3.52 mW**

36. 6, 7, 8

37. –

38. The LED generates a light source in response to the application of an electric voltage. The LCD depends on ambient light to utilize the change in either reflectivity or transmissivity caused by the application of an electric voltage.

39. The LCD display has the advantage of using approximately 1000 times less power than the LED for the same display, since much of the power in the LED is used to produce the light, while the LCD utilizes ambient light to see the display. The LCD is usually more visible in daylight than the LED since the sun's brightness makes the LCD easier to see. The LCD, however, requires a light source, either internal or external, and the temperature range of the LCD is limited to temperatures above freezing.

40. $$\eta\% = \frac{P_{\max}}{(A_{\text{cm}^2})(100\text{ mW/cm}^2)} \times 100\%$$

$$9\% = \frac{P_{\max}}{(2\text{ cm}^2)(100\text{ mW/cm}^2)} \times 100\%$$

$P_{\max}$ = **18 mW**

41. The greatest rate of increase in power will occur at low illumination levels. At higher illumination levels, the change in V_{OC} drops to nearly zero, while the current continues to rise linearly. At low illumination levels the voltage increases logarithmically with the linear increase in current.

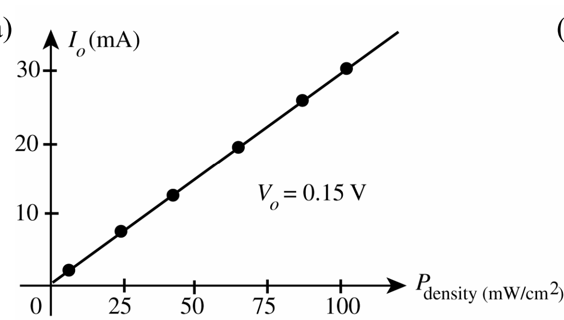
42. (a) Fig. 16.48 ⇒ **79 mW/cm²**

(b) It is the maximum power density available at sea level.

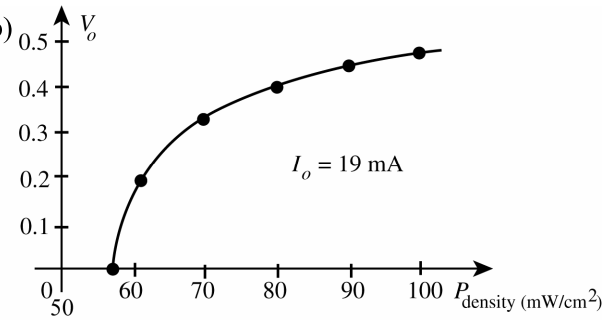
(c) Fig. 16.48 ≅ **12.7 mA**

(b)

43. (a)

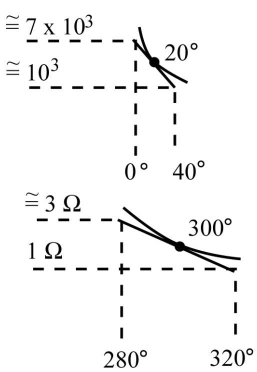


(b)



(c) The curve of I_o vs P_{density} is quite linear while the curve of V_o vs P_{density} is only linear in the region near the optimum power locus (Fig 16.48).

44. Since log scales are present, the differentials must be as small as possible.



$$\frac{\Delta R}{\Delta T} = \frac{(7000-1000)\Omega}{(40-0)^\circ} = \frac{6000\ \Omega}{40^\circ} = 150\ \Omega/^\circ\text{C}$$

$$\frac{\Delta R}{\Delta T} = \frac{(3-1)\Omega}{40^\circ} = \frac{2\ \Omega}{40^\circ} = 0.05\ \Omega/^\circ\text{C}$$

From the above 150 Ω/°C: 0.05 Ω/°C = 3000:1
Therefore, the highest rate of change occurs at lower temperatures such as 20°C.

45. No. 1 Fenwall Electronics Thermistor material.
Specific resistance $\cong 10^4 = 10{,}000\ \Omega$ cm

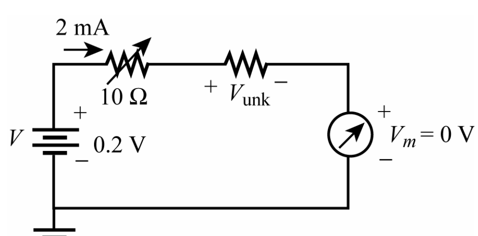
$R = \dfrac{\rho\ell}{A}$ $\underbrace{2\text{x}}_{\text{twice}}$ $\quad \therefore R = 2 \times (10{,}000\ \Omega) = \mathbf{20\ k\Omega}$

46. (a) $\cong 10^{-5}$ A = **10 μA**

(b) Power ≅ **0.1 mW**, $R \cong 10^7\ \Omega$ = **10 MΩ**

(c) Log scale ≅ **0.3 mW**

47.



$V = IR + IR_{\text{unk}} + V_m$
$V = I(R + R_{\text{unk}}) + 0$ V

$$R_{\text{unk}} = \frac{V}{I} - R = \frac{0.2\ \text{V}}{2\ \text{mA}} - 10\ \Omega = 100\ \Omega - 10\ \Omega = \mathbf{90\ \Omega}$$

Chapter 17

1. –

2. –

3. –

4. (a) *p-n* junction diode

   (b) The SCR will not fire once the gate current is reduced to a level that will cause the forward blocking region to extend beyond the chosen anode-to-cathode voltage. In general, as I_G decreases, the blocking voltage required for conduction increases.

   (c) The SCR will fire once the anode-to-cathode voltage is less than the forward blocking region determined by the gate current chosen.

   (d) The holding current increases with decreasing levels of gate current.

5. (a) Yes

   (b) No

   (c) No. As noted in Fig. 17.8b the minimum gate voltage required to trigger all units is 3 V.

   (d) $V_G = 6$ V, $I_G = 800$ mA is a good choice (center of preferred firing area).
   $V_G = 4$ V, $I_G = 1.6$ A is less preferable due to higher power dissipation in the gate. Not in preferred firing area.

6. In the conduction state, the SCR has characteristics very similar to those of a *p-n* junction diode (where $V_T = 0.7$ V).

7. The smaller the level of R_1, the higher the peak value of the gate current. The higher the peak value of the gate current the sooner the triggering level will be reached and conduction initiated.

8. (a) $V_P = \left(\frac{V_{\text{sec}}(\text{rms})}{2}\right)\sqrt{2}$

   $= \frac{117\text{ V}}{2}\left(\sqrt{2}\right) = 82.78\text{ V}$

   $V_{DC} = 0.636(82.78\text{ V})$
   $= \mathbf{52.65\ V}$

   (b) $V_{AK} = V_{DC} - V_{Batt} = 52.65\text{ V} - 11\text{ V} = \mathbf{41.65\ \ V}$

(c) $V_R = V_Z + V_{GK}$
$= 11\text{ V} + 3\text{ V}$
$= 14\text{ V}$
At 14 V, SCR_2 conducts and stops the charging process.

(d) At least 3 V to turn on SCR_2.

(e) $V_2 \cong \frac{1}{2}V_P = \frac{1}{2}(82.78\text{ V}) = \mathbf{41.39\text{ V}}$

9. –

10. (a) Charge toward 200 V but will be limited by the development of a negative voltage $V_{GK}\left(= V_Z - V_{C_1}\right)$ that will eventually turn the GTO off.

(b) $\tau = R_3C_1 = (20\text{ k}\Omega)(0.1\ \mu\text{F})$
$= 2\text{ ms}$
$5\tau = \mathbf{10\text{ ms}}$

(c) $5\tau' = \frac{1}{2}(5\tau) = 5\text{ ms} = 5R_{GTO}C_1$

$$R_{GTO} = \frac{5\text{ ms}}{5C_1} = \frac{5\text{ ms}}{5(0.1\times10^{-6}\text{ F})} = \mathbf{10\text{ k}\Omega}\ \left(=\frac{1}{2}(20\text{ k}\Omega - \text{ above})\right)$$

11. (a) $\cong$ **0.7 mW/cm²**

(b) 0°C → 0.82 mW/cm²
100°C → 0.16 mW/cm²
$\frac{0.82 - 0.16}{0.82} \times 100\% \cong \mathbf{80.5\%}$

12. $V_C = V_{BR} + V_{GK} = 6\text{ V} + 3\text{ V} = 9\text{ V}$
$V_C = 40(1 - e^{-t/RC}) = 9$
$40 - 40e^{-t/RC} = 9$
$40e^{-t/RC} = 31$
$e^{-t/RC} = 31/40 = 0.775$
$RC = (10 \times 10^3\ \Omega)(0.2 \times 10^{-6}\text{ F}) = 2 \times 10^{-3}\text{ s}$
$\log_e(e^{-t/RC}) = \log_e 0.775$
$-t/RC = -t/2 \times 10^{-3} = -0.255$
and $t = 0.255(2 \times 10^{-3}) = \mathbf{0.51\text{ ms}}$

13. –

14. $V_{BR_1} = V_{BR_2} \pm 10\%\ V_{BR_2}$
$= 6.4\text{ V} \pm 0.64\text{ V} \Rightarrow$ **5.76 V → 7.04 V**

15. –

16. $\dfrac{V - V_P}{I_P} > R_1$

$\dfrac{40\text{ V} - [0.6(40\text{ V}) + 0.7\text{ V}]}{10\times 10^{-6}} = \mathbf{1.53\ M\Omega} > R_1$

$\dfrac{V - V_V}{I_V} < R_1 \Rightarrow \dfrac{40\text{ V} - 1\text{ V}}{8\text{ mA}} = 4.875\text{ k}\Omega < R_1$

$\therefore$ **1.53 MΩ > R_1 > 4.875 kΩ**

17. (a) $\eta = \dfrac{R_{B_1}}{R_{B_1} + R_{B_2}\big|_{I_E=0}} \Rightarrow 0.65 = \dfrac{2\text{ k}\Omega}{2\text{ k}\Omega + R_{B_2}}$ $\quad R_{B_2}$ = **1.08 kΩ**

(b) $R_{BB} = \left(R_{B_1} + R_{B_2}\right)\Big|_{I_E=0}$ = 2 kΩ + 1.08 kΩ = **3.08 kΩ**

(c) $V_{R_{B_1}} = \eta V_{BB}$ = 0.65(20 V) = **13 V**

(d) $V_P = \eta V_{BB} + V_D$ = 13 V + 0.7 V = **13.7 V**

18. (a) $\eta = \dfrac{R_{B_1}}{R_{BB}}\Bigg|_{I_E=0}$

$0.55 = \dfrac{R_{B_1}}{10\text{ k}\Omega}$

R_{B_1} = **5.5 kΩ**

$R_{BB} = R_{B_1} + R_{B_2}$

10 kΩ = 5.5 kΩ + R_{B_2}

R_{B_2} = **4.5 kΩ**

(b) $V_P = \eta V_{BB} + V_D$ = (0.55)(20 V) + 0.7 V = **11.7 V**

(c) $R_1 < \dfrac{V - V_P}{I_p} = \dfrac{20\text{ V} - 11.7\text{ V}}{50\ \mu\text{A}} = 166\text{ k}\Omega$

ok: 68 kΩ < 166 kΩ

(d) $t_1 = R_1 C \log_e \dfrac{V - V_V}{V - V_P} = (68 \times 10^3)(0.1 \times 10^{-6}) \log_e \dfrac{18.8}{8.3} = 5.56 \text{ ms}$

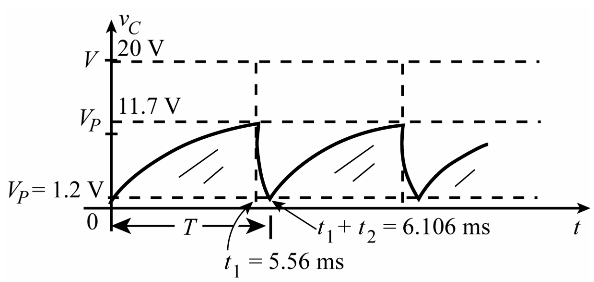
$t_2 = (R_{B_1} + R_2)\, C \log_e \dfrac{V_P}{V_V} = (0.2 \text{ k}\Omega + 2.2 \text{ k}\Omega)(0.1 \times 10^{-6}) \log_e \dfrac{11.7}{1.2}$

$= 0.546 \text{ ms}$

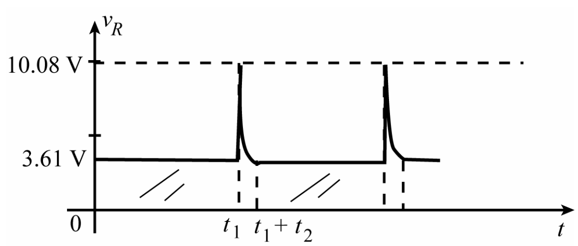
$T = t_1 + t_2 = 6.106 \text{ ms}$

$f = \dfrac{1}{T} = \dfrac{1}{6.106 \text{ ms}} = \mathbf{163.77 \text{ Hz}}$

(e)



(f)



$V_{R_2} = \dfrac{R_2 V}{R_2 + R_{BB}} = \dfrac{2.2 \text{ k}\Omega(20 \text{ V})}{2.2 \text{ k}\Omega + 10 \text{ k}\Omega}$

$= \mathbf{3.61 \text{ V}}$

$V_{R_2} \cong \dfrac{R_2(V_P - 0.7 \text{ V})}{R_2 + R_{B_1}}$

$= \dfrac{2.2 \text{ k}\Omega(11.7 \text{ V} - 0.7 \text{ V})}{2.2 \text{ k}\Omega + 0.2 \text{ k}\Omega}$

$= \mathbf{10.08 \text{ V}}$

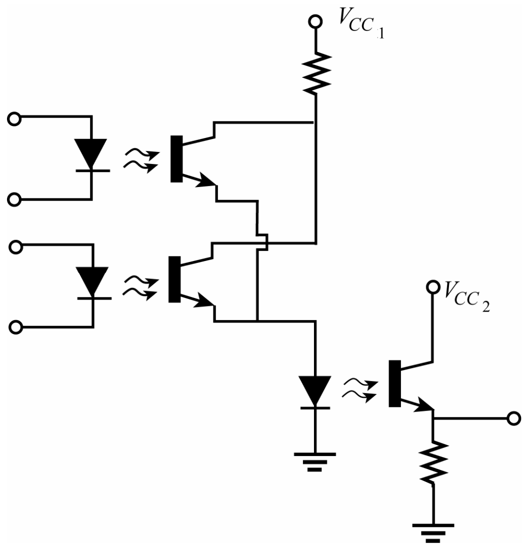
(g) $f \cong \dfrac{1}{R_1 C \log_e(1/(1-\eta))} = \dfrac{1}{(6.8 \text{ k}\Omega)(0.1\ \mu\text{F})\log_e 2.22} = \mathbf{184.16 \text{ Hz}}$

difference in frequency levels is partly due to the fact that $t_2 \cong 10\%$ of t_1.

19. $I_B = \mathbf{25\ \mu A}$

$I_C = h_{f_e} I_B = (40)(25\ \mu\text{A}) = \mathbf{1 \text{ mA}}$

20.



21. (a) $D_F = \dfrac{\Delta I}{\Delta T}$

$$= \frac{0.95 - 0}{25-(-50)} = \frac{0.95}{75} = \mathbf{1.26\%/°C}$$

(b) Yes, curve flattens after 25°C.

22. (a) At 25°C, $I_{CEO} \cong 2$ nA
At 50°C, $I_{CEO} \cong 30$ nA

$$\frac{\Delta I_{CEO}}{\Delta T} = \frac{(30-2)\times 10^{-9}\text{ A}}{(50-25)°\text{C}} = \frac{28\text{ nA}}{25°\text{C}} = \mathbf{1.12\text{ nA/°C}}$$

I_{CEO} (35°C) = I_{CEO}(25°C) + (1.12 nA/°C)(35°C − 25°C)
= 2 nA + 11.2 nA
= **13.2 nA**

From Fig. 17.55 I_{CEO} (35°C) ≅ **4 nA**

Derating factors, therefore, cannot be defined for large regions of non-linear curves. Although the curve of Fig. 17.55 appears to be linear, the fact that the vertical axis is a log scale reveals that I_{CEO} and T(°C) have a non-linear relationship.

23. $$\frac{I_o}{I_i} = \frac{I_C}{I_F} = \frac{20\text{ mA}}{\cong 45\text{ mA}} = \mathbf{0.44}$$

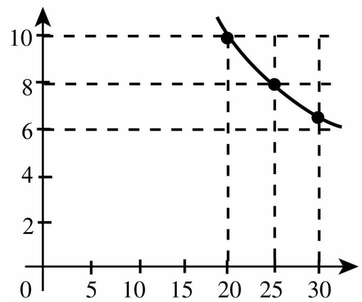
Yes, relatively efficient.

24. (a) $P_D = V_{CE}I_C = 200$ mW

$I_C = \dfrac{P_D}{V_{CE_{max}}} = \dfrac{200\text{ mW}}{30\text{ V}} = 6.67$ mA @ $V_{CE} = 30$ V

$V_{CE} = \dfrac{P_D}{I_C} = \dfrac{200\text{ mW}}{10\text{ mA}} = 20$ V @ $I_C = 10$ mA

$I_C = \dfrac{P_D}{V_{CE}} = \dfrac{200\text{ mW}}{25\text{ V}} = 8.0$ mA @ $V_{CE} = 25$ V



Almost the entire area of Fig. 17.57 falls within the power limits.

(b) $\beta_{dc} = \dfrac{I_C}{I_F} = \dfrac{4\text{ mA}}{10\text{ mA}} = \mathbf{0.4}$, Fig. 17.56 $\dfrac{I_C}{I_F} \cong \dfrac{4\text{ mA}}{10\text{ mA}} = \mathbf{0.4}$

The fact that the I_F characteristics of Fig. 17.57 are fairly horizontal reveals that the level of I_C is somewhat unaffected by the level of V_{CE} except for very low or high values. Therefore, a plot of I_C vs. I_F as shown in Fig. 17.56 can be provided without any reference to the value of V_{CE}. As noted above, the results are essentially the same.

25. (a) $I_C \geq$ **3 mA**

(b) At $I_C = 6$ mA; $R_L = 1$ kΩ, $t = 8.6$ μs
$R_L = 100$ Ω; $t = 2$ μs
1 kΩ:100 Ω = 10:1
8.6 μs:2 μs = 4.3:1
ΔR:$\Delta t \cong$ **2.3:1**

26. $\eta = \dfrac{3R_{B_2}}{3R_{B_2} + R_{B_2}} = \dfrac{3}{4} = \mathbf{0.75}$, $V_G = \eta V_{BB} = 0.75(20\text{ V}) = \mathbf{15\ V}$

27. $V_P = 8.7$ V, $I_P = 100$ μA $\quad Z_P = \dfrac{V_P}{I_P} = \dfrac{8.7\text{ V}}{100\ \mu\text{A}} = \mathbf{87\ k\Omega}$ (≅ open)

$V_V = 1$ V, $I_V = 5.5$ mA $\quad Z_V = \dfrac{V_V}{I_V} = \dfrac{1\text{ V}}{5.5\text{ mA}} = \mathbf{181.8\ \Omega}$ (relatively low)

87 kΩ: 181.8 Ω = 478.55:1 ≅ **500:1**

28. Eq. 17.23: $T = RC\log_e\left(\dfrac{V_{BB}}{V_{BB}-V_P}\right) = RC\log_e\left(\dfrac{V_{BB}}{V_{BB}-(\eta V_{BB}+V_D)}\right)$

Assuming $\eta V_{BB} \gg V_D$, $T = RC\log_e\left(\dfrac{V_{BB}}{V_{BB}(1-\eta)}\right) = RC\log_e(1/1-\eta) = RC\log_e\left(\dfrac{1}{1-\dfrac{R_{B_1}}{R_{B_1}+R_{B_2}}}\right)$

$= RC\log_e\left(\dfrac{R_{B_1}+R_{B_2}}{R_{B_2}}\right) = RC\log_e\left(1+\dfrac{R_{B_1}}{R_{B_2}}\right)$ Eq. 17.24

29. (a) Minimum V_{BB}:

$$R_{\max} = \frac{V_{BB}-V_P}{I_P} \geq 20\text{ k}\Omega$$

$$\frac{V_{BB}-(\eta V_{BB}+V_D)}{I_P} = 20\text{ k}\Omega$$

$$V_{BB} - \eta V_{BB} - V_D = I_P\,20\text{ k}\Omega$$

$$V_{BB}(1-\eta) = I_P\,20\text{ k}\Omega + V_D$$

$$V_{BB} = \frac{I_P\,20\text{ k}\Omega + V_D}{1-\eta}$$

$$= \frac{(100\ \mu\text{A})(20\text{ k}\Omega)+0.7\text{ V}}{1-0.67}$$

$$= \mathbf{8.18\ V}$$

10 V OK

(b) $R < \dfrac{V_{BB}-V_V}{I_V} = \dfrac{12\text{ V}-1\text{ V}}{5.5\text{ mA}} = 2\text{ k}\Omega$

$R <$ **2 kΩ**

(c) $T \cong RC\log_e\left(1+\dfrac{R_{B_1}}{R_{B_2}}\right)$

$$2\times10^{-3} = R(1\times10^{-6})\underbrace{\log_e\left(1+\frac{10\text{ k}\Omega}{5\text{ k}\Omega}\right)}_{\log_e 3\,=\,1.0986}$$

$$R = \frac{2\times10^{-3}}{(1\times10^{-6})(1.0986)}$$

$R =$ **1.82 kΩ**

Solutions for Laboratory Manual to accompany

Electronic Devices and Circuit Theory

Tenth Edition

Prepared by
Franz J. Monssen

EXPERIMENT 1: OSCILLOSCOPE AND FUNCTION GENERATOR OPERATIONS

Part 1: The Oscilloscope

a. it focuses the beam on the screen
b. adjusts 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. selects unit of time/screen division on *x*-axis
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
k. determines mode of triggering of the sweep voltage
m. the input impedance of many scopes consists of the parallel combination of a 1 Meg resistance and a 30pf capacitor
n. measuring device which reduces loading of scope on a circuit and effectively increases input impedance of scope by a factor of 10.

Part 2: The Function Generator

d. T = l/*f* = 1/1000 Hz = l ms
e. (calculated): 1 ms*[l cm/.2 ms] = 5cm
(measured): 5 cm = same
f. (calculated): l ms*[cm/.5ms] =2 cm
(measured): 2 cm = same
g. (calculated): 1 ms*[cm/1ms] = l cm
(measured): l cm = same
h. .2 ms/cm takes 5 boxes to display total wave
.5 ms/cm takes 2 boxes to display total wave
1 ms/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.

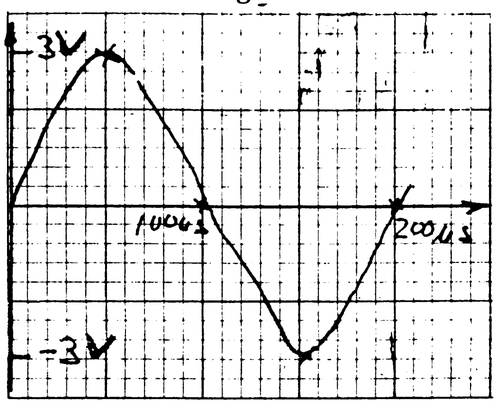
j. (calculated): 2cm * [2V/cm] = 4Vp-p
k. 8 * [.5V/cm] = 4Vp-p
1. the signal occupied full screen; the
peak amplitude did not change with a
change in the setting of the vertical sensitivity
m. no: there is no voltmeter built into function
generator

Part 3: Exercises

a. chosen sensitivities: Vert. Sens. = l V/cm
Hor. Sens. = 50 μs/cm

T(calculated): 4cm*[50 μs/cm)= 200 μs

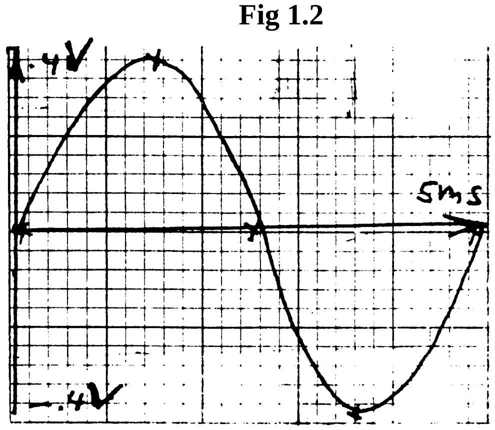
Fig 1.1



b. chosen sensitivities: Vert. Sens. = .l V/cm
Hor. Sens. = 1 ms/cm

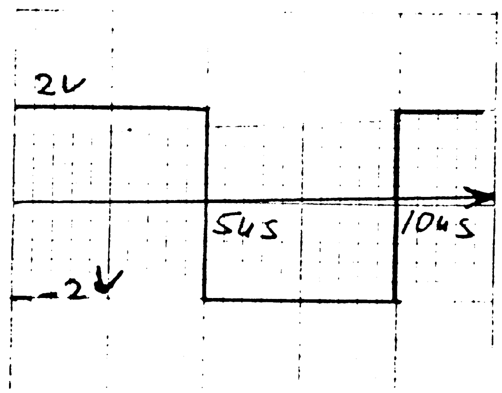
T(calculated):5 cm*[l ms/cm] = 5 ms

Fig 1.2



c. chosen sensitivities: Vert. Sens. = l V/cm
Hor. Sens. = l μs/cm
T(calculated):10 cm*[1μs/cm]=10 μs

Fig 1.3

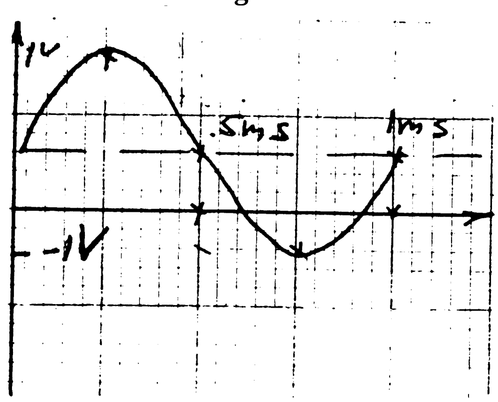


Part 4: Effect of DC Levels

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.

Fig 1.5

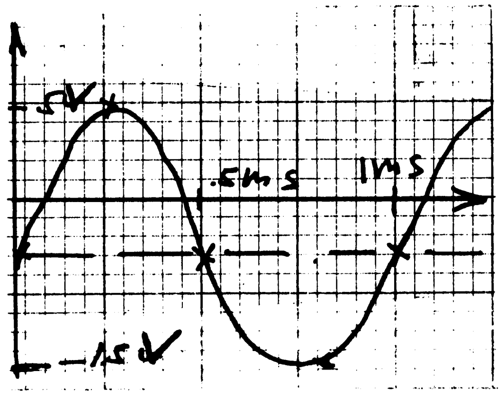


i. Switch AC-GND-DC switch, make copy of waveform above.
The vertical shift of the waveform was equal to the battery voltage.

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.

Fig 1.6



Part 5: Problems

1. b. f = 2000/(2*3.14) = 318Hz
   c. T = l/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

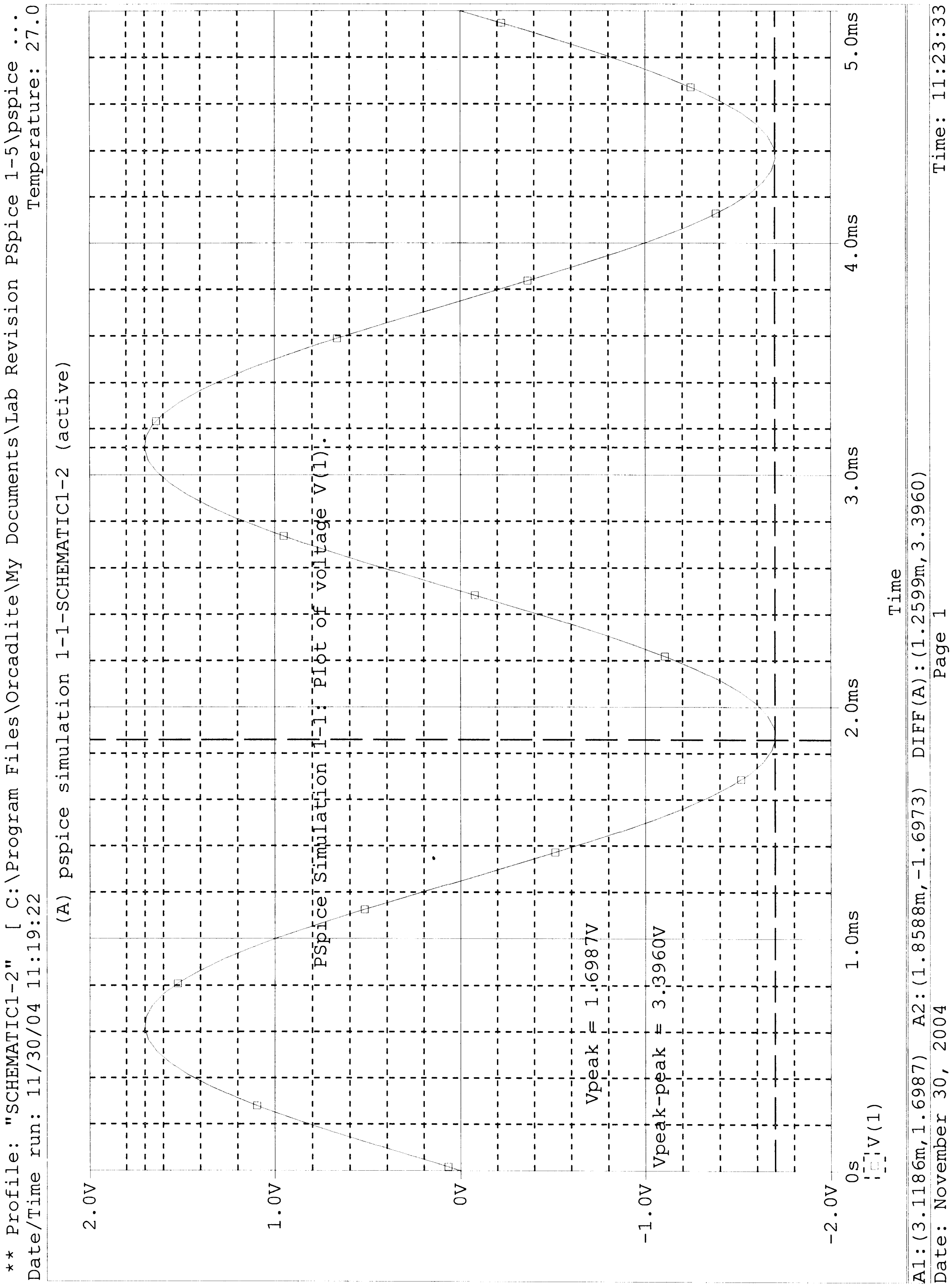
2.
   a. f = 2 * 3.14 * 4000/(2 * 3.14*) = 4 KHz
   c. T = l/f =1/4 Khz = 250 μs
   d. by inspection:Vpeak)= 8 mV
   e. V(peak-peak) = 2 * V(peak) = 16 mV
   f. V(rms) = .707 * 8 mV = 5.66 mV
   g. by inspection: Vdc = 0V

3. V(t) = 1.7 sin (2.51 Kt) volts

Part 6: Computer Exercise

PSpice Simulation 1-1

See Probe Plot page 191.


** Profile: "SCHEMATIC1-2" [C:\Program Files\Orcadlite\My Documents\Lab Revision PSpice 1-5\pspice ...
Date/Time run: 11/30/04 11:19:22
Temperature: 27.0
(A) pspice simulation 1-1-SCHEMATIC1-2 (active)
2.0V
1.0V
0V
-1.0V
-2.0V
0s
1.0ms
2.0ms
3.0ms
4.0ms
5.0ms
V(1)
Time
PSpice Simulation 1-1: Plot of voltage V(1).
Vpeak = 1.6987V
Vpeak-peak = 3.3960V
A1:(3.1186m,1.6987) A2:(1.8588m,-1.6973) DIFF(A):(1.2599m,3.3960)
Date: November 30, 2004
Page 1
Time: 11:23:33

EXPERIMENT 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(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.

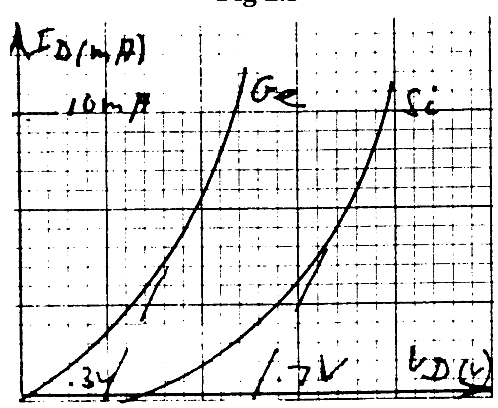
Table 2.4

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 = 9.9 Mohms
V_R(measured) = 9.1 mV
I_S(calculated) = 8.21 nA

c. V_R(measured) = 5.07 mV
I_S(calculated) = 4.58 μA

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) = 3.28 M*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) = 540 mV
V_T(germanium) = 260 mV

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 $R_D = V_D/I_D$, therefore, the resistance of a diode declines with increasing temperature.

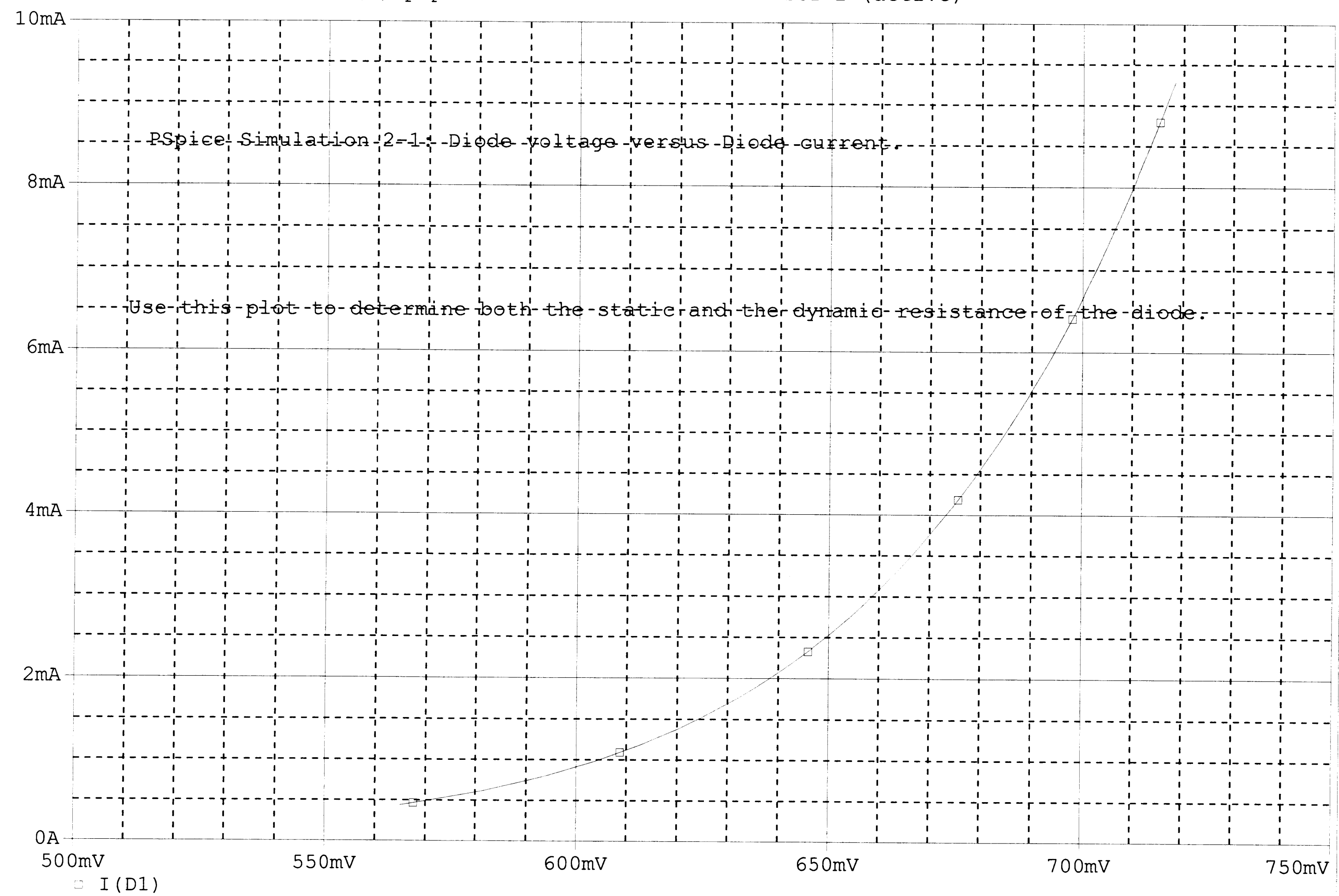
d. As the temperature across a diode increases, so does the current. Therefore, relative to the diode current, the diode has a positive temperature coefficient.

Part 9: Computer Exercises
PSpice Simulation 2-1

1. See Probe plot page 195.
2. $R_{D\ 600\text{mV}} = 658\ \Omega$
   $R_{D\ 700\ \text{mV}} = 105\ \Omega$
4. $R_{D\ 600\ \text{mV}} = 257\ \Omega$
5. See Probe Plot V(D1) versus I(D1)
7. Silicon
8. See Probe plot page 196.
9. See Probe plot page 196.
10. See Probe plot page 196.

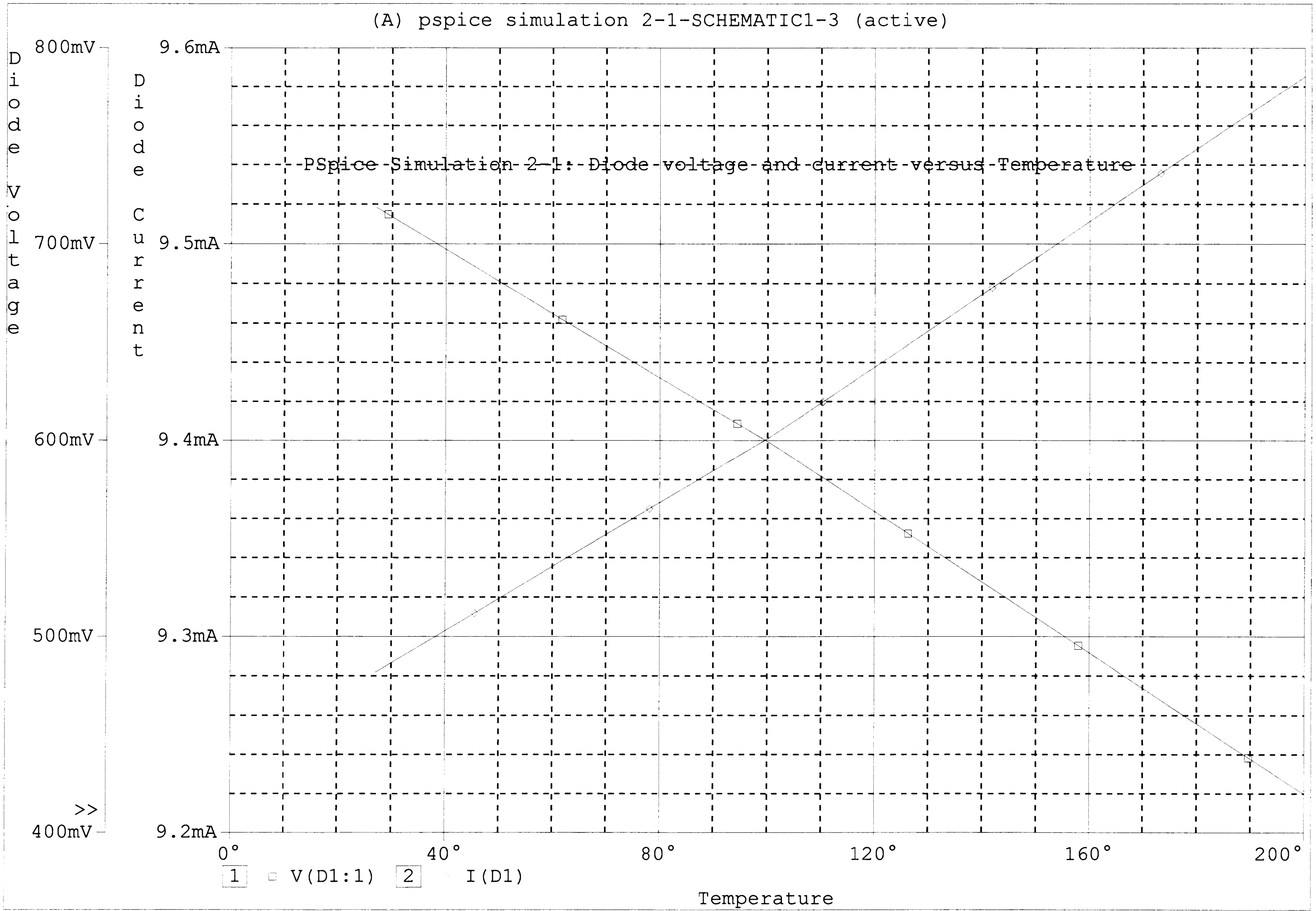
** Profile: "SCHEMATIC1-2" [C:\Documents and Settings\Owner\My Documents\Lab Revision PSpice 1-5\ps...
Date/Time run: 12/08/04 15:46:21
Temperature: 27.0

(A) pspice simulation 2-1-SCHEMATIC1-2 (active)



Date: December 08, 2004
Page 1
Time: 15:53:16

** Profile: "SCHEMATIC1-3" [C:\Documents and Settings\Owner\My Documents\Lab Revision PSpice 1-5\ps...
Date/Time run: 12/02/04 10:16:16 Temperature: 27.0, 100.0, 200.0



Date: December 02, 2004 Page 1 Time: 10:21:40

EXPERIMENT 3: SERIES AND PARALLEL DIODE CONFIGURATIONS

Part 1: Threshold Voltage V_T

Fig 3.2
Firing voltage: Silicon: 595 mV Germanium: 310 mV

Part 2: Series Configuration

b. V_D = .59 V
V_O (calculated) = 5 – .595 = 4.41 V
I_D = 4.41/2.2 K = 2 mA

c. V_D(measured) = .59 V
V_O(measured) = 4.4 V
I_D(from measured) = 2 mA

e. V_D = 595 mV
V_O(calculated) = (5 – .595) 1 K/(1 K + 2.2 K) = 1.33 V
I_D = 1.36 mA

f. V_D = .57 V
V_O = 1.36 V
I_D(from measured) = 1.36 V/1 K = 1.36 mA

g. V_D(measured) = 5 V
V_O(measured) = 0 V
I_D(measured) = 0 A

h. V_D(measured) = 5 V
V_O(measured) = 0 V
I_D(measured) = 0 A

j. V_1(calculated) = .905 V
V_O(calculated) = 4.1 V
I_D(calculated) = 1.86 mA

Part 7: Computer Exercise
PSpice Simulation 3-2

1. 638.0 mV

EXPERIMENT 4: HALF-WAVE AND FULL-WAVE RECTIFICATION

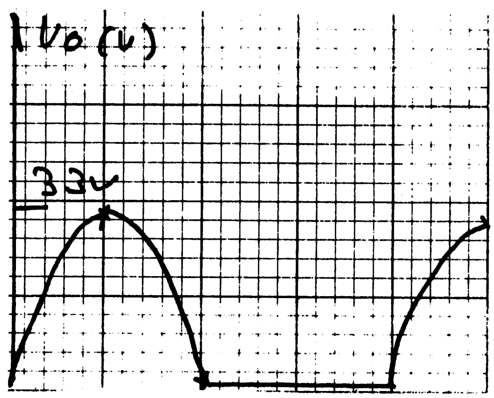
Part 1: Threshold Voltage
V_T = .64 V

Part 2: Half-wave Rectification

b. Vertical sensitivity = 1 V/cm
Horizontal sensitivity = .2 ms/cm

c.

Fig 4.4



d. Both waveforms are in essential agreement.

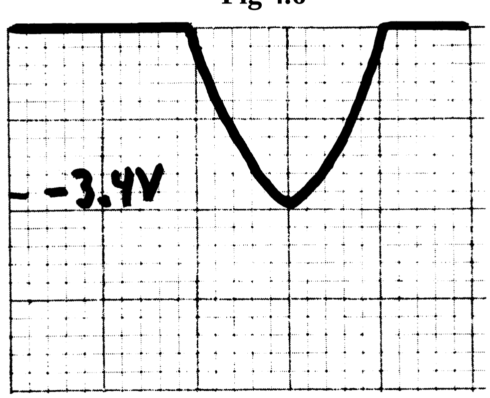
e. V_{dc} = (4 – .64)/3.14 = 1.07 V

f. V_{dc}(measured) = .979 V
% 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.

h.

Fig 4.6

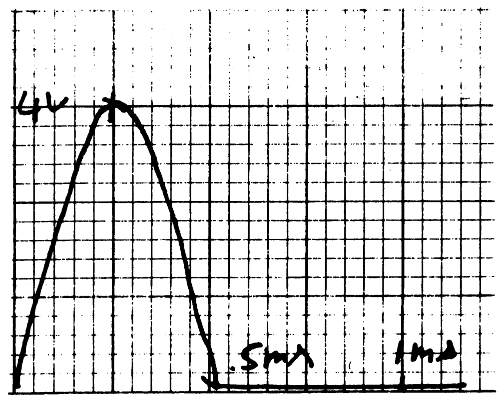


i. V_{dc}(calculated) = –1.07 V
V_{dc}(measured) = –.970 V

Part 3: Half-Wave Rectification (continued)

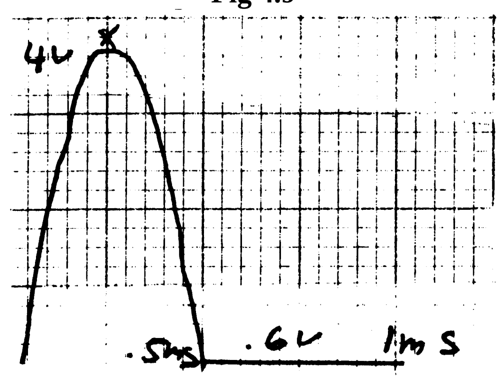
b.

Fig 4.8



c.

Fig 4.9



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.

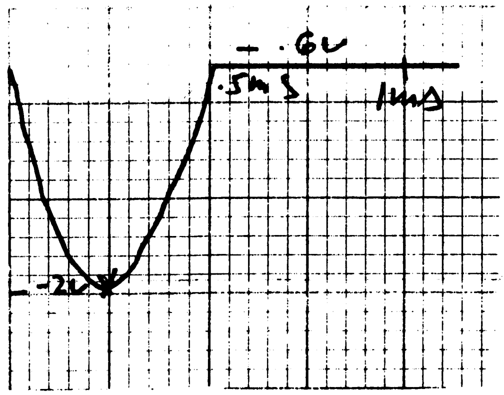
e. V_{DC} = (.318)*3.4 = 1.08 Volts

f. Difference = [1.08 – .979]/1.08*100 = 9.35%

Part 4: Half-Wave Rectification (continued)

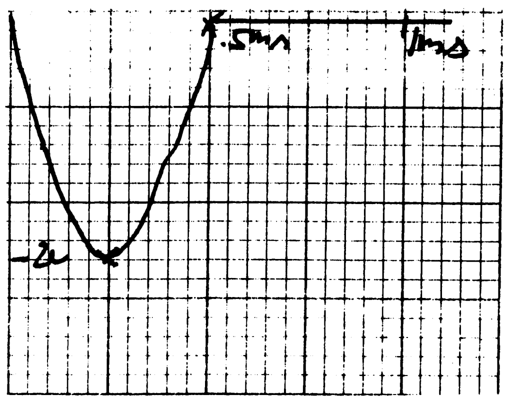
b.

Fig 4.11



c.

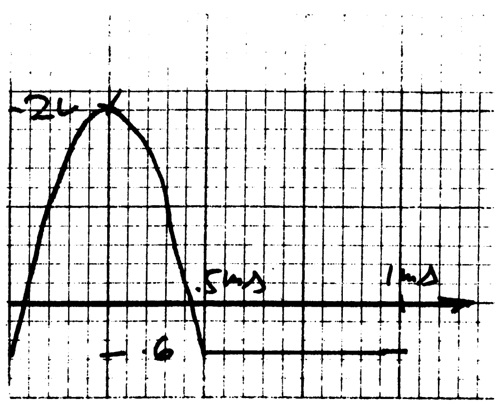
Fig 4.12



There was a computed 2.1% difference between the two waveforms.

d.

Fig 4.13



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)

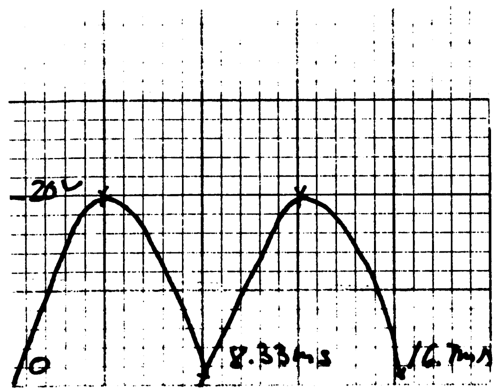
a. $V_{(secondary)rms}$ = 14 V

This value differs by 1.4 V rms from the rated voltage of the secondary of the transformer.

b. $V_{(peak)}$ = 1.41*14 = 20 V

c.

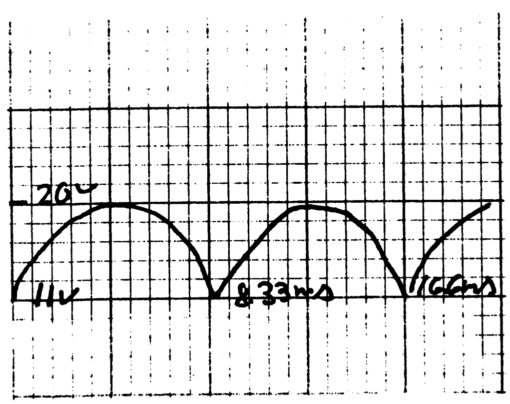
Fig 4.15



Vertical sensitivity: 5 V/cm
Horizontal sensitivity: 2 ms/cm

d.

Fig 4.16

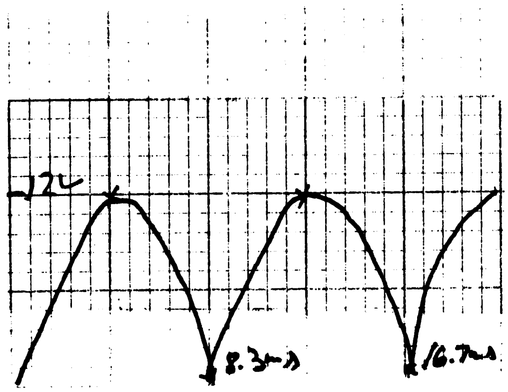


Again, the difference between expected and actual was very slight.

e. V_{dc}(calculated) = (.6326)*(20) = 12.7 V
V_{dc}(measured) = 11.36 V
% Difference = –10.6%

g. Vertical sensitivity = 5 V/cm
Horizontal sensitivity = 2 ms/cm

Fig 4.17



i. V_{dc}(calculated) = (.636)*(12) = 7.63 V

j V_{dc}(measured) = 7.05 V
% Difference = –7.6%

k. The effect was a reduction in the dc level of the output voltage.

Part 6: Full-Wave Center-tapped Configuration

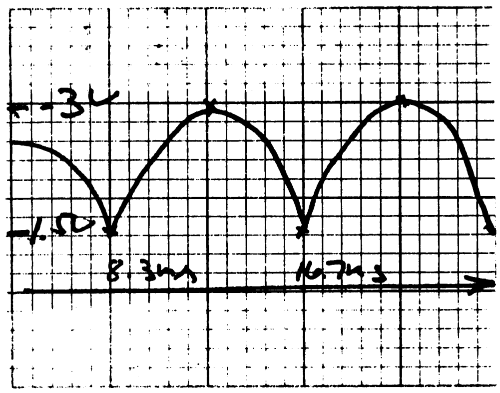
a. V_{rms}(measured) = 6.93 V
V_{rms}(measured) = 6.97 V

As is shown from the data, the difference for both halves of the center-tapped windings from the rated voltage is .6 volts.

b. Vertical sensitivity = 5 V/cm
Horizontal sensitivity = 2 ms/cm

c.

Fig 4.21

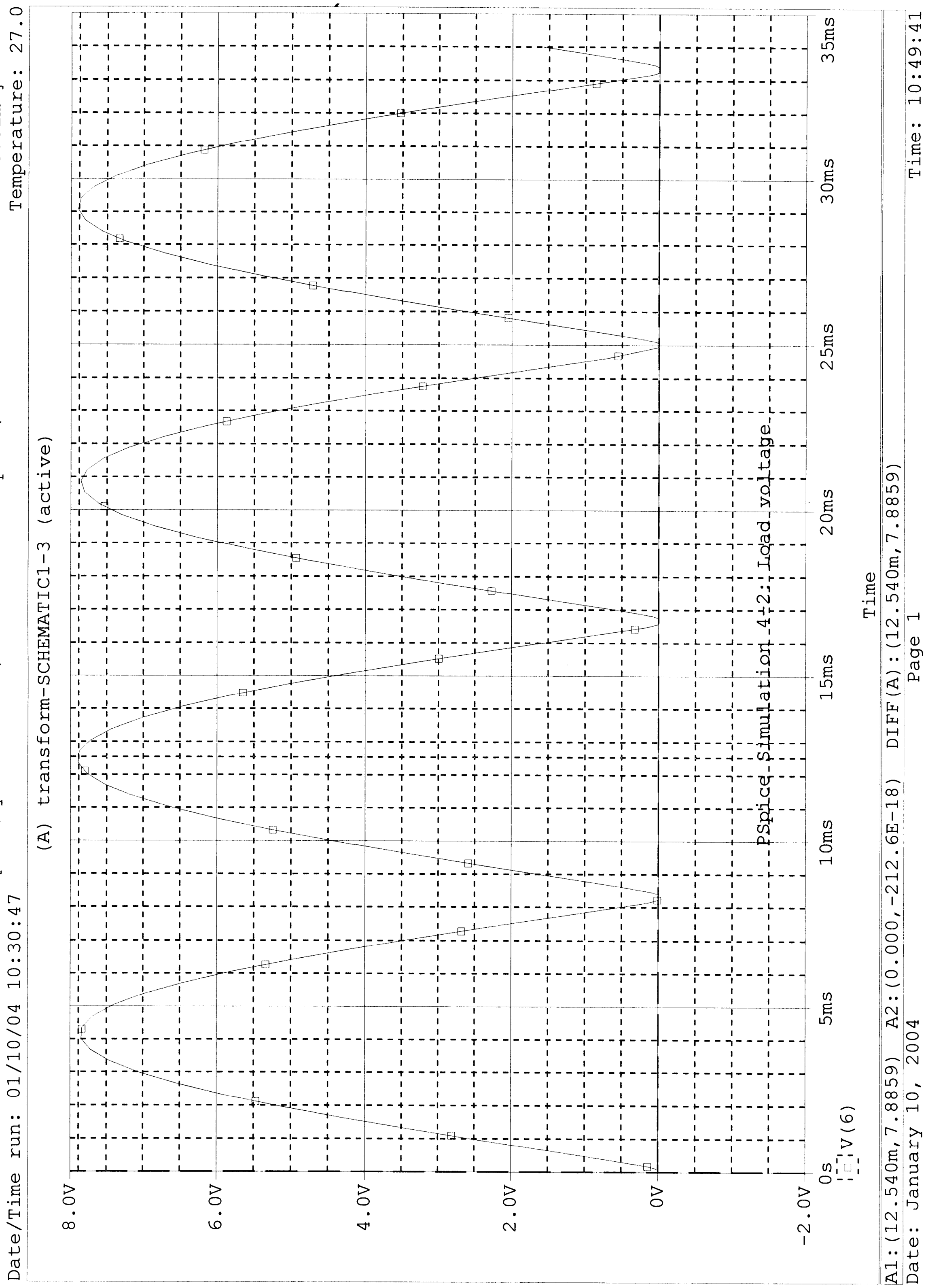


d. V_{dc}(calculated) = 3.5 V
V_{dc}(measured) = 3.04 V

Part 7: Computer Exercise

PSpice Simulation 4-2

1. V_p = 8.47 V; relative phase shift is equal to 180°
2. PIV = 2 Vp
3. 180° out of phase
4. See Probe plot page 204.
   Its amplitude is 7.89 V
5. Yes
6. Reasonable agreement.


** Profile: "SCHEMATIC1-3" [C:\My Documents\Lab Revision Pspice\transform-SCHEMATIC1-3.sim]
Date/Time run: 01/10/04 10:30:47
Temperature: 27.0
(A) transform-SCHEMATIC1-3 (active)
8.0V
6.0V
4.0V
2.0V
0V
-2.0V
0s
5ms
10ms
15ms
20ms
25ms
30ms
35ms
V(6)
Time
PSpice Simulation 4-2: Load voltage
A1:(12.540m,7.8859) A2:(0.000,-212.6E-18) DIFF(A):(12.540m,7.8859)
Date: January 10, 2004
Page 1
Time: 10:49:41

EXPERIMENT 5: CLIPPING CIRCUITS

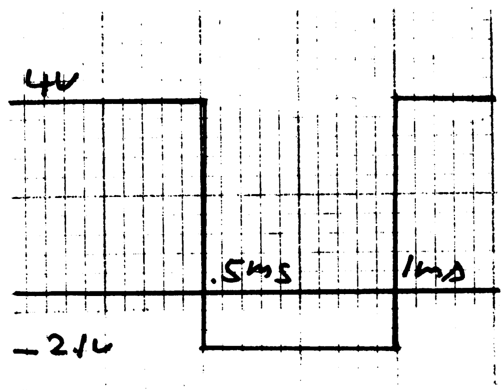
Part 1: Threshold Voltage

V_T(Si) = .618 V
V_T(Ge) = .299 V

Part 2 Parallel Clippers

b. V_O(calculated) = 4 V
c. V_O(calculated) = –1.5 – .618 = –2.2 V
d.

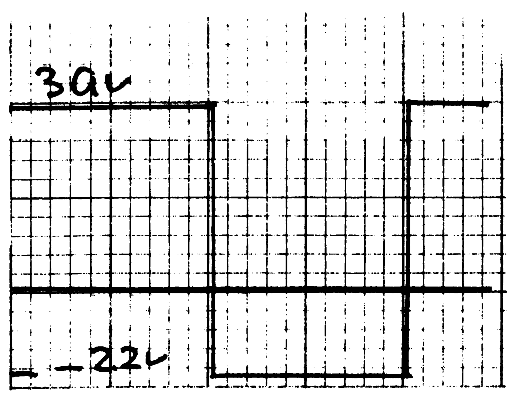
Fig 5.2



Vertical sensitivity = 1 V/cm
Horizontal sensitivity = .2 ms/cm

e.

Fig 5.3



No measured differences appeared between expected and observed waveforms.

f. V_O(calculated) = 4 V

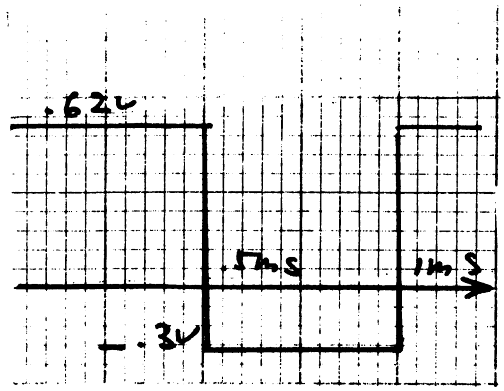
g. V_O(calculated) = .62 V

Part 3: Parallel Clippers (continued)

b. V_O(calculated) = .61 V
c. V_O(calculated) = .34 V

d.

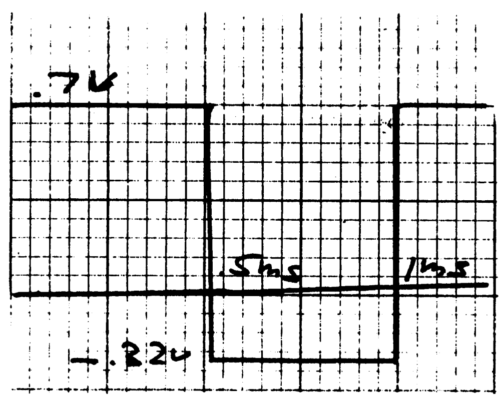
Fig 5.7



Vertical sensitivity = 1 V/cm
Horizontal sensitivity = .2 ms/cm

e.

Fig 5.8

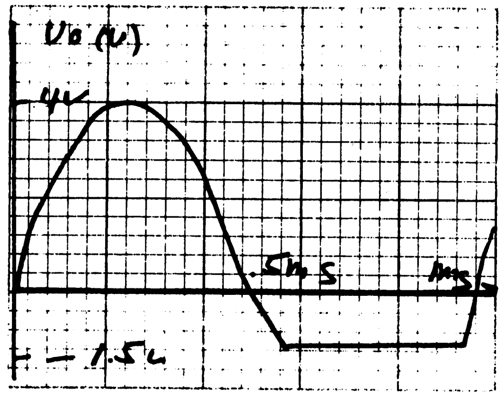


The waveforms agree.

Part 4: Parallel Clippers (Sinusoidal Input)

b. V_O(calculated) = 4 V when V_i = 4 V
V_O(calculated) = –2 V when V_i = –4 V
V_O(calculated) = 0 V when V_i = 0 V

Fig 5.9



c. Waveforms agree within 6.5%.

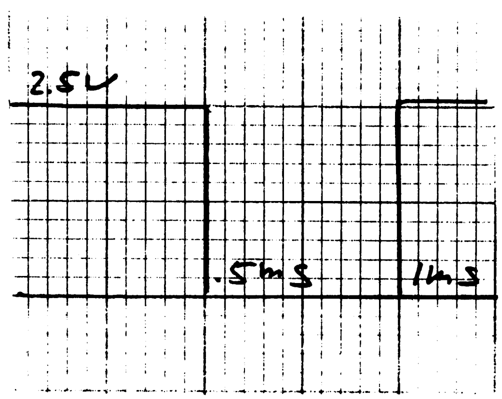
Part 5: Series Clippers

b. V_O(calculated) = 2.5 V when V_i = 4 V

c. V_O(calculated) = 0 V when V_i = –4 V

d.

Fig 5.12



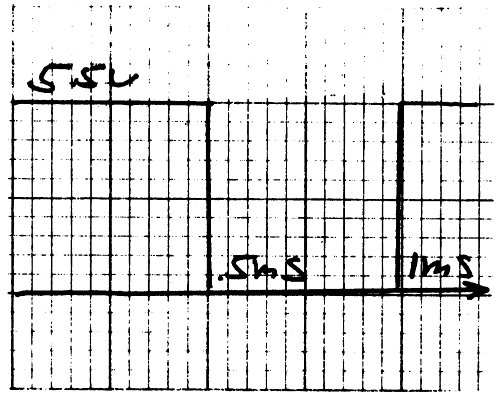
Vertical sensitivity = 1 V/cm
Horizontal sensitivity = .2 ms/cm

e. agree within 5.1%

f. V_O(calculated) = 5.5 V when V_i = 4 V

g. V_O(calculated) = 0 V when V_i = –4 V h.

Fig 5.14



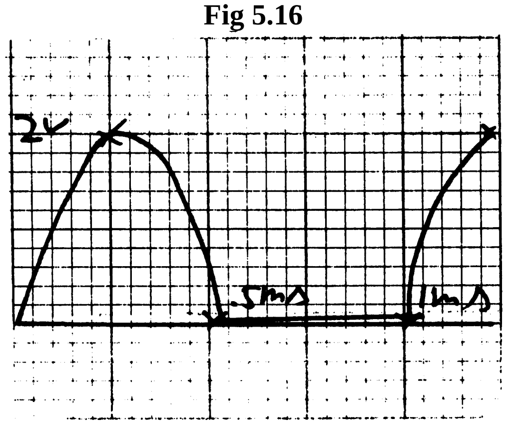
Vertical sensitivity = 2 V/cm
Horizontal sensitivity = .2 ms/cm

i. no major differences

Part 6: Series Clippers (Sinusoidal Input)

b. V_O(calculated) = 2 V when V_i = 4 V
V_O(calculated) = 0 V when V_i = –4 V
V_O(calculated) = 0 V when V_i = 0 V

Fig 5.16



Vertical sensitivity = 1 V/cm
Horizontal sensitivity = .2 ms/cm

Part 7: Computer Exercises

PSpice Simulation 5-2

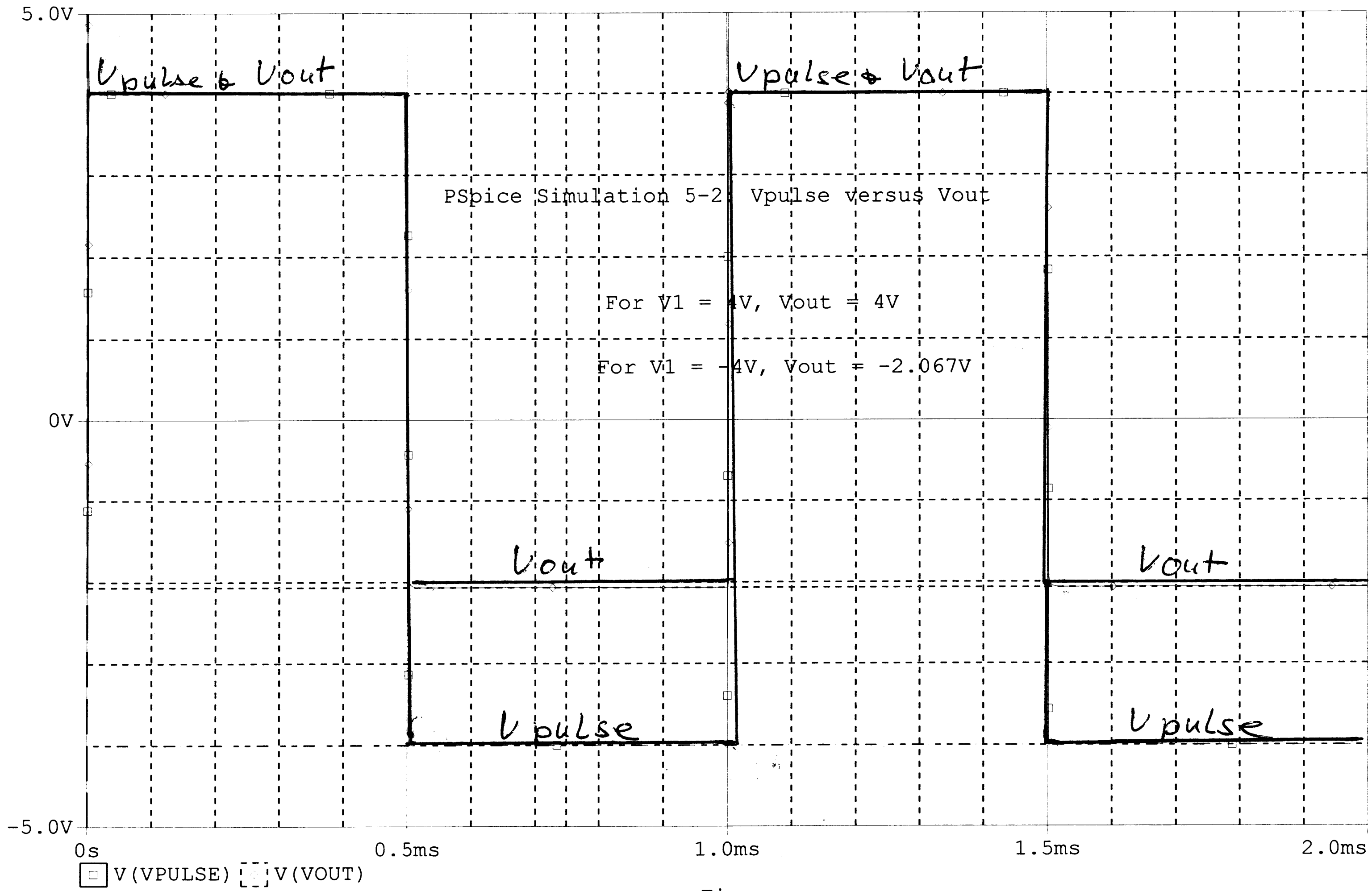
1. See Probe plot page 210.
2. $V_{OUT} = 4$ V
3. No
4. $V_{OUT} = -2.067$ V
5. Yes, V_{OUT}(ideal) = –1.5 V
6. Reasonable agreement
7. No significant discrepancies
8. See Probe plot page 211.

PSpice Simulation 5-3

1. See Probe plot page 212.
2. In close agreement
3. No
4. For $V_1 = 4$ V; $V_{out} = V_1 - V_{D1} - 1.5\text{ V} = 4\text{ V} - .6 - 1.5\text{ V} = 1.9\text{ V}$
   For $V_1 = -4$ V; $I_{(D1)} = 0$ A, $\therefore$ $V_{out} = 0$ V
5. See Probe plot page 213.
6. See Probe plot page 213.
7. See Probe plot page 213.
8. See Probe plot page 213.
9. Forward bias voltage of about 600 mV when "ON".
   Reverse diode voltage of diode is –4 V – 1.5 V = –5.5 V

** Profile: "SCHEMATIC1-1" [C:\Documents and Settings\Owner\My Documents\Lab Revision PSpice 1-5\ps...
Date/Time run: 12/03/04 11:10:11 Temperature: 27.0

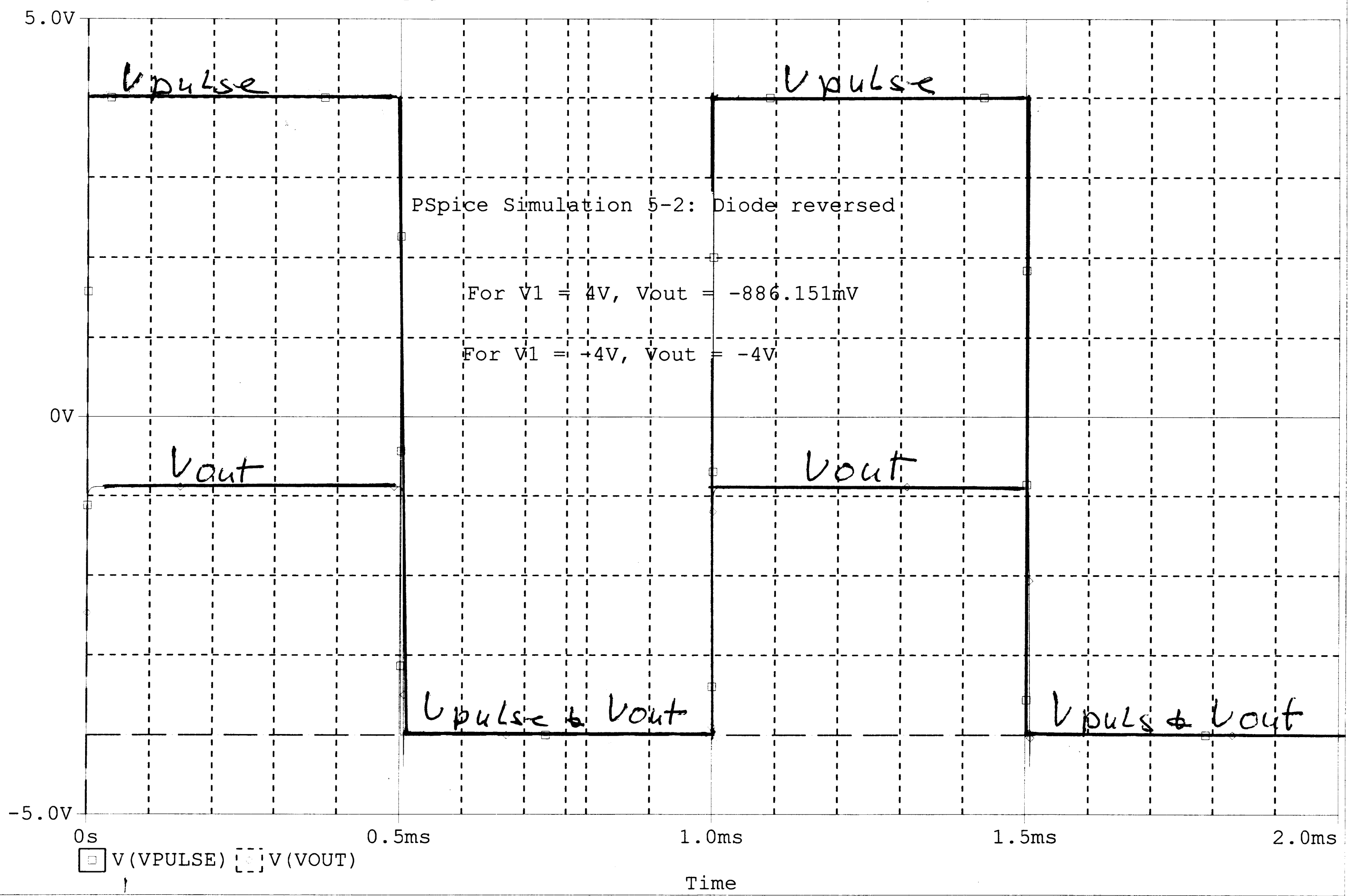
(A) pspice simulation 5-2-SCHEMATIC1-1 (active)



A1:(748.869u,-2.0663) A2:(0.000,-4.0000) DIFF(A):(748.869u,1.9337)
Date: December 03, 2004 Page 1 Time: 11:16:40

** Profile: "SCHEMATIC1-1" [C:\Documents and Settings\Owner\My Documents\Lab Revision PSpice 1-5\ps...
Date/Time run: 12/03/04 11:21:17 Temperature: 27.0

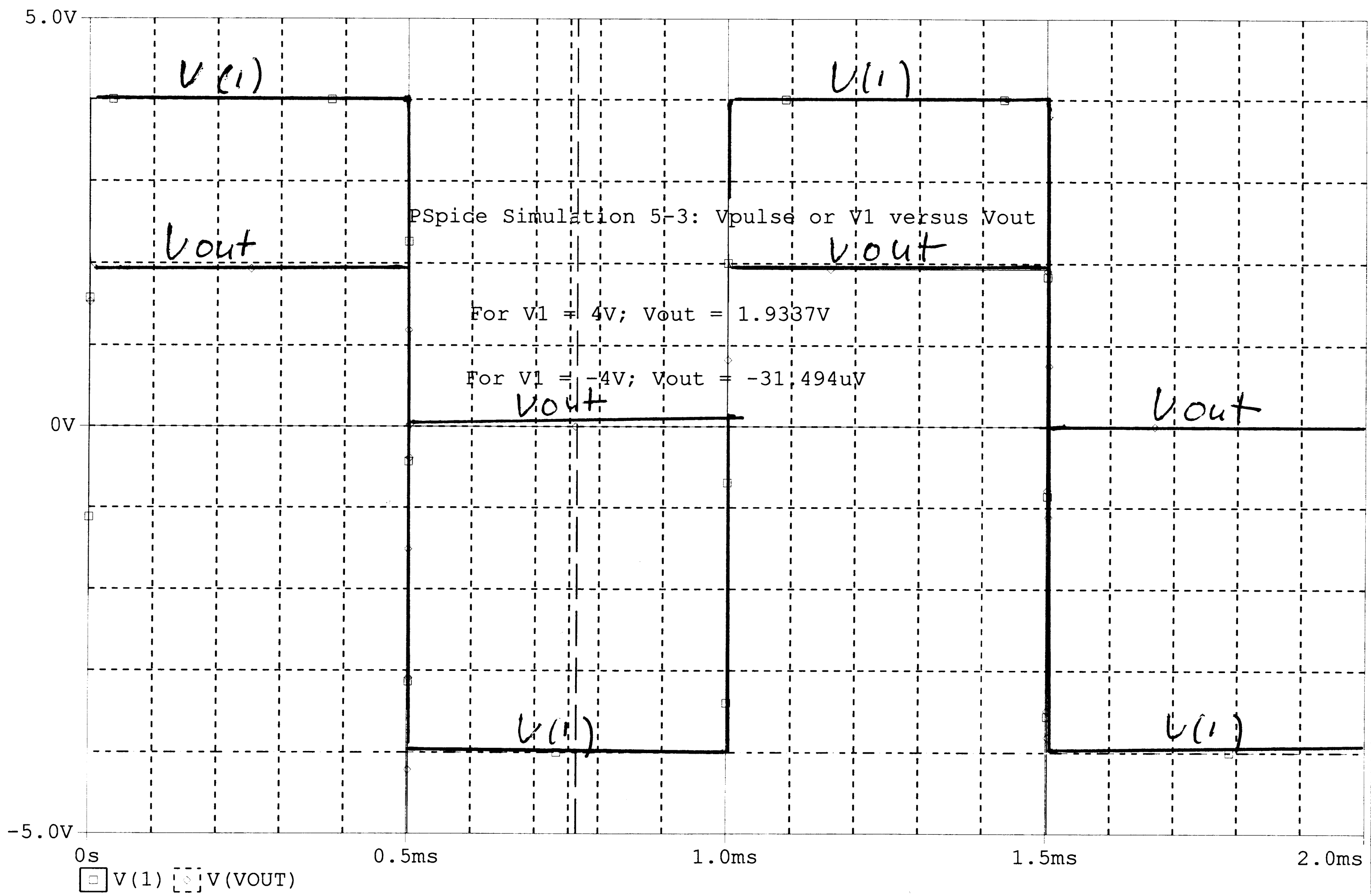
(A) pspice simulation 5-2-SCHEMATIC1-1 (active)



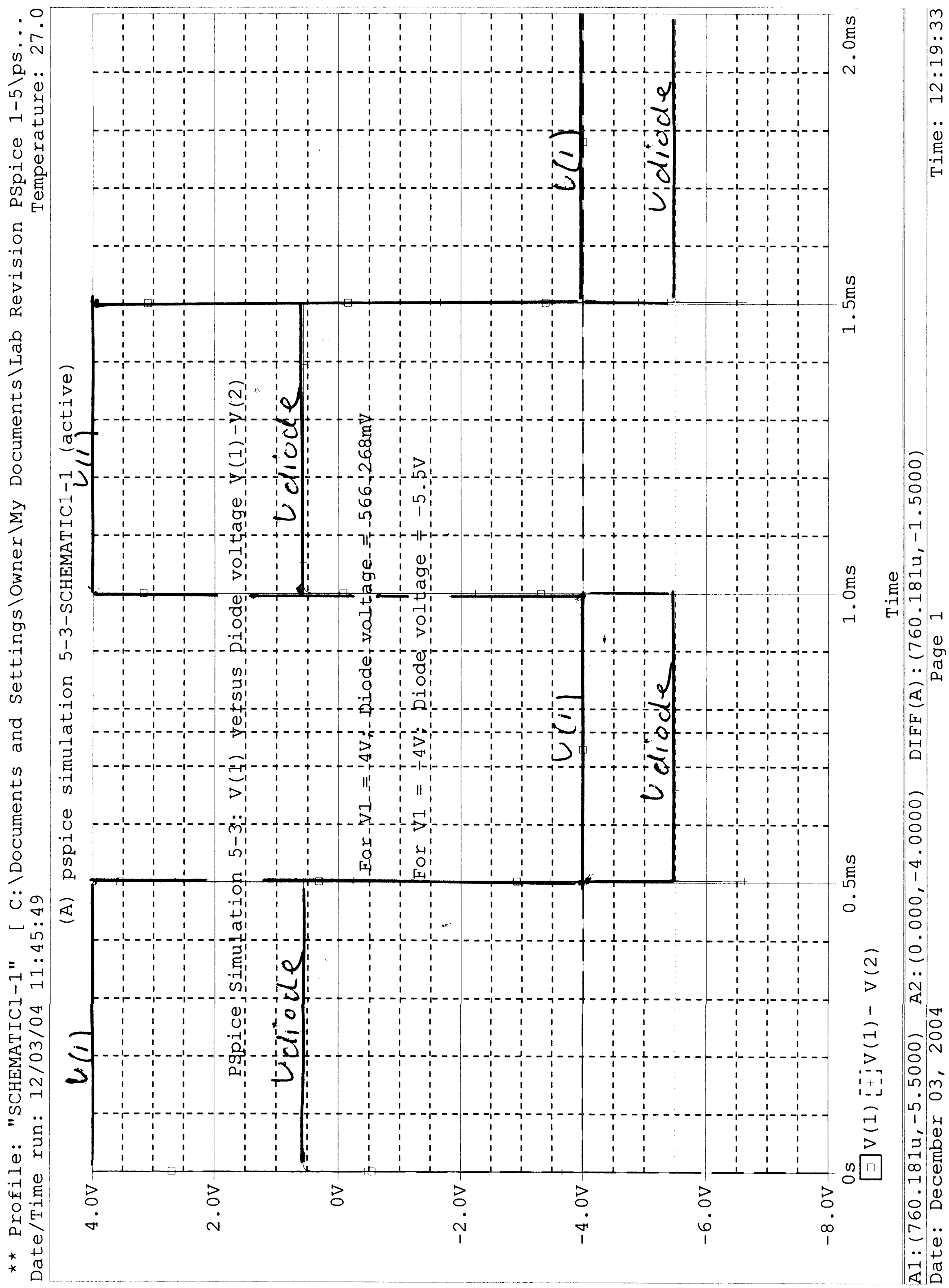
A1:(766.968u,-4.0000) A2:(0.000,-4.0000) DIFF(A):(766.968u,31.471u)
Date: December 03, 2004 Page 1 Time: 11:25:06

** Profile: "SCHEMATIC1-1" [C:\Documents and Settings\Owner\My Documents\Lab Revision PSpice 1-5\ps...
Date/Time run: 12/03/04 11:45:49 Temperature: 27.0

(A) pspice simulation 5-3-SCHEMATIC1-1 (active)



A1:(753.394u,-31.494u) A2:(764.706u,-4.0000) DIFF(A):(-11.312u,4.0000)
Date: December 03, 2004 Page 1 Time: 11:56:29


** Profile: "SCHEMATIC1-1" [C:\Documents and Settings\Owner\My Documents\Lab Revision PSpice 1-5\ps...
Date/Time run: 12/03/04 11:45:49
Temperature: 27.0
(A) pspice simulation 5-3-SCHEMATIC1-1 (active)
PSpice Simulation 5-3: V(1) versus Diode voltage V(1)-V(2)
For V1 = 4V; Diode voltage = 566.268mV
For V1 = -4V; Diode voltage = -5.5V
V(1)
Vdiode
4.0V
2.0V
0V
-2.0V
-4.0V
-6.0V
-8.0V
0s
0.5ms
1.0ms
1.5ms
2.0ms
V(1) V(1)- V(2)
Time
A1:(760.181u,-5.5000) A2:(0.000,-4.0000) DIFF(A):(760.181u,-1.5000)
Date: December 03, 2004
Page 1
Time: 12:19:33

EXPERIMENT 6: CLAMPING CIRCUITS

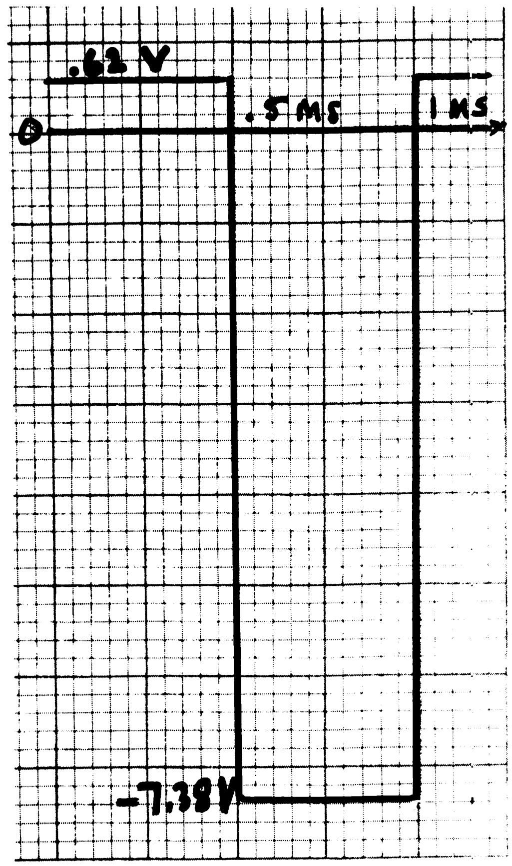
Part 1: Threshold Voltage
V_T = .62 V

Part 2: Clampers (*R*, *C*, Diode Combination)

b. V_C(calculated) = 4 – 0.62 = 3.38 V
V_O(calculated) = 0.62 V

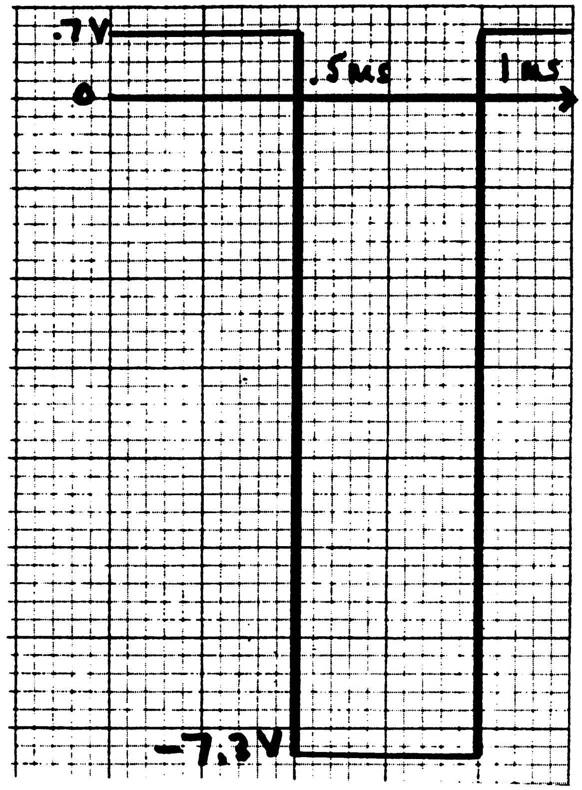
c. V_O(calculated) = –4 – 3.38 V = –7.38 V

d. **Fig 6.2**



Vertical sensitivity = 1 V/cm
Horizontal sensitivity = .2 ms/cm

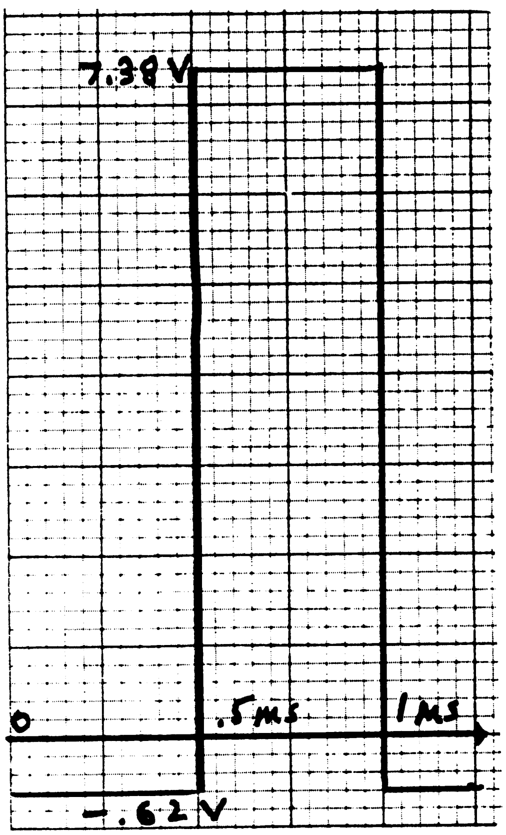
e. **Fig 6.3**



f. V_C(calculated) = –3.38 V
V_O(calculated) = –0.62 V

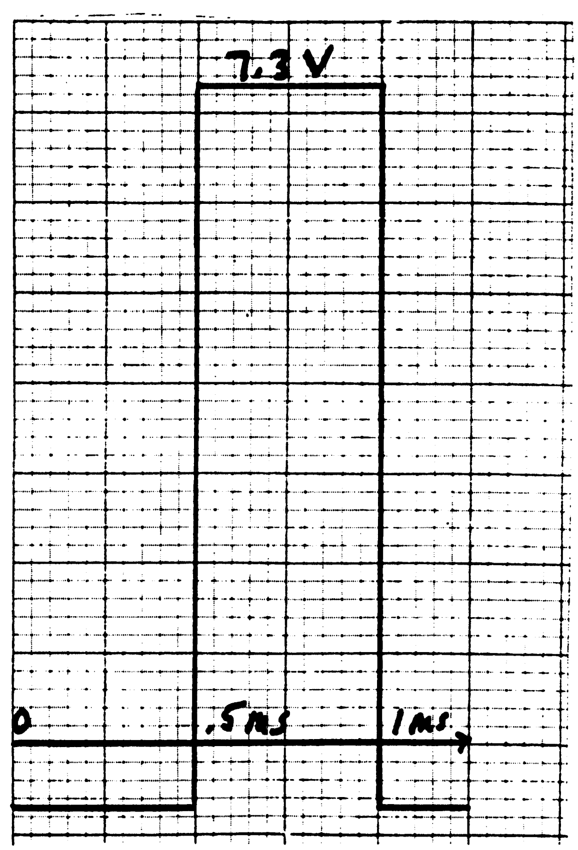
g. V_O(calculated) = 7.38 V

h. **Fig 6.4**



Vertical sensitivity = 1 V/cm
Horizontal sensitivity = .2 ms/cm

i. **Fig 6.5**

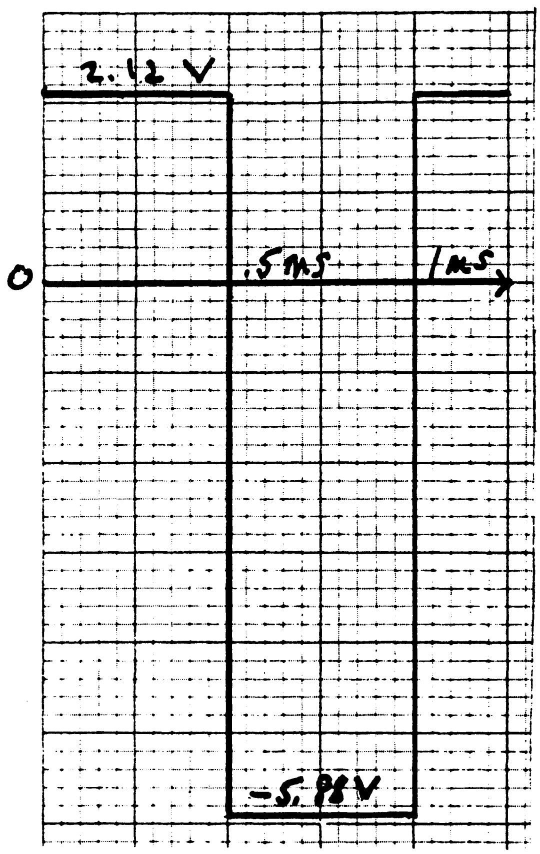


Part 3: Clampers with a DC battery

b. V_C(calculated) = 1.88 V
V_O(calculated) = 0.62 V + 1.5 V = 2.12 V

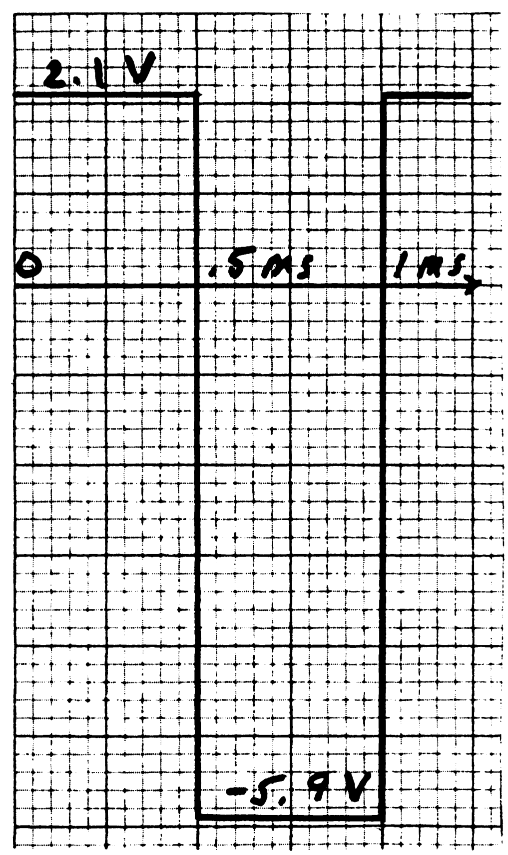
c. V_O(calculated) = –1.88 V – 4 V = –5.88 V

d. **Fig 6.7**



Vertical sensitivity = 1 V/cm
Horizontal sensitivity = .2 ms/cm

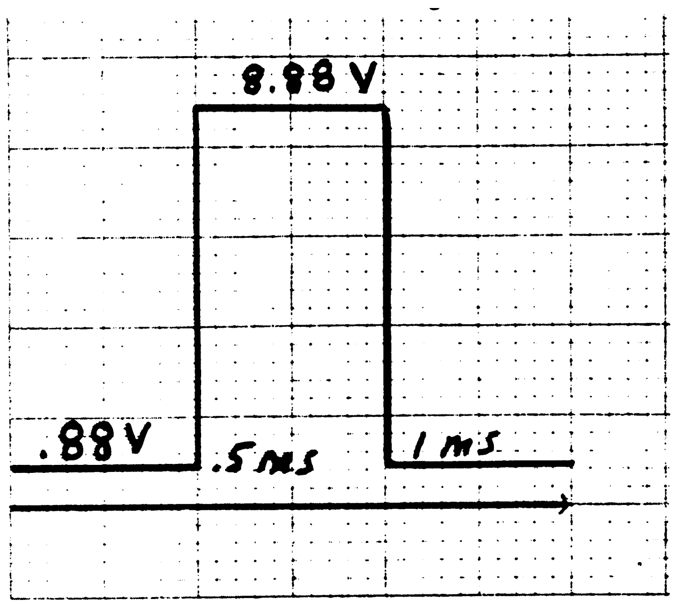
e. **Fig 6.8**



f. V_C(calculated) = 4.88 V
V_O(calculated) = 1.5 V – 0.62 V = 0.88 V

g. V_O(calculated) = 4 V + 4.88 V = 8.88 V

h. **Fig 6.9**

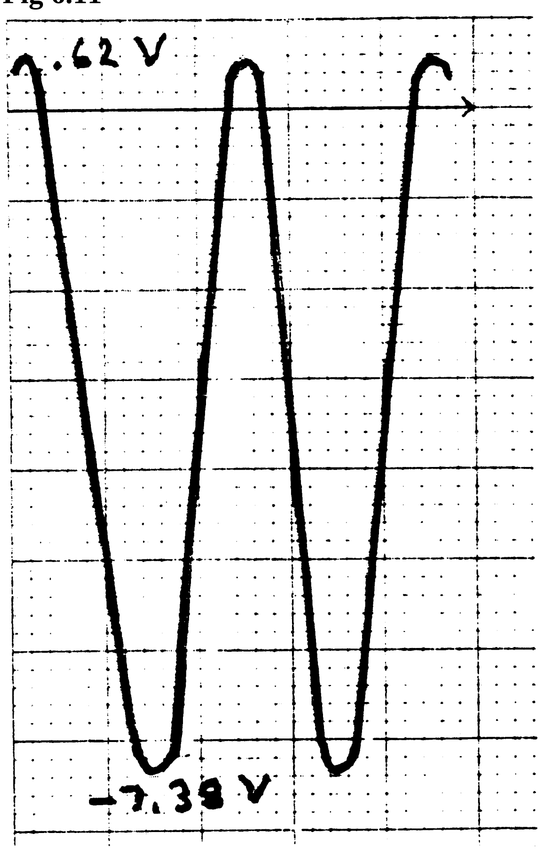


Vertical sensitivity = 2 V/cm
Horizontal sensitivity = .2 ms/cm

Part 4: Clampers (Sinusoidal Input)

b. V_O(calculated) = 0 V when V_i = 2 V
V_O(calculated) = –2 V when V_i = –3.6 V
V_O(calculated) = –1.6 V when V_i = 0 V

Fig 6.11



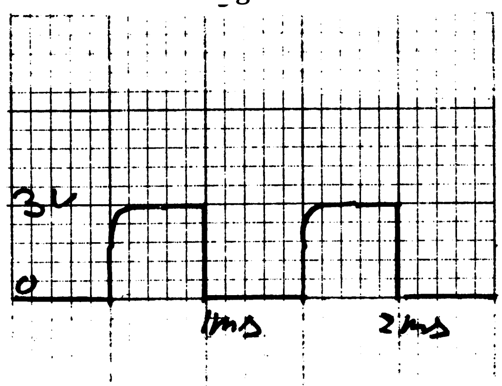
Vertical sensitivity = 1 V/cm
Horizontal sensitivity = .2 ms/cm

Part 5: Clampers (Effect of R)

a. Tau(calculated) = R*C = 103 ms
b. T(calculated) = 1/f = 1 ms
   T/2(calculated) = 1 ms/2 = .5 ms
c. 5Tau(calculated) = 5*103 ms = 515 ms
d. otherwise the capacitor voltage will not remain constant
e. 5Tau(calculated) = 5 ms
f. 5 ms/.5 ms = 10

g.

Fig 6.13

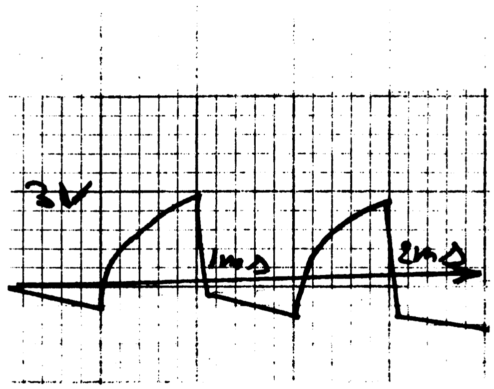


Vertical sensitivity = 1 V/cm
Horizontal sensitivity = .2 ms/cm

i. 5Tau = .5 ms
j. .5 ms/.5ms = 1

k.

Fig 6.14



Vertical sensitivity = 1 V/cm
Horizontal sensitivity = .2 ms/cm

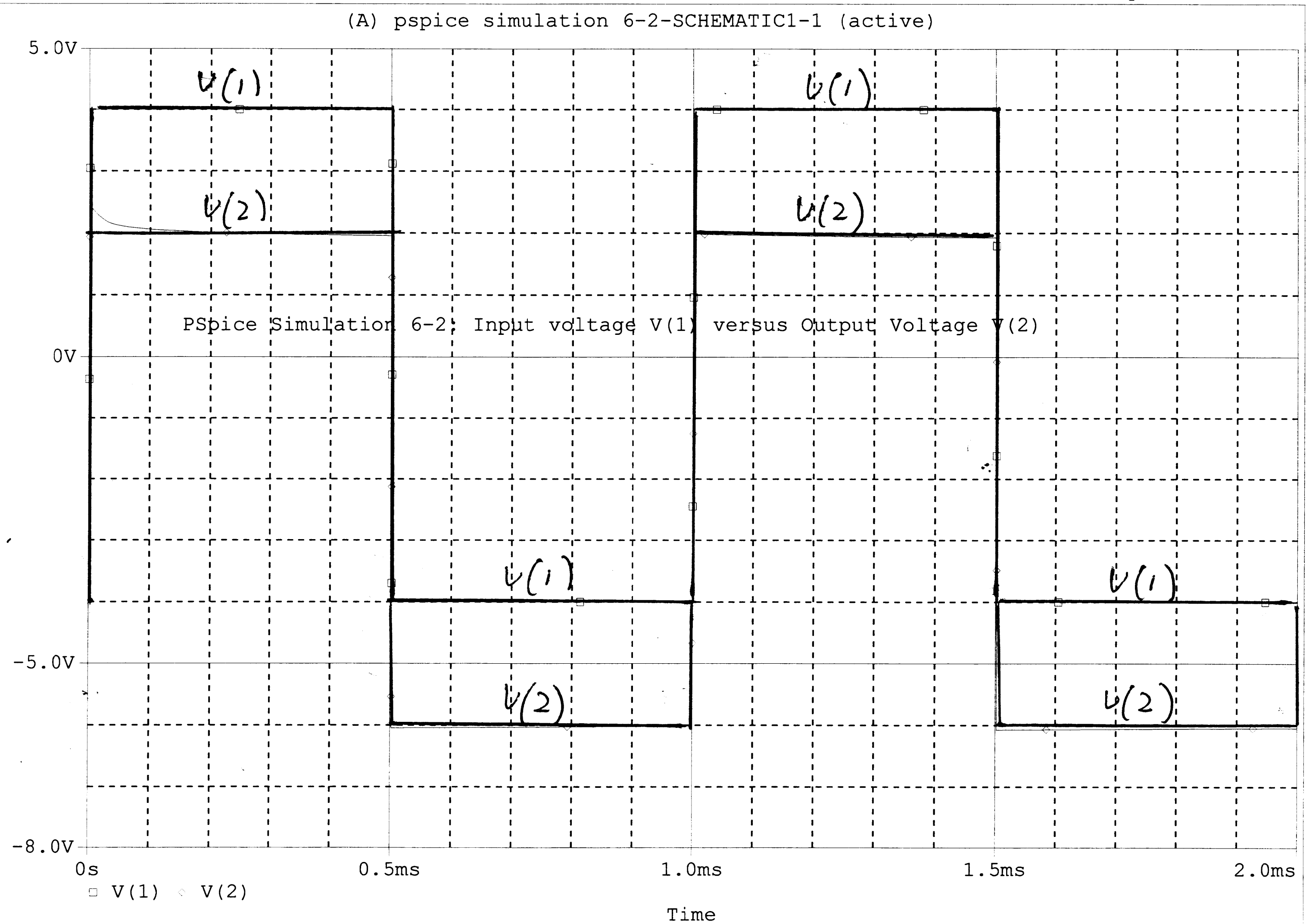
m. 5Tau = 2.5 T or Tau = 1/2 T

Part 6: Computer Exercise

PSpice Simulation 6-2

1. See Probe Plot page 220.
2. They are the same.
3. V_O(calculated) is close to $V(2)$ of Probe plot.
4. See Probe plot page 221.
5. $V(1, 2)$ remains at 2 V during the cycle of $V(1)$
6. It rises exponentially toward its final value of 2 V.
7. See Probe plot page 222.

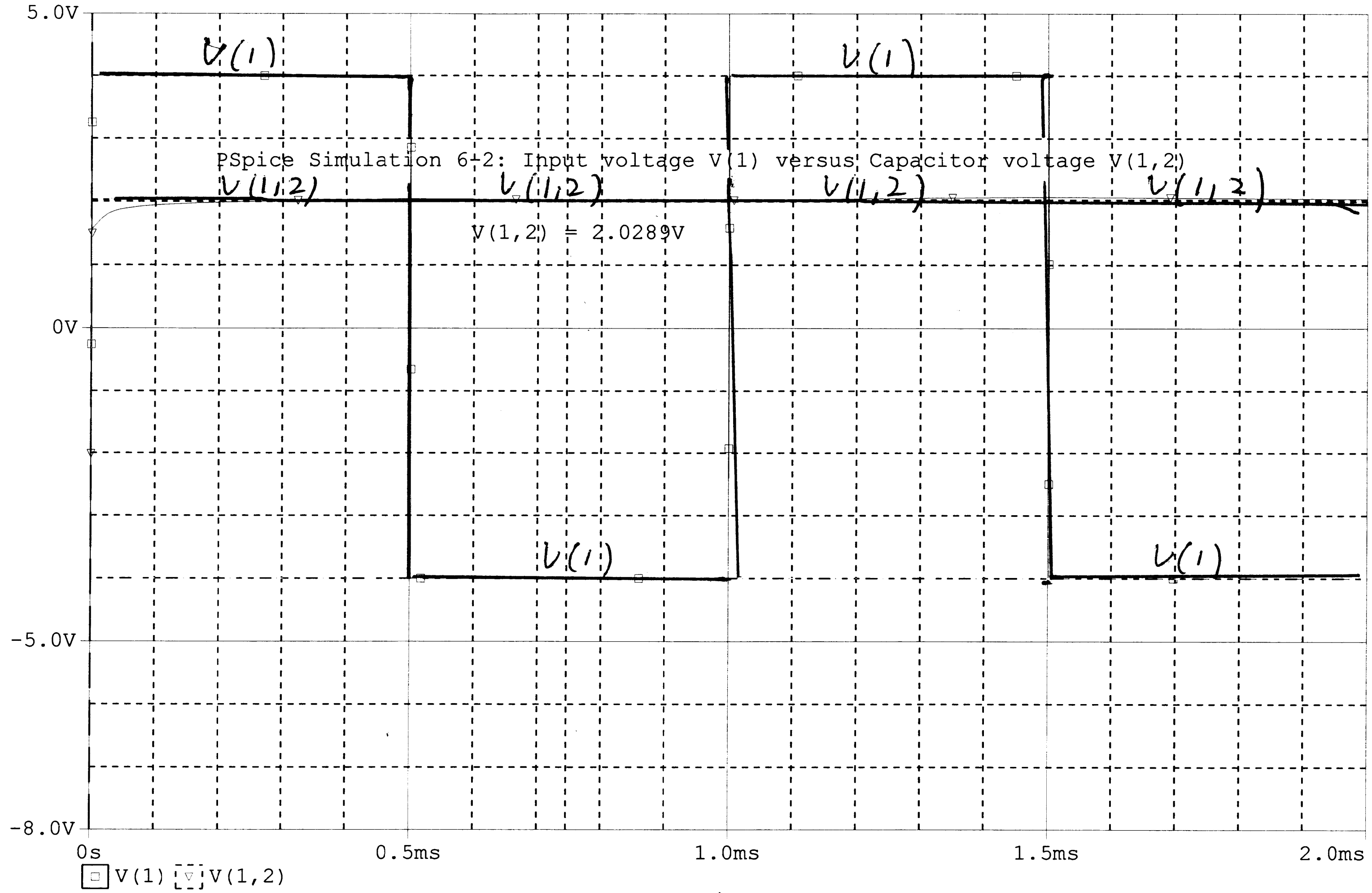
** Profile: "SCHEMATIC1-1" [C:\Documents and Settings\Owner\My Documents\Lab Revision 6-10\pspice s...
Date/Time run: 12/03/04 13:36:15 Temperature: 27.0



Date: December 03, 2004 Page 1 Time: 13:40:19

** Profile: "SCHEMATIC1-1" [C:\Documents and Settings\Owner\My Documents\Lab Revision 6-10\pspice s...
Date/Time run: 12/03/04 13:36:15 Temperature: 27.0

(A) pspice simulation 6-2-SCHEMATIC1-1 (active)



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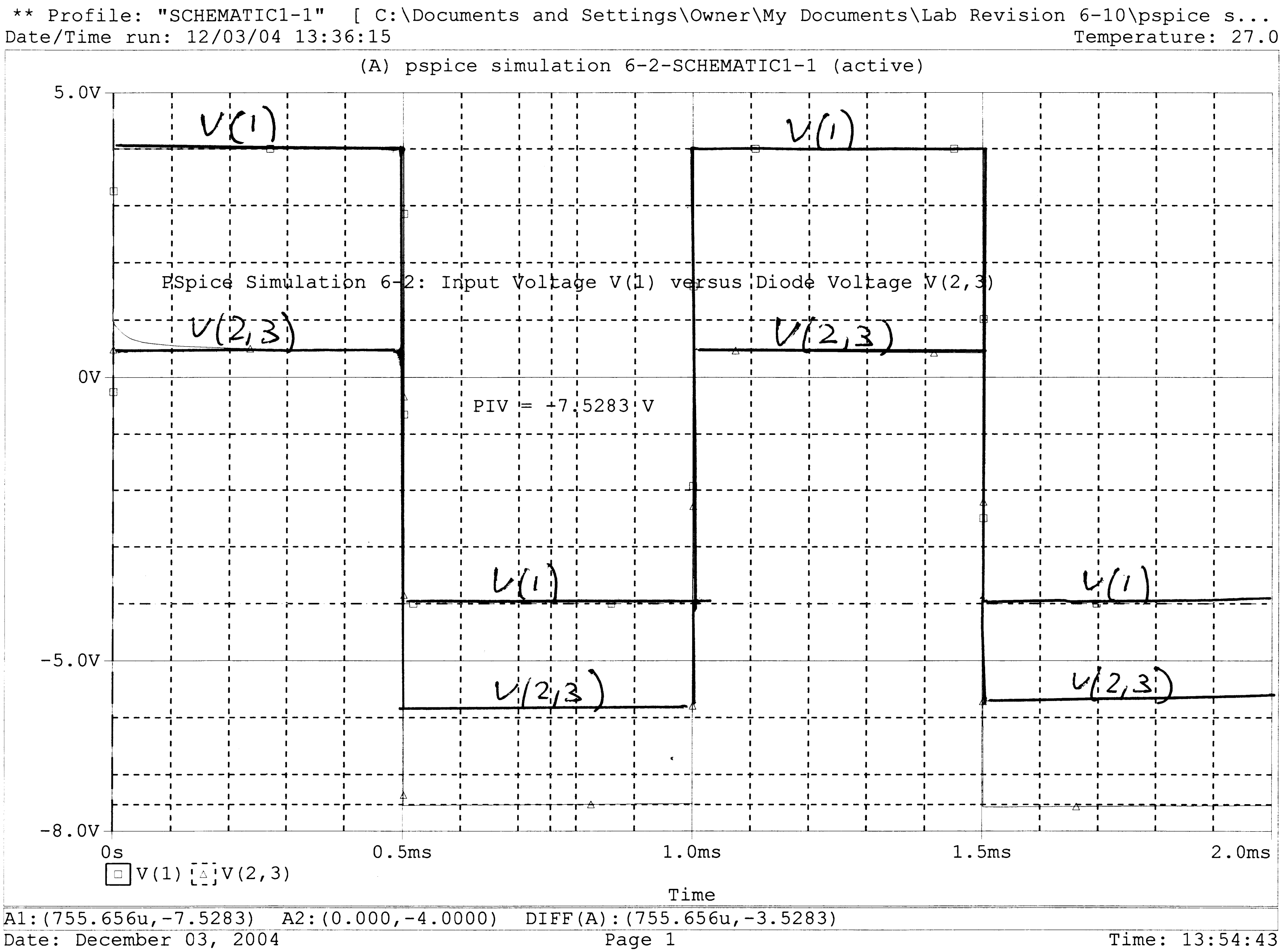
Date: December 03, 2004 Page 1 Time: 13:47:13


** Profile: "SCHEMATIC1-1" [C:\Documents and Settings\Owner\My Documents\Lab Revision 6-10\pspice s...
Date/Time run: 12/03/04 13:36:15
Temperature: 27.0
(A) pspice simulation 6-2-SCHEMATIC1-1 (active)
PSpice Simulation 6-2: Input Voltage V(1) versus Diode Voltage V(2,3)
PIV = -7.5283 V
5.0V
0V
-5.0V
-8.0V
0s
0.5ms
1.0ms
1.5ms
2.0ms
V(1)
V(2,3)
V(1)
V(2,3)
V(1)
V(2,3)
V(1)
V(2,3)
□ V(1) △ V(2,3)
Time
A1:(755.656u,-7.5283) A2:(0.000,-4.0000) DIFF(A):(755.656u,-3.5283)
Date: December 03, 2004
Page 1
Time: 13:54:43

EXPERIMENT 7: LIGHT-EMITTING AND ZENER DIODES

Part 1: LED Characteristics

b. V_D(measured) = 1.6 V
V_R(measured) = 49.1 mV
I_D(calculated) = 49.1 mV/101.4 ohms = 484 μA

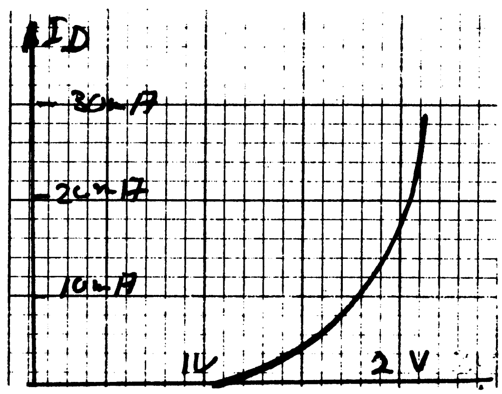
c. V_D(measured) = 1.9 V
V_R(measured) = 1.55 V
I_D(calculated) = 1.55 V/101.4 ohms = 15.3 mA

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

e.

Fig 7.2



h. The reversed biased Si diode prevents any current from flowing through the circuit, hence, the LED will not light.

k. V_R(V) = 3.48 V, therefore I_D(mA) = 1.6 mA and LED is in the "good brightness" region.

Part 2: Zener Diode Characteristics

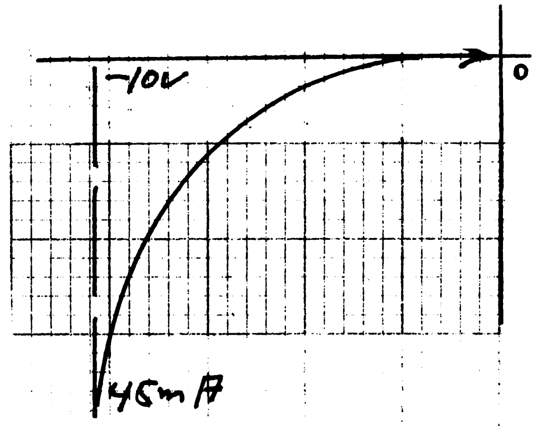
b. and c.

Table 7.2

E (V)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
V_Z (V)	0	1	2	3	4	5	6	7	8	9	10	10	10.1	10.2	10.3	10.4
V_R (V)	0	0	0	0	0	0	0	0	0	.1	.97	1.9	2.8	3.7	4.6	4.6
I_Z (mA)	0	0	0	0	0	0	0	0	0	.99	9.6	18.7	27.6	36.5	45.4	45.4

d.

Fig 7.5



e. V_Z(V) (approximated) = (10.4 + 9)/2 = 9.7 V

f. r_{av}(ohms) = (10.4 – 9)/(.045 – .0099) = 39.9 ohms

g. R_Z(ohms) = 39.9 ohms
V_Z(V) = 9.7 V

Part 3: Zener Diode Regulation

a. R (meas) = 979 ohms
R_L (meas) = 986 ohms
V_Z (V) = 10.2 V

b. V_L (V) = 986*15/(979 + 986) = 7.53 V
V_R (V) = 979*15/(979 + 986) = 7.47 V
I_R (mA) = 7.47/979 = 7.64 mA
I_L (mA) = 7.53/986 = 7.63 mA
I_Z (mA) = $I_R - I_L$ = 10 μA

c. V_L (measured) = 7.5 V
V_R (measured) 7.49 V
I_R (calculated) = 7.65 mA
I_L (calculated) = 7.60 mA
I_Z (calculated) = 50 μA

d. V_L (calculated) = 11.5 V
V_R (calculated) 3.54 V
I_R (calculated) = 3.62 mA
I_L (calculated) = 3.48 mA
I_Z (calculated) = .14 mA

e. V_L (measured) = 9.82 V
V_R (measured) = 3.54 V
I_R (calculated) = 3.54 mA
I_L (calculated) = 2.98 mA
I_Z (calculated) = .56 mA

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. $R_{min}/(R_{min} + 979)*15 = 9.82$ V
R_L(calculated) = 1.86 Kohms

g. Since 2.2 Kohms > R_{min} = 1.86 Kohms, therefore, diode is in the "on" state.

Part 4: LED-Zener diode combination

b. V_D = 1.86 V
I_D = 15.8 mA
V_Z = 10.07 V
V_{ab}(calculated) = 11.9 V

c. V_L (calculated) = 11.9 V
I_L (calculated) = 5.41 mA

e. E (calculated) = $V_R + V_L$ = 6.93 + 11.9 = 18.9 V

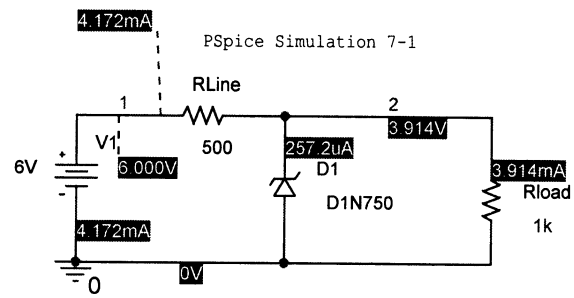
f. E (measured) = 19.1 V

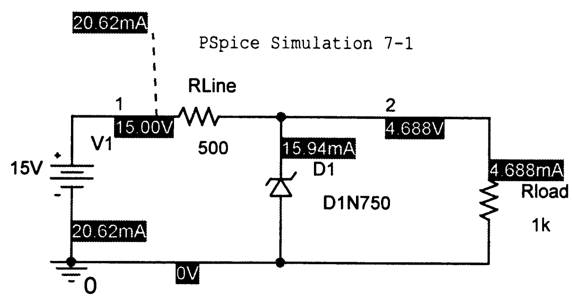
The two values are in agreement within 1.06% using E (calculated) as reference.

Part 5: Computer Exercise

PSpice Simulation 7-1

1. – 8. See Circuit diagram





9. Yes

EXPERIMENT 8: BIPOLAR JUNCTION TRANSISTOR (BJT) CHARACTERISTICS

Part 2: The Collector Characteristics

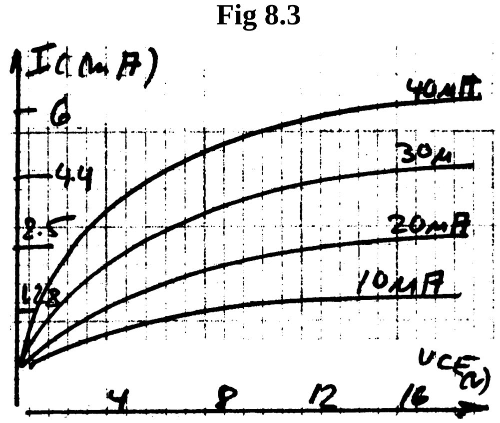
d., f., g., h.

Table 8.3

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.

Fig 8.3



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}.

Part 5: Exercises

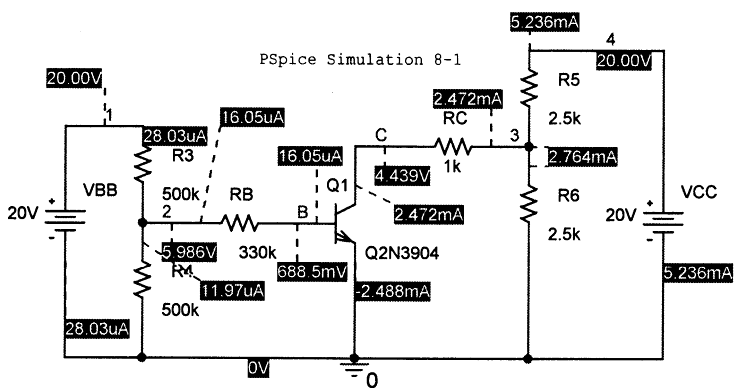
1. Beta(average) = 141
The arithmetic average occurred in the center of Fig 8.3.

2. $V_{BE(\text{average})}$ = .678 V
Given that .7 V 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.
Beta would be a constant anywhere along that line.

Part 6: Computer Exercise
PSpice Simulation 8-1

1. See Circuit diagram.



2.

	Experimental	PSpice
α	.99	.99
β	150	208

EXPERIMENT 9: FIXED- AND VOLTAGE-DIVIDER BIAS OF BJTs

Part 1: Determining β

b. V_{BE}(measured) = .67 V
V_{RC}(measured) = 4.9 V

c. $I_B = (V_{CC} - V_{BE})/R_B$ = (20 – .67)/1.108 M = 17.4 μA
$I_C = V_{RC}/R_C$ = 4.9/2.73 K = 1.79 mA

d. Beta I_C/I_B = 1.79 mA/17.4 μA = 105

Part 2: Fixed-bias configuration

a. I_B(calculated) = 17 μA
I_C(calculated) = 1.79 mA

b. V_B(calculated) = $V_{CC} - I_B * R_B$ = .67 V
V_C(calculated) = $V_{CC} - I_C * R_C$ = 13.4 V
V_E(calculated) = 0 V(emitter is at ground)
V_{CE}(calculated) = $V_C - V_E$ = 13.4 V

c. V_B(measured) = .67 V
V_C(measured) = 13.4 V
V_E(measured) = 0 V
V_{CE}(measured) = 13.34 V
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) = .68 V
V_{RC}(measured) = 16.7 V
I_B(from measured) = 17.4 μA
I_C(from measured) = 6.12 mA
Beta(calculated) = 352

Table 9.1

Transistor Type	V_{CE} (V)	I_C (mA)	I_B (μA)	β
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

2N3904	I_E (mA)	I_C (mA)	I_B μA)
(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)	I_B (μA)	Beta
2N3904	10.1	3.87	36.5	103
2N4401	9.6	4.03	17.2	234

f.

Table 9.5

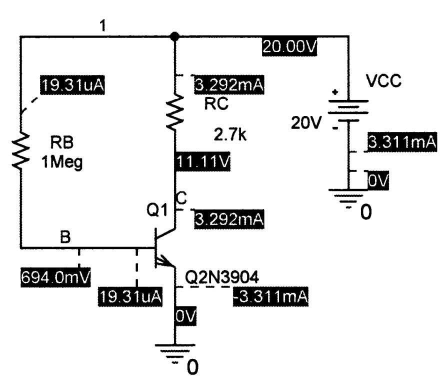
% Δ β	% Δ I_C	% Δ V_{CE}	% Δ I_B
56	41	4.9	53

Part 4: Computer Exercises

PSpice Simulation 9-1

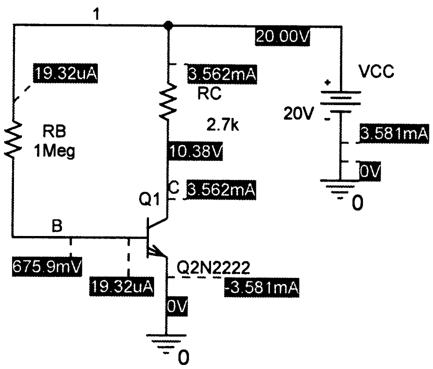
1.-3. See circuit diagram.

PSpice Simulation 9-1



4. See circuit diagram.

PSpice Simulation 9-1



5. 8.24%

6. $\%\Delta I_B = 0.05\%$
$\%\Delta I_C = 8.2\%$
$\%\Delta I_E = 8.15\%$

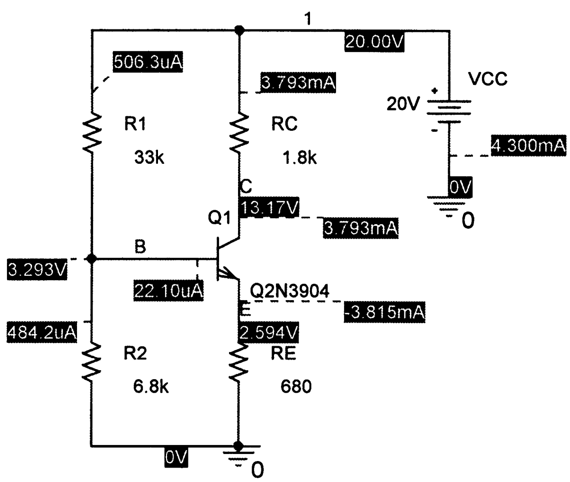
7. $\%\Delta V_{CE} = -6.57\%$

8. $S(\beta) = .995$

PSpice Simulation 9-2

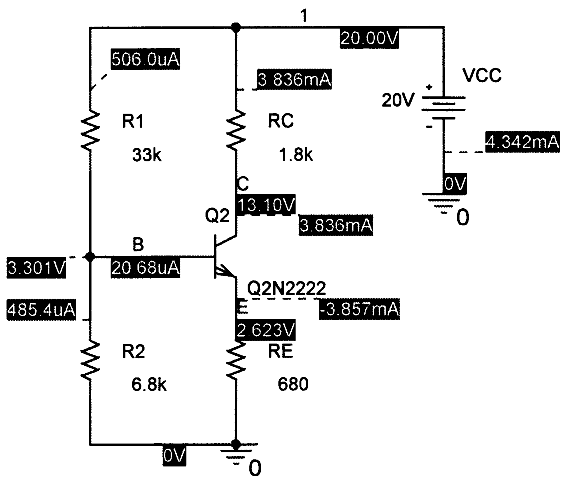
1.-3. See circuit diagram.

PSpice Simulation 9-2



4. See circuit diagram.

PSpice Simulation 9-2



5. $\%\Delta\beta = 8.24\%$
6. $\%\Delta I_B = -6.47\%$
   $\%\Delta I_C = 1.13\%$
   $\%\Delta I_E = 1.10\%$
7. $\%\Delta V_{CE} = -0.94\%$
8. $S(\beta) = \dfrac{1.13\%}{8.24\%} = 0.13$
9. Circuit with Q2N2222.
10. Same as #9.
11. Same as #9.

Part 5: Problems and Exercises

1. a. $I_{C(\text{sat, fixed bias})} = 20/2.73\text{ K} = 7.33\text{ mA}$

   b. $I_{C(\text{sat,volt-divider bias})} = 20/(1.86\text{ K} + 692) = 7.83\text{ mA}$

   c. 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).

3. a.

Table 9.6

Fixed bias	$\%\Delta I_C$	$\%\Delta V_{CE}$	$\%\Delta I_B$
	$\%\Delta\beta$	$\%\Delta\beta$	$\%\Delta\beta$
	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.

4. a. $I_C = \beta(V_{CC} - .67)/R_B$ mA

b. $I_C = [R_2/(R_1 + R_2)*V_{CC} - .7]/[(R_1 \parallel R_2)/\beta + R_E]$ mA

c. In equation 4a, the Beta factor cannot be eliminated by a judicious choice of circuit components. In 4b however, if the quantity $R_1 \parallel R_2/\beta$ is made much smaller than R_E, then I_C is no longer dependent upon Beta. In particular:

$$I_C = [R_2/(R_1 + R_2)*V_{CC} - .7]/R_E \text{ mA}$$

In that case, we have achieved Beta independent biasing.

EXPERIMENT 10: EMITTER AND COLLECTOR FEEDBACK BIAS OF BJTs

Part 1: Determination of β

b. V_B (measured) = 5.04 V
V_{RC} (measured) = 4.04 V

c. I_B (from measured) = (20 – 5.41)/1.1 M = 13.6 μA
I_C (from measured) = 4.04/2.2 K = 1.84 mA

d. β = 1.84 mA/13.6 μA = 135

Part 2: Emitter-bias configuration

a. Using KVL:

$-20 + I_C * (1.01\ M/\beta) + .67\ V + I_C * (2.23\ K) = 0\ V$
therefore: $I_C = (20 - .67)/9.1\ K = 2.1\ mA$
$I_B = 2.1\ mA/135 = 15\ \mu A$

b. and c.

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 (μA)	I_C (mA)			
2N3904	15.0	2.1			
2N4401	11.7	3.3			
Measured Values					
Transistor type	V_B (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	4.8
Transistor type	I_B (μA)	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

% $\Delta\beta$	% ΔI_C	%ΔV_{CE}	% ΔI_B
90.7	54.5	–58.5	–19

Part 3: Collector Feedback Configuration (R_E = 0 ohms)

b. Using KVL:
$-20 + I_C(3.2\text{ K}) + I_C(395\text{ K})/150 + .7\text{ V} = 0\text{ V}$
from which: $I_B = 21\ \mu$A and $I_C = 3.4$ mA

Table 10.4

Calculated Values					
Transistor type	V_B (V)	V_C (V)	V_{CE} (V)	I_B (μA)	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 (μA)	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

% $\Delta\ \beta$	% ΔI_C	% ΔV_{CE}	% ΔI_B
83	22.8	–39.9	–33

Part 4: Collector Feedback Configuration (with R_E)

a. For 2N3904:
$-20 + I_C(3.2\text{ K}) + I_C(395\text{ K}/150) + I_C(2.2\text{ K}) = 0\text{ V}$
from which: $I_B = 15\ \mu$A and $I_C = 2.4$ mA

for 2N4401:
$-20 + I_C(3.2\text{ K}) + I_C(395\text{ K}/286) + I_C(2.2\text{ K}) = 0\text{ V}$
from which: $I_B = 9.7\ \mu$A and $I_C = 2.8$ mA

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 (μA)
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 (μA)
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

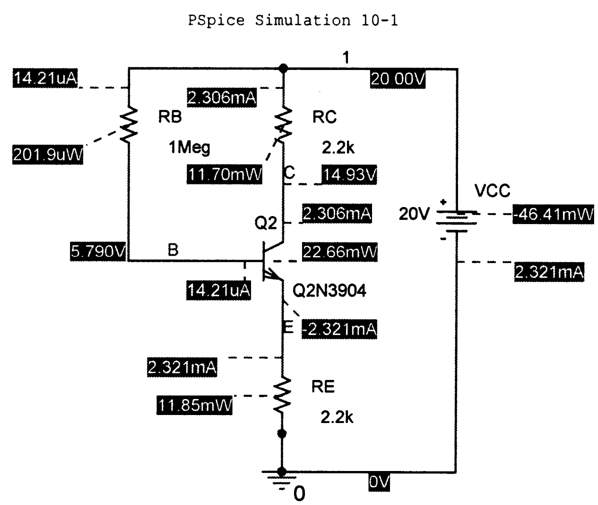
Table 10.9

% Δ β	% Δ I_C	% Δ V_{CE}	% Δ I_B
83.2	23.8	–41.2	–50.3

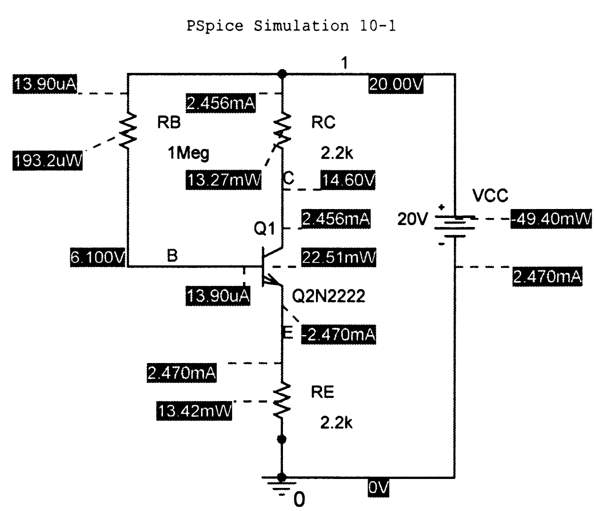
Part 5: Computer Exercises

PSpice Simulation 10-1

1–6. See Circuit diagram.



7. See Circuit diagram.



8. $\%\Delta\beta = 8.87\%$

9. $\%\Delta I_B = -2.18\%$
 $\%\Delta I_C = 6.50\%$
 $\%\Delta I_E = 6.42\%$

10. $\%\Delta V_{CE} = -7.43\%$

11. $S(\beta) = .73$

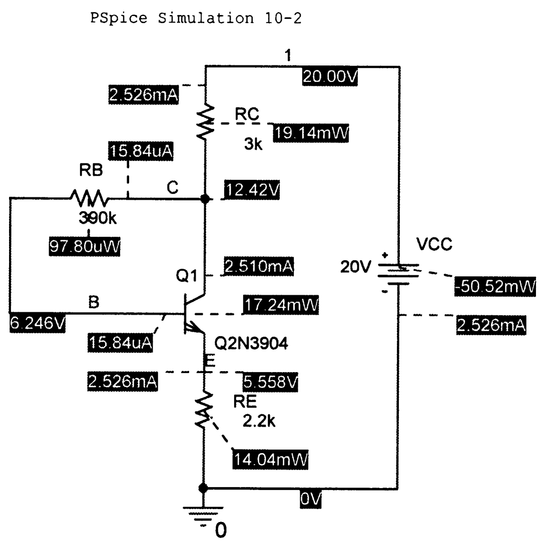
12. P(Q2N3904) = 46.41 mW
 P(Q2N2222) = 49.40 mW
 Yes

13. Yes, see circuit diagram above.

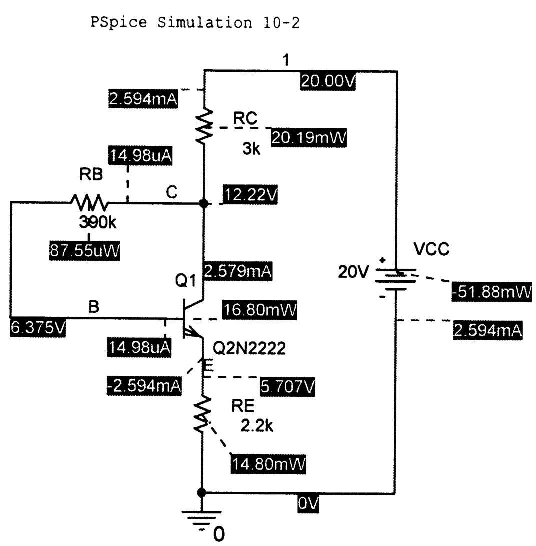
14. Yes, see circuit diagram above.

PSpice Simulation 10-2

1–6. See Circuit diagram.



7. See Circuit diagram.



8. $\%\Delta\beta = 8.64\%$
9. $\%\Delta I_B = -5.43\%$
$\%\Delta I_C = 2.75\%$
$\%\Delta I_E = 2.69\%$
10. $\%\Delta V_{CE} = -4.96\%$
11. $S(\beta) = .32$
12-14. See circuit diagrams above.

Part 6: Problems and Exercises

1. a. $I_{C(\text{sat})}$ 20/(2.2 K + 2.2 K) = 4.55 mA

   b. $I_{C(\text{sat})}$ = 20/3 K = 6.67 mA

   c. $I_{C(\text{sat})}$ = 20/5.2 K = 3.85 mA

   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	$\frac{\% \Delta I_C}{\% \Delta \beta}$	$\frac{\% \Delta V_{CE}}{\% \Delta \beta}$	$\frac{\% \Delta I_B}{\% \Delta \beta}$

   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 R_E = 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:
$-V_{CC} + I_C/\beta{*}R_B + V_{BE} + I_C{*}R_E = 0$ V
from this:
$I_C = (V_{CC} - V_{BE})/(R_B/\beta + R_E)$ mA
This division results in:

$I_C = \beta(V_{CC} - V_{BE})/(R_B + \beta{*}R_E)$ mA
If $\beta{*}R_E >> R_B$ then $I_C = (V_{CC} - V_{BE})/R_E$ mA

5. Using KVL:
$-V_{CC} + I_C{*}R_C + I_C/\beta{*}R_B + V_{BE} = 0$ V
from this:
$I_C = (V_{CC} - V_{BE})/(R_C + R_B/\beta)$
if $R_C >> R_B/\beta$ then $I_C = (V_{CC} - V_{BE})/R_C$ mA
6. Using KVL:
$-V_{CC} + I_C{*}R_C + I_C/\beta{*}R_B + V_{BE} + I_C{*}R_E = 0$ V
from this:
$I_C = (V_{CC} - V_{BE})/(R_C + R_E + R_B/\beta)$ 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: Collector-Feedback Configuration

a. R_C = (15 – 7.5)V/5 mA = 1.5 Kohms
R_C(commercial) = 1.5 ohms

d. V_{RC}(measured) = 5.14 V
V_{CEQ}(measured) = 7.7 V
I_{CQ}(from measured) = 3.4 mA
β(calculated) = 104

e. The most critical values for proper operation of this design is the voltage V_{CEQ} measured at 7.7 V. It being within 2.7% of the design makes this a workable design.

f. $R_B/(\beta * R_C)$ = 214 K/(104*1.5 K) = 1.37

g. $R_{F1} + R_{F2}$ = 189 K
R_B(commercial) + 214 K

h. No, the value of R_B is fixed both by V_{CC} and V_{BE}, neither of which changed.

i. V_{RC}(measured) = 5.64 V
V_{CEQ}(measured) = 9.27 V
I_{CQ}(from measured) = 3.76 mA
β(calculated) = 3.73 mA/([9.27 – .7)/214 K] = 108

j. The measured voltage V_{CE} is somewhat high due to the measured current I_C being below its design value. In general, the lowest I_C which will yield proper V_{CE} 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) = 214 K/(108*1.5 K) = 1.4
$R_B/(\beta * R_C)$(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. $S(\beta)$ = 3.76 mA – 3.4 mA)/3.4 mA = .8

Part 2: Emitter-bias Configuration

a. R_C(calculated) = [(V_{CC} – (7.5 + 1.5)]V/5 mA = 1.2 K
R_C(commercial) = 1.2 K

b. R_E(calculated) = 1.5 V/5 mA = 300 ohms
R_E(commercial) = 285 ohms

d. R_B(measured) = $R_1 + R_2$ = 392 K
R_B(commercial) = 394 K

e. V_{RC}(measured) = 6.04 V
V_{CE}(measured) = 7.55 V
I_C(from measured) = 4.7 mA
β(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) = 950 K
R_B(commercial) = 1 M

i. Yes, it changed from 214 K to a value of 950 K. 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) = 5.2 V
V_{CEQ}(measured) = 8.6 V
I_{CQ}(calculated) = 4.2 mA
β(calculated) = 372

k. The important voltage V_{CEQ} was measured at 8.61 V while it was specified at 7.5 V. Thus, it was larger by 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 Betas 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/5 mA = 1.2 K
R_C(commercial) = 1.25 K

b. R_E = 1.5 V/5 mA = 300 ohms
R_E(commercial) = 285 ohms

d. R_2(calculated) = 2.94 K
R_2(commercial) = 3.2 K
R_1(calculated) = 17.1 K
R_1(commercial) = 18.2 VK

e. V_{RC}(measured) = 6.47 V
V_{CEQ}(measured) = 7.09 V
I_{CQ}(calculated) = 5.2 mA
β(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. $R_1 \parallel R_2/(\beta^* R_E)$ = .066

g. V_{RC}(measured) = 6.98 V
V_{CEQ}(measured) = 6.47 V
I_{CQ}(calculated) = 5.6 mA
β(calculated) = 368

h. The measured values of the previous part show that the circuit design is relatively independent of Beta.

i. The Betas are about the same.

j. $R_1 \parallel R_2/(\beta^* R_E)_{(2N4401)}$ = .026
$R_1 \parallel R_2(\beta^* R_E)_{(2N3904)}$ = .066

k. $S(\beta)$ = .051

Part 4: Problems and Exercises

1.

Table 11.1

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 parameter for this design is the voltage V_{CEQ}. Given that its variation for the various designs is less than 10%, the results are satisfying.

2.

Table 11.2

Configuration	Stability factors	
	$R_B/(\beta R_C)$	$S(\beta)$
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 R_2, while decreasing the current gain of the circuit, stabilized the circuit in regard to any current changes.

3. Using KVL:

$-V_{CC} + I_C * R_C + I_C/\beta * R_B + V_{BE} = 0$ V
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:

$-V_{CC} + I_C/\beta * R_B + I_C * R_E + V_{BE} = 0$ V
from which: $I_C = (V_{CC} - V_{BE})/(R_E + R_B)/\beta)$ mA
for stable operation, make: $R_E >> R_B/\beta$

5. Using KVL:

$-V_{BB} + I_C/\text{Beta} * R_1 \parallel R_2 + V_{BE} + I_C * R_E = 0$ V
where: $V_{BB} = R_1/(R_1 + R_2) * V_{CC}$

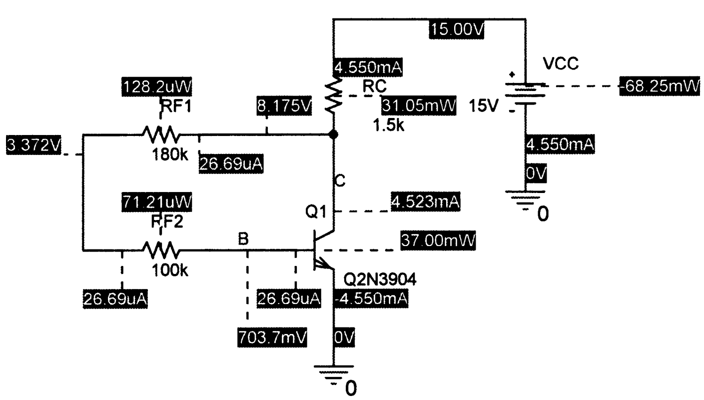
from which: $I_C = (V_{BB} - V_{BE})/(R_E + R_1 \parallel R_2/\beta)$ mA
for stable operation: make $R_E >> R_1 \parallel R_2/\beta$

Part 5: Computer Exercises

PSpice simulation 11-1

1. See Circuit diagram.

PSpice Simulation 11-1

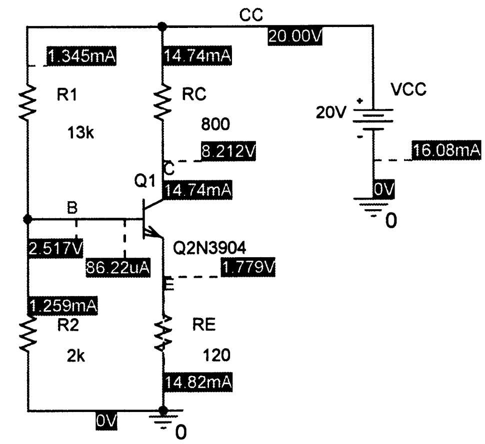


2. $\beta = 170.5$
3. $S = 1.095$
4. Yes
5. See Circuit diagram above.

PSpice simulation 11-2

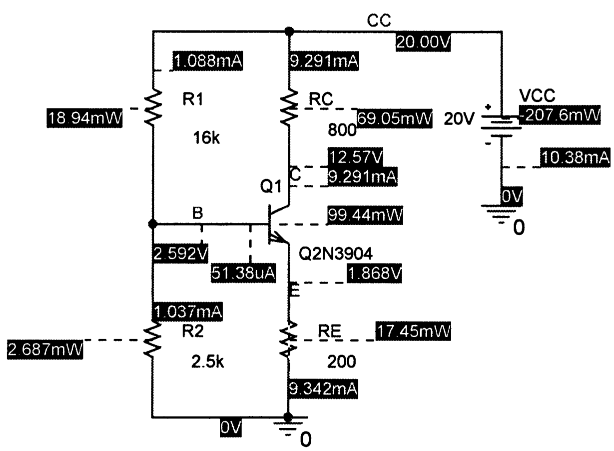
1. See Circuit diagram.

PSpice Simulation 11-2: The "bad" design.



2. β = 170.96
3. S = 0.08
4. No
5. See Circuit diagram.

PSpice Simulation 11-2: The "good" design.



6. Yes
7. Not needed
8. See circuit diagram above.

EXPERIMENT 12: JFET CHARACTERISTICS

Part 1: Measurement of the Saturation Current I_{DSS} and Pinch-off Voltage V_P

c. V_R(measured) = .754 V

d. ID_{SS} = 7.44 mA

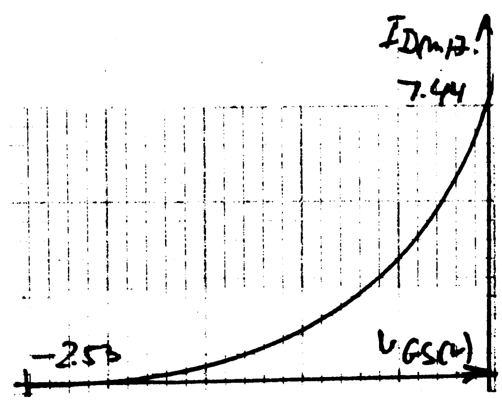
e. V_p(measured) = –2.53 V

f.

1. ID_{SS} = 8.3 mA, V_p = –3.1 V
2. ID_{SS} = 9.1 mA V_p = –3.9 V

It is extremely unlikely that two 2N4416 ever have the same saturation current and pinch-off voltage.

Fig 12.1



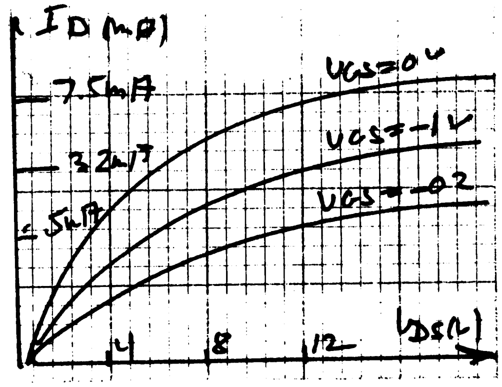
Part 2: Drain-Source Characteristics

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

Fig 12.3



ID_{SS} (Fig 12.3) = 7.5 mA
ID_{SS} (Part 1) = 7.44 mA
V_P (Fig 12.3) = –3 V
V_P(Part 1) = –2.53 V

Part 3: Transfer Characteristics

a. b.

Table 12.2

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 $V_{GS(\text{off})}$ are used.

Part 5: 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} = 10 mA; V_P = –5 V; and I_D = 4 mA
   V_{GS}(calculated) = $(-5)*[(.4)^{1/2}]$ = –3.16 V

   a. gm_O(calculated) = 2*(7.44 mA)/2.53 = 5.88 ms
   b. The slope of the Shockley curve is maximum at V_{GS} = 0 V.
   c. gm(calculated) = $gm_O(1 - V_P/V_P)$ = 0 S when $V_{GS} = V_P$.

   The slope of the transfer curve at $V_{GS} = V_P$ = 0 S d.

	$V_{GS}/V_P = 1/4$	$V_{GS}/V_P = 1/2$	$V_{GS}/V_P = 3/4$
g_m	4.41 mS	2.94 mS	1.47 mS
Note: $gm_0 = 5.88$ mS			

e. The slope is a constant value.

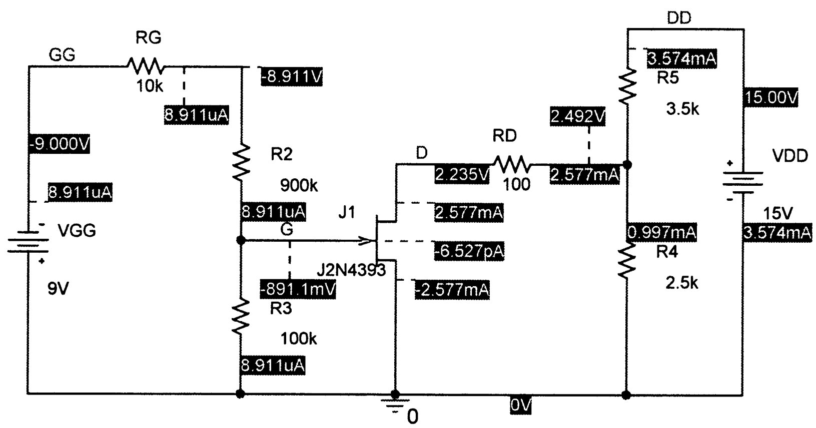
f. It is proportional to the derivative of Shockley's equation.

Part 6: Computer Exercises

PSpice Simulation 12-1

1-4. See Circuit diagram.

PSpice Simulation 12-1



PSpice Simulation 12-2

Part A

4. See Probe Plot page 247.

5. $I_{DSS} = 16$ mA

6. $V_P = -1.5$ V

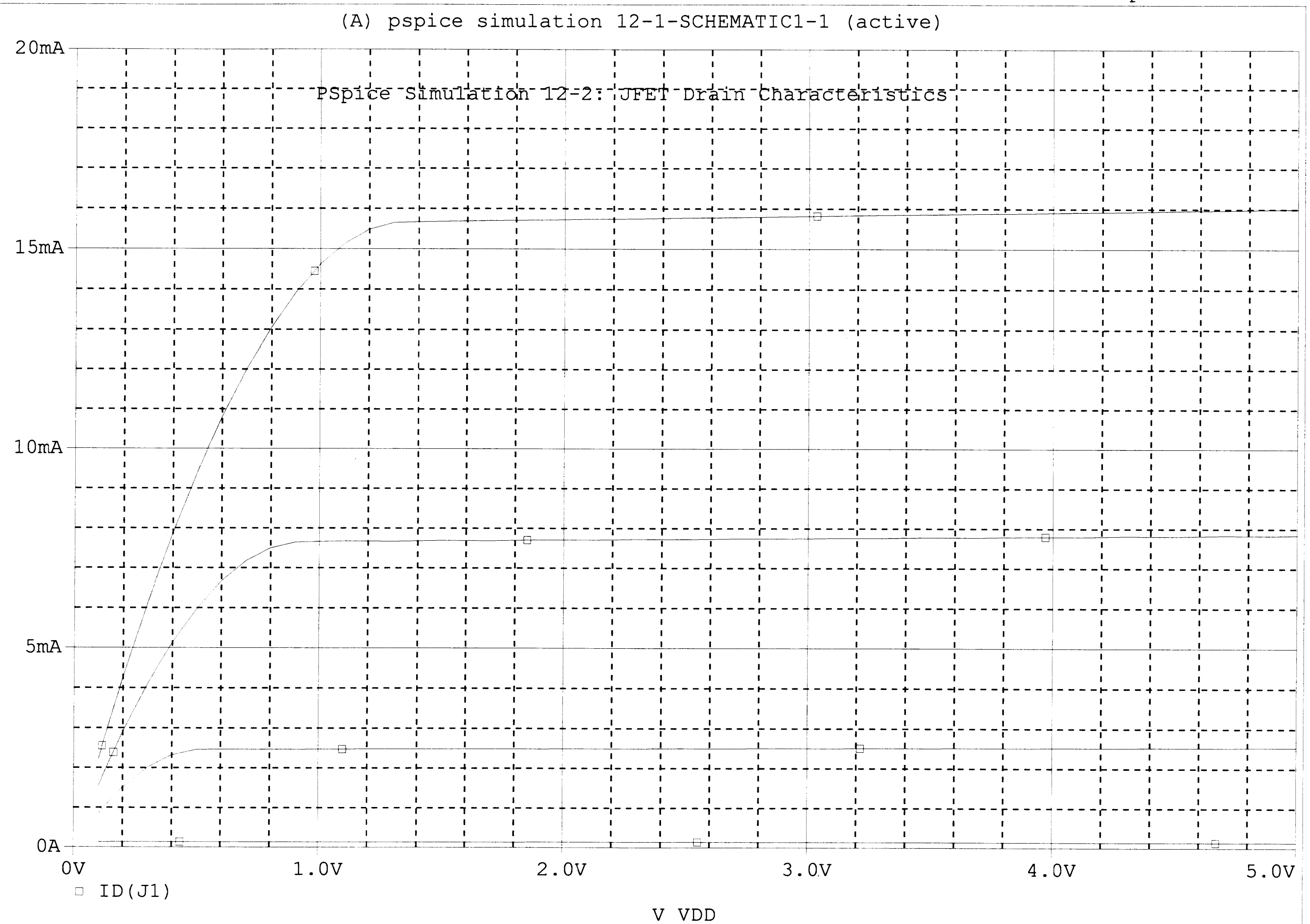
Part B

4. See Probe plot page 248.

5. $I_{DSS} = 18.2$ mA

$V_P = -1.4$ V

** Profile: "SCHEMATIC1-1" [C:\Program Files\OrcadLite\My Documents\Lab Revision PSpice 11-15\pspic...
Date/Time run: 11/22/04 12:18:52 Temperature: 27.0



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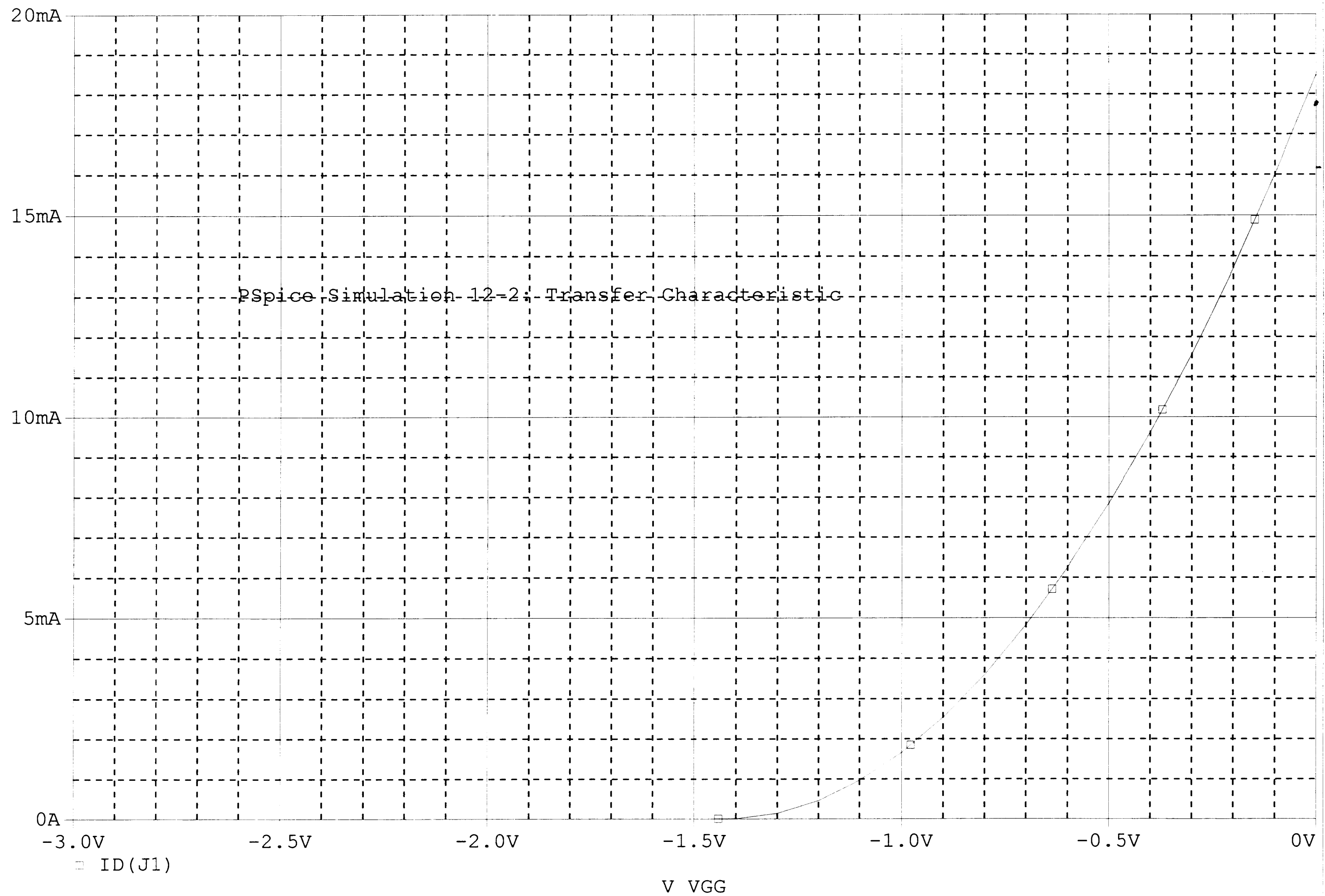
Date/Time run: 11/23/04 11:28:15 Temperature: 27.0

(A) pspice simulation 12-1-SCHEMATIC1-2 (active)



Date: November 23, 2004 Page 1 Time: 11:30:14

EXPERIMENT 13: JFET BIAS CIRCUITS

Part 1: Fixed-Bias Network

b. ID_{SS} = 12 mA
c. V_P(measured) = –6 V
e. $I_D = 12^{-3}(1 - 1/6)^{1/2}$ = 8.33 mA
f. V_{RD}(measured) = 8 V
   I_{DQ}(measured) = 8.2 mA
   R_D(measured) = 976 ohms

Part 2: Self-Bias Network

b. I_{DQ} = 2.64 mA
   V_{GSQ} = –3.3 V
c. V_{GS}(calculated) = –3.3 V
   V_D(calculated) = 12.4 V
   V_S(calculated) = 3.1 V
   V_{DS}(calculated) = 9.3 V
   V_G(calculated) = 0 V
d. V_{GS}(measured) = –3.4 V
   V_D(measured) = 12.2 V
   V_S(measured) = 2.1 V
   V_{DS}(measured) = 9.1 V
   V_G(measured) = 0 V

The percent differences are determined with the calculated values as the reference.

V_{GS}(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) = 4.8 mA
   V_{GS}(calculated) = –2.4 V
d. V_D(calculated) = 10.3 V
   V_S(calculated) = 5.2 V
   V_{DS}(calculated$_)$ = 5.1 V
e. V_{GSQ}(measured) = –2.3 V
   V_D(measured) = 10.4 V
   V_S(measured) = 5.3 V
   V_{DS}(measured) = 5.1 V

f. The percent differences are determined with calculated values as the reference.

V_{GS}(calculated %) = –4.2 %
V_D(calculated %) = .97%
V_S(calculated %) = 1.9%
V_{DS}(calculated %) = 1.2%

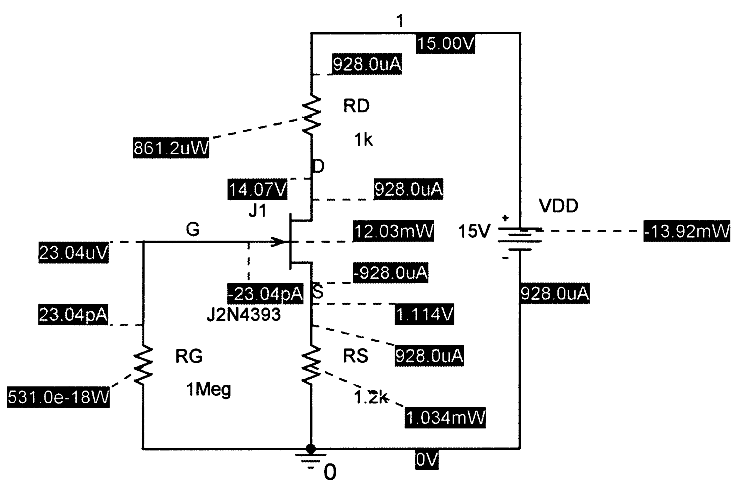
g. I_{DQ}(measured) = 4.8 mA
I_{DQ}(calculated %) = .4%

Part 4: Computer Exercises

PSpice Simulation 13-1

1. 928 μA
2. 12.96 V
3. –1.114 V
4. 13.92 mW
5. See Circuit diagram.

PSpice Simulation 13-1: Self-bias circuit

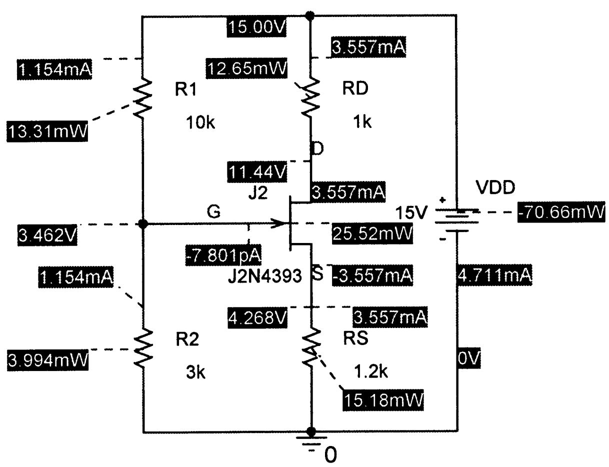


6. Negligible due to back bias of gate-source function
7. 12.03 mW
8. No

PSpice Simulation 13-2

1-8. See circuit diagram.

PSpice Simulation 13-2:Voltage-divider-bias circuit.



9. No

EXPERIMENT 14: DESIGN OF JFET BIAS CIRCUITS

Part 1: Determining ID_{SS} and V_P

b. ID_{SS}(measured) = 10.8 mA
c. V_P(measured) = –6 V

Part 2: Self-bias Circuit Design

a. ID_Q(calculated) = 5.4 mA
   V_{DSQ}(calculated) = 15 V
   V_{DD}(calculated) = 30 V
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 = 13.2 V
   R_D = 2.4 K
f. V_{DSQ}(measured) = 14.7 V
   I_{DQ}(measured) = 5.6 mA
   V_{DSQ}(calculated) = 15 V
   I_{DQ}(calculated) = 5.4 mA

g. Agreements between calculated and measured values are within 10% of each other and thus are within acceptable limits.

h. V_{DSQ}(measured) = 13.7 V
   I_{DQ}(measured) = 6 mA
   ID_{SS}(borrowed JFET) = 9.8 mA
   V_P(borrowed JFET) = –5.1 V

   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) =
   $[ID_{SS(\text{min})} * ID_{SS(\text{max})}]^{1/2}$ = [5 mA*15mA)]$^{1/2}$ = 8.66 mA

   V_P (geometric average) = $[1*6]^{1/2}$ = 2.45 V

   Statistically, these values are most likely the ones encountered.

Part 3: Voltage-divider Circuit Design

a. V_{GS}(calculated) = –2.6 V

b. $R_S = (V_{GG} – V_{GS})/I_{DQ}$ = (6 – 2.6)V/4 mA = 850 ohms
   R_S(commercial value) = 820 ohms
   V_G(calculated) = $V_{GS} + I_D*R_S$ = 2.6 + 4 mA*820 = 5.85 V

c. V_{RD}(calculated) = $V_{DD} - V_{DSQ} - V_{RS}$ = 20 – 8 – 3.28 = 8.72 V
where $V_{RS} = I_{DQ}*R_S$ = 4 mA*820 = 3.28 V

$R_D = [V_{DD} - (V_{DSQ} + V_{RS})]/I_D$ = [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:

$R_1 = R_2*(V_{DD} - V_G)/V_G$ = 10 K*(20 – 5.85)/5.85 = 24.2 Kohms
R_1(commercial value) = 22 Kohms

e. V_{DSQ}(measured) = 7.9 V
ID_Q(measured) = 4.2 mA
V_{DSQ}(specified) = 8 V
I_{DQ}(specified) = 4 mA

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 I_{DQ} and V_{DSQ} 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 V_G. 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) = 13.7 V
I_{DQ}(measured) = 3.68 mA
I_{DSS}(borrowed JFET) = 9.8 mA
V_P(borrowed JFET) = –5.1 V

Part 4: Problems and Exercises

1. R_D(commercial value) = 2.7 Kohms
R_S(commercial value) = 180 ohms

2. R_D(commercial value) = 2.4 Kohms
R_S(commercial value) = 680 ohms
R_1(commercial value) = 6.8 Kohms
R_2(commercial value) = 33 Kohms

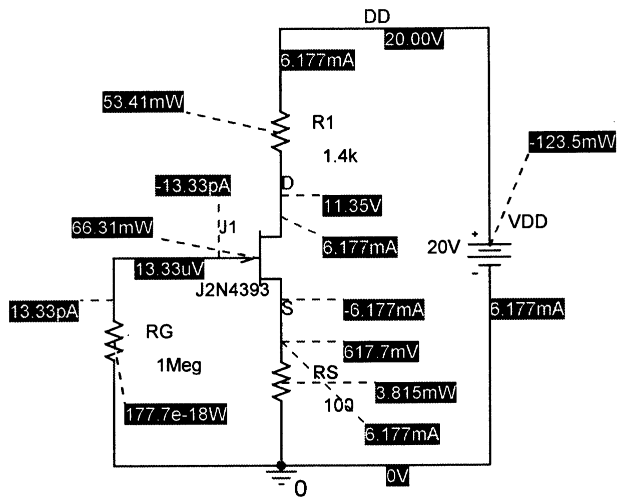
3. In the design, use the geometric mean of both the given ranges on *IDSS* and *VP* for a given type JFET.

Part 5: Computer Exercises

PSpice Simulation 14-1

1-6. See circuit diagram.

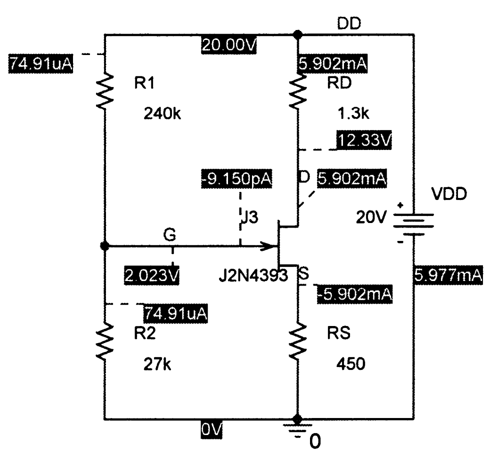
PSpice Simulation 14-1



PSpice Simulation 14-2

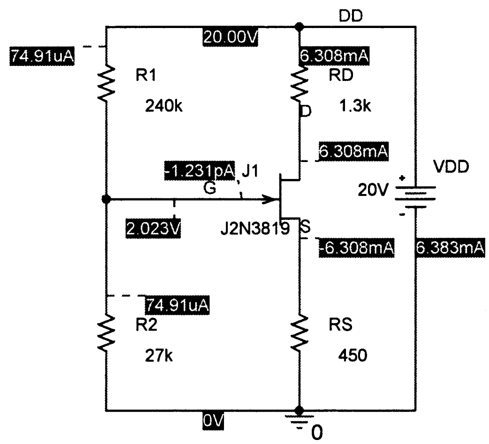
1. See circuit diagram.

PSpice Simulation 14-2: Voltage divider bias



2. See circuit diagram.

PSpice Simulation 14-2: Voltage divider bias



3. See above circuit diagrams.
4. $\%V_{DS} = 7.37\%$
5. Yes

EXPERIMENT 15: COMPOUND CONFIGURATIONS

Part 1: Determining the BJT(β) amd JFET (I_{DSS} and V_P) Parameters

a. R_B(measured) = 982 Kohms
R_C(measured) = 2.6 Kohms

$I_B = (V_{CC} – V_{BE})/R_B$ = (20 – .7)/982 K = 19.7 μA

V_{RC}(measured) = 6.45 V
$I_C = V_{RC}/R_C$ = 6.45/2.6 K = 2.48 mA
β(calculated) = 1.48 mA/19.7 μA = 126

Part 2: Capacitive-Coupled Multistage System with Voltage-Divider Bias

b. V_{B1} = 4.7 K/(4.7 K + 15 K)* 20 = 4.8 V
V_{E1} = 4.8 – .7 = 4.1 V
$I_{E1} = I_{C1} = V_{E1}/R_{E1}$ = 4.1/1 K = 4.1 mA
$V_{C1} = V_{CC} – I_{C1} * R_{C1}$ = 20 – 4.1 mA*2.7 K = 9.2 V
V_{B2} = 2.4 K/(2.4 K + 15 K)*20 = 2.8 V
V_{E2} = 2.8 – .7 = 2.1 V
$I_{E2} = I_{C2} = V_{E2} /R_{E2}$ = 2.1/470 = 4.6 mA
$V_{C2} = V_{CC} – I_{C2} * R_{C2}$ = 20 – 4.6 mA * 1.2 K = 14.5 V

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 = 4.7 K/(4.7 k + 15 k) * 30 = 7.2 V
$V_E = V_B$ – .7 V = 6.5 V
$I_E = I_D$ = 6.5 V/1.2 K = 5.4 mA
$V_D = V_{DD}*R_D$ = 30 – 5.4 mA*985 = 24.7 V

For the JFET used: ID_{SS} = 10.1 mA
V_P = –3.2 V

determine V_{GS}:

$I_D/ID_{SS} = [1 - V_{GS}/V_P]^{1/2}$ mA = 5.4 mA/10.1 mA = $[1 - V_{GS}/3.2]^{1/2}$ mA

therefore:

$[5.4 \text{ mA}/10.1 \text{ mA}]^2 = [1 - V_{GS}/3.2]$

.286 = $[1 - V_{GS}/3.2]$

from which: V_{GS} = (1 – .286)*3.2 = –2.28 V
remember: V_{GS} is a negative number:

$V_C = V_B - V_{GS}$ = 7.2 – (–2.28) = 9.5 V

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}(calculated from measured values) = $V_B - V_C$ = 7.1 – 8.7 = –1.6 V
V_{GS}(measured) = –1.7 V

g. $V_{RD} = V_{DD} - V_D$ = 30 – 24.7 = 5.3 V
I_D = 5.3 V/985 = 5.4 mA
I_D(measured) = 6.4 mA

The percent difference between the measured and the calculated values of I_D was 18.5%, with the calculated value of I_D used as the standard of reference.

V_E(calculated) = 7.2 – .7 = 6.5 V
I_C(calculated) = 6.5 V/1.26 K = 5.2 mA
I_C(measured) = 5.06 mA

The percent difference between the measured and the calculated values of I_C was –2.7%, with the calculated value of I_D used as the standard of reference.

Part 5: 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.

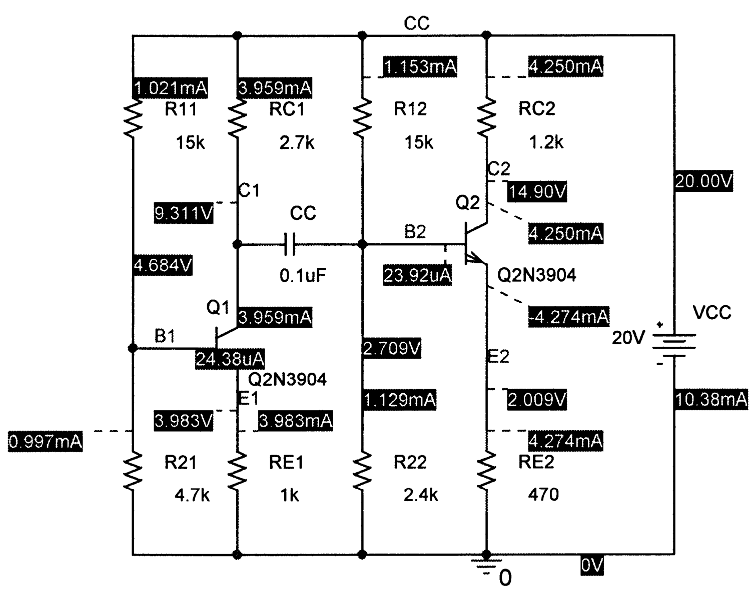
2. Again, depending on how good the design of the voltage divider bias circuit is, the changes in the circuit voltages and currents should be kept to a minimum.

Part 6: Computer Exercises

PSpice Simulation 15-1

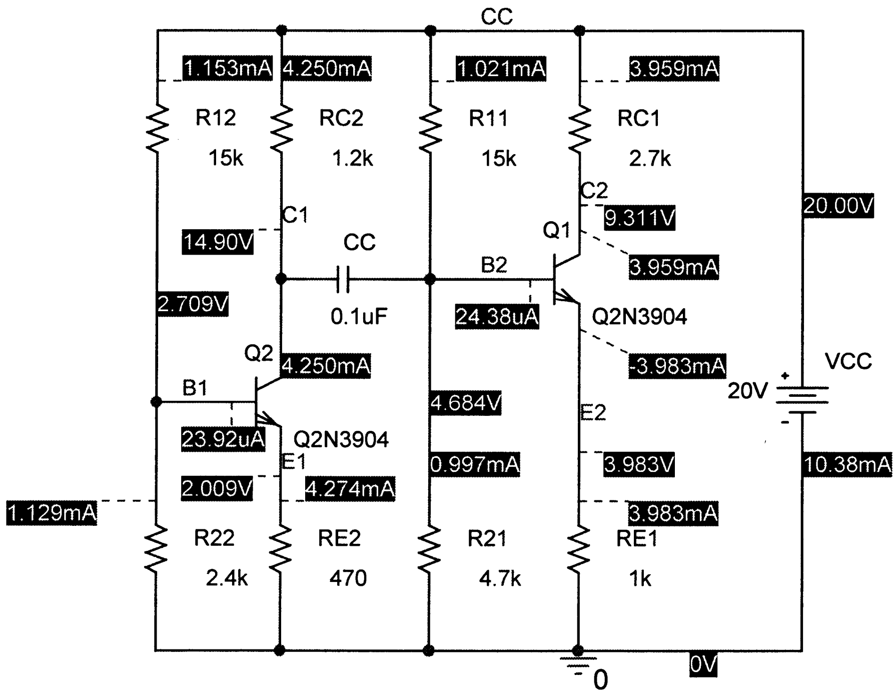
1-11. See below.

PSpice Simulation 15-1: AC coupled multistage amplifier



PSpice Simulation 15-1: AC coupled multistage amplifier

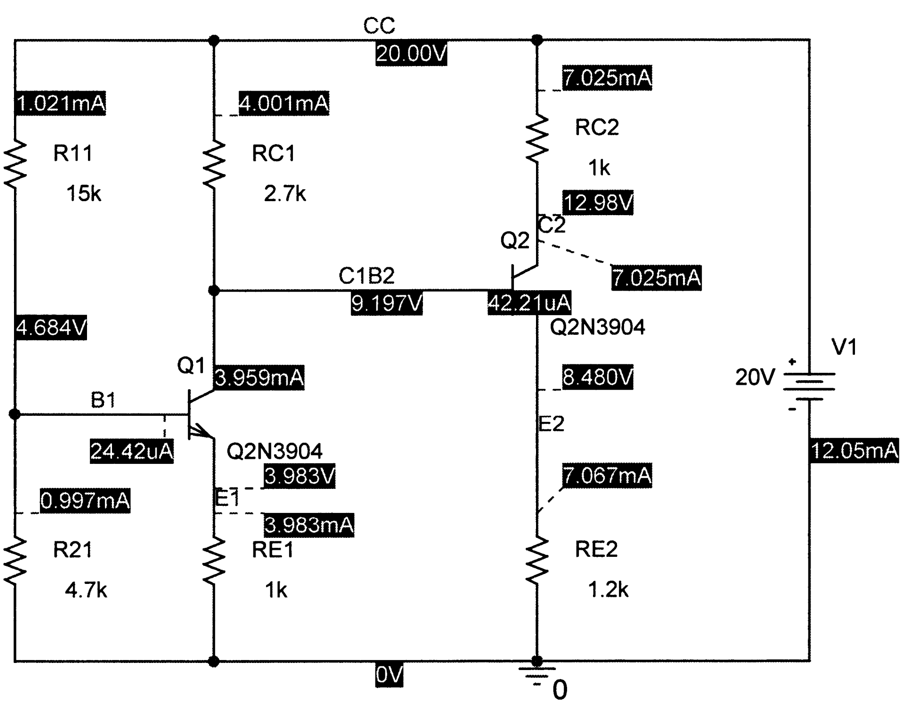
Stages interchanged



PSpice Simulation 15-2

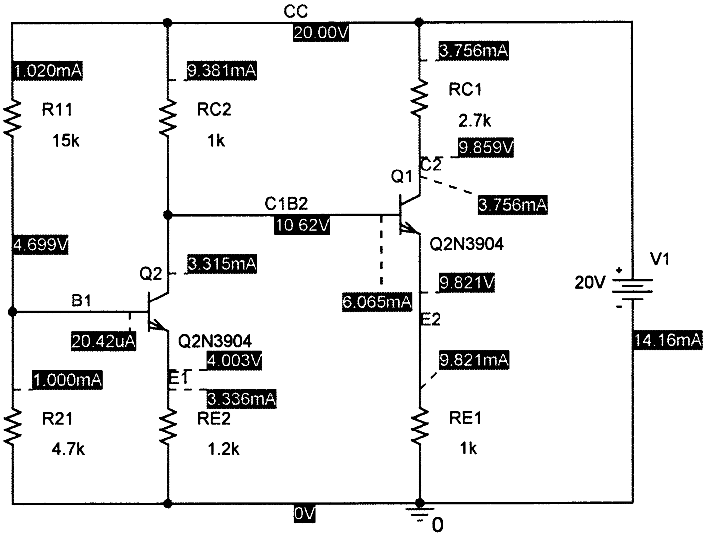
1-11. See below.

PSpice Simulation 15-2: DC coupled multistage amplifier



PSpice Simulation 15-2: DC coupled multistage amplifier

Stages interchanged



EXPERIMENT 16: MEASUREMENT TECHNIQUES

Part 1: AC and DC Voltage Amplitude Measurements
DC MEASUREMENT

e. V_O(calculated) = 2K/(2K + 3.9 K)*12 = 3.86 V
f. V_O(measured) = 3.78 V
%Diff. (calculated) = –2%
g. V_O(measured shift) = 3.8 V
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

h. $V_{i(\text{rms})}$(calculated) = 8/2*.707 = 2.82 V

i. $V_{O(\text{rms})}$(calculated) = [(2 K || 3.9 K + j0)*(2.82 + j0)]/(2.41 K – j1.59 K) = $1.34\angle 33.4$ V

j. V_O(measured) = 1.31 V
% diff. (calculated) = –1.51%

k. $V_{O(p-p)}$(measured) = 3.72 V

l. If we convert the measured rms value of V_O 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 = 100 μs/div

c. number of divisions = 5.6

d. Period(T) = 100 μs/div*5.6 div = 560 μs

e. Frequency(f) = 1/T = 1/560 μs = 1800 Hz

f. f(dial setting) = 1750 Hz

g. The dial setting on the signal generator at best can only give an approximate setting of the frequency.

h. f(counter) = 1810 Hz

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. $V_{i(\text{rms})}$(calculated) = 6/2*.707 = 2.12 V

c. $V_{O(\text{rms})} = (0 - j1.59\ \text{K})*(2.12 + j0)/(1\text{k} - j1.59\ \text{K}) = 1.81\angle{-31.6}$ V
$V_{O(p-p)(\text{rms})}$ = 1.81*1.41*2 = 5.1 V

f. $A_{(\text{number of divisions})}$ = .8
g. $B_{(\text{number of divisions})}$ = 10

h. angle θ(calculated) = –31.6 degrees

j. The network is a lag network, i.e., the output voltage V_O lags the input voltage by the angle theta, in our case it lags it by –31.6 degrees.

k. $V_{R(\text{rms})}$(calculated) = 1.1 V
$V_{R(p-p)}$(calculated) = 3.1 V
angle theta = 58.4 degrees
The output voltage V_O leads the input voltage by 58.4 degrees. Note that an angle of 58.4 degrees is the complement of an angle of 31.6 degrees.

l. $V_{R(p-p)}$(measured) = 3 V
angle θ = 58 degrees
It's a lead angle.

Part 4: Loading Effects

c. $V_{O(p-p)}$(calculated) = 1 K/(1 K + 1 K)*8 = 4 V

d. $V_{O(p-p)}$(measured) = 3.98 V

f. $V_{O(p-p)}$(calculated) = 1 M/(1 M + 1 M)*8 = 4 V
$V_{O(p-p)}$(measured) = 2.7 V

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 1 Mohm, therefore, $R_{\text{scope}} \parallel R_2$ = 500 kohms.
Thus, V_O is considerably reduced.

h. $R_{(\text{prime})} = 1\ \text{M}/[Vi/V_O - 1] = 1\ \text{M}/[8/2.7 - 1]$ = 588 kohms
$R_{(\text{scope})} = -R_{(\text{prime})}*R_2/[R_{(\text{prime})} - R_2]$ = 1.43 Megohms

Most general purpose oscilloscopes have an input impedance consisting of a real part of 1 Megohms in parallel with a 30 pf capacitor. The result obtained for the real part of that impedance is reasonably close to that.

i. $V_{O(p-p)}$(calculated) = 1 K/(1 K + 1 M)*8 = 8 mV
j. $V_{O(p-p)}$(measured) = 7.9 mV

k. The results agree within 1.25 percent.

Part 5: Problems and Exercises

1. No. for the frequency of operation, the capacitor represents an impedance of $1.59k\angle -90$ 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 = 5 div*.1 ms/div = .5 ms
   $f = 1/T$ = 1/.5 ms = 2 KHz

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

Part 6: Computer Exercises

PSpice Simulation 16-1

1. See Probe plot page 264.
2. See Probe plot page 264.
3. See Probe plot page 265.
4. See Probe plot page 265.
5. 33.74°
6. V_{out}
9. See Probe plot page 266.
10 See Probe plot page 266.
11. $V_{in(rms)} = 2.84$ V
    $V_{out(rms)} = 1.32$ V
12. Yes
13. See Probe plot page 267.
14. See Probe plot page 267.
15. $V_{out} = \dfrac{R3}{R2 + R3}(12\text{ V}) = \dfrac{2\text{ K}}{(212 + 3.9\text{ K})}(12\text{ V})$
    $= 4.067$ V
16. Agree

** Profile: "SCHEMATIC1-1" [C:\Program Files\OrcadLite\Lab Revision PSpice 16-20\pspice simulation ...
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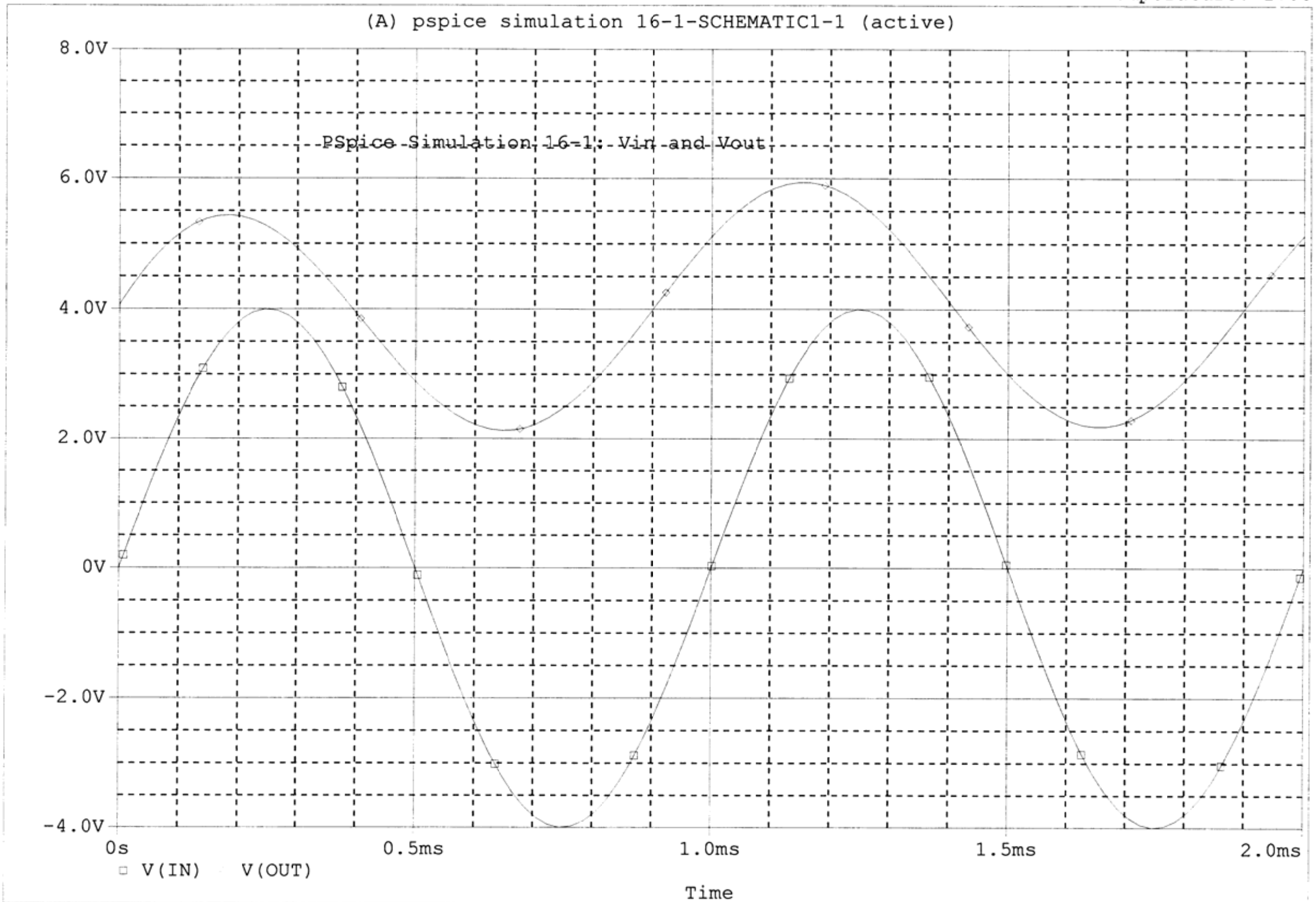
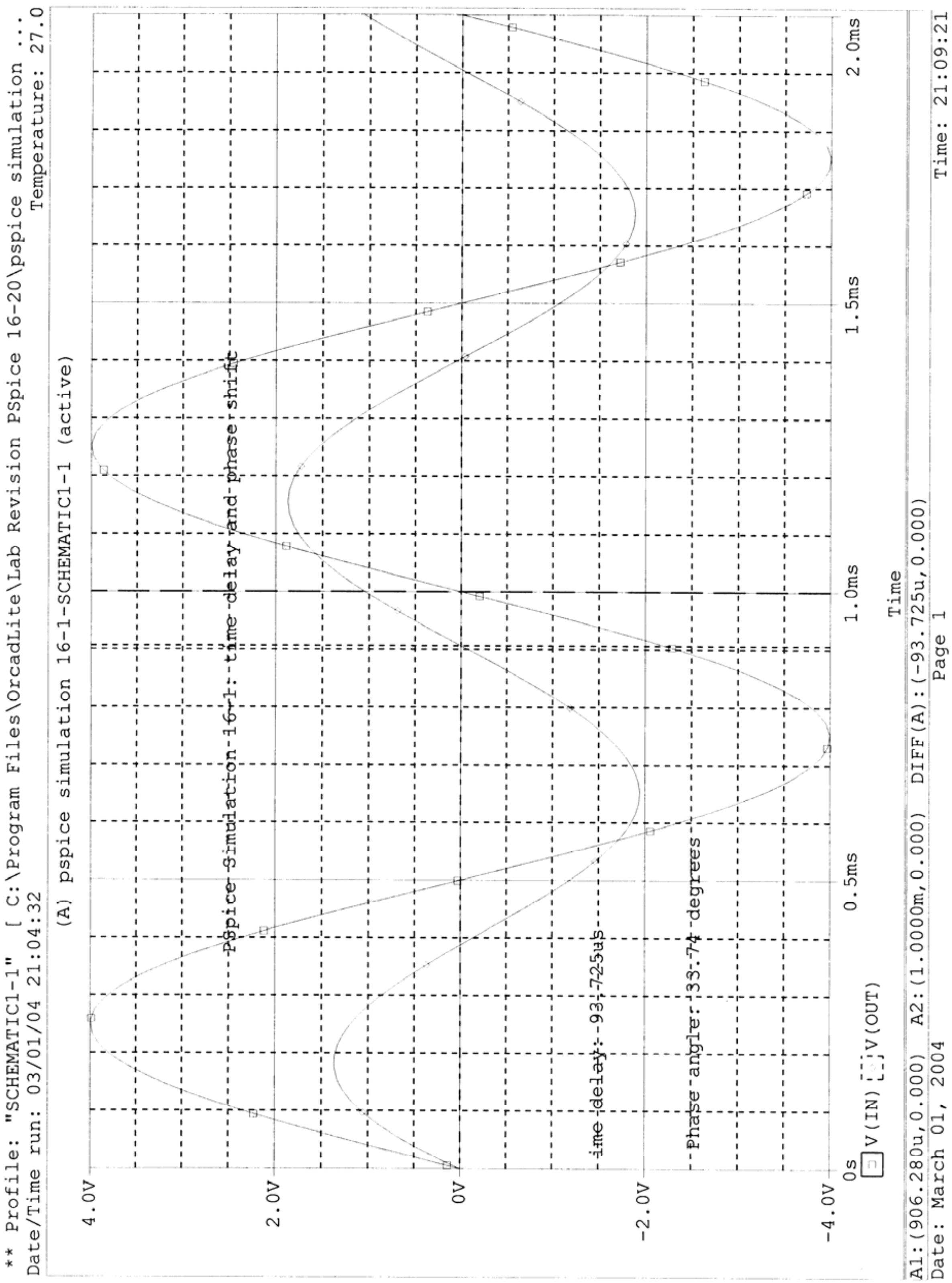


Date: March 01, 2004 Page 1 Time: 21:03:19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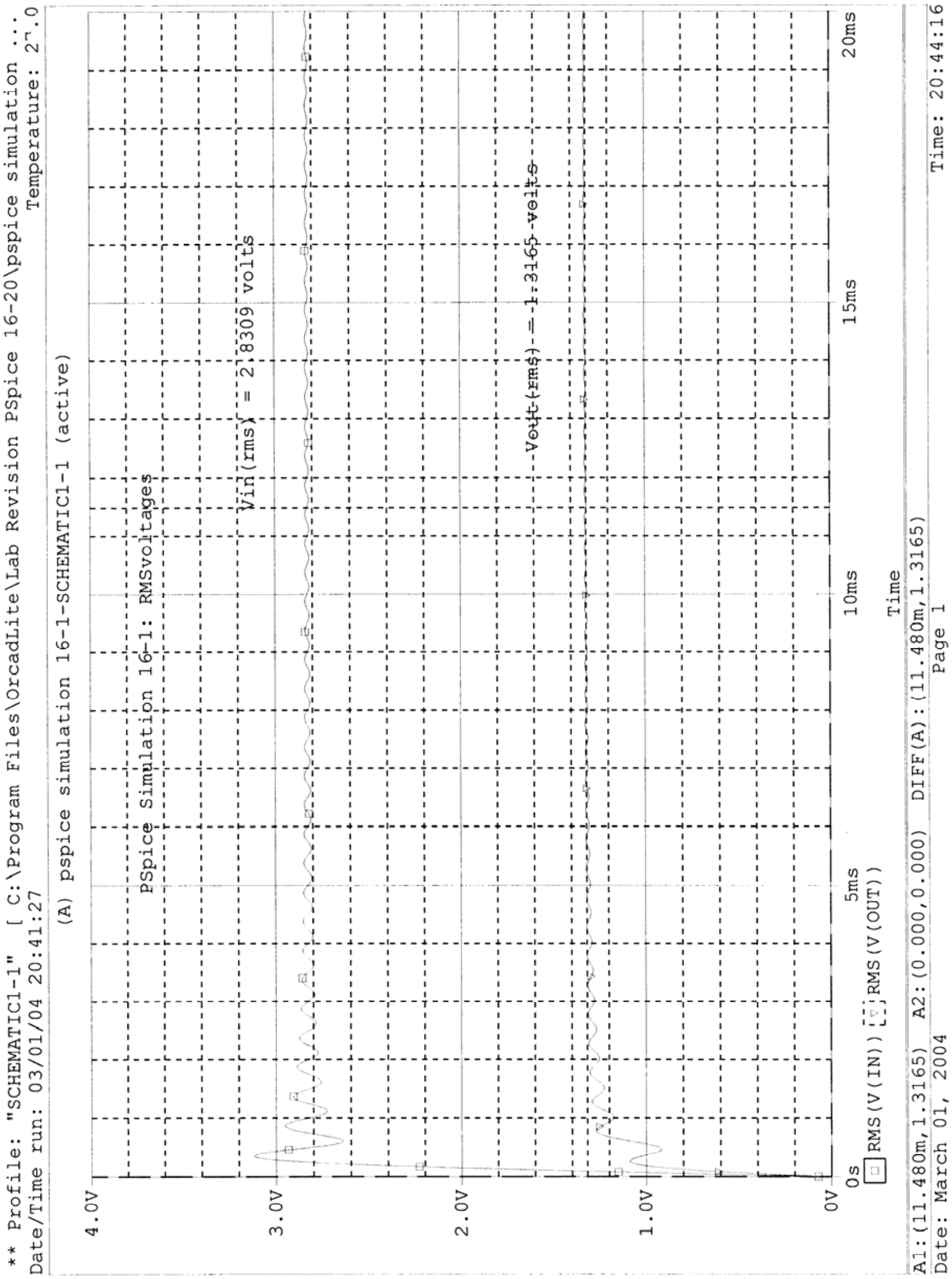
Date/Time run: 03/01/04 21:04:32
Temperature: 27.0
(A) pspice simulation 16-1-SCHEMATIC1-1 (active)
PSpice Simulation 16-1: time delay and phase shift
ime delay: -93.725us
Phase angle: 33.74 degrees
4.0V
2.0V
0V
-2.0V
-4.0V
0s
0.5ms
1.0ms
1.5ms
2.0ms
V(IN) V(OUT)
Time
A1:(906.280u,0.000) A2:(1.0000m,0.000) DIFF(A):(-93.725u,0.000)
Date: March 01, 2004
Page 1
Time: 21:09:21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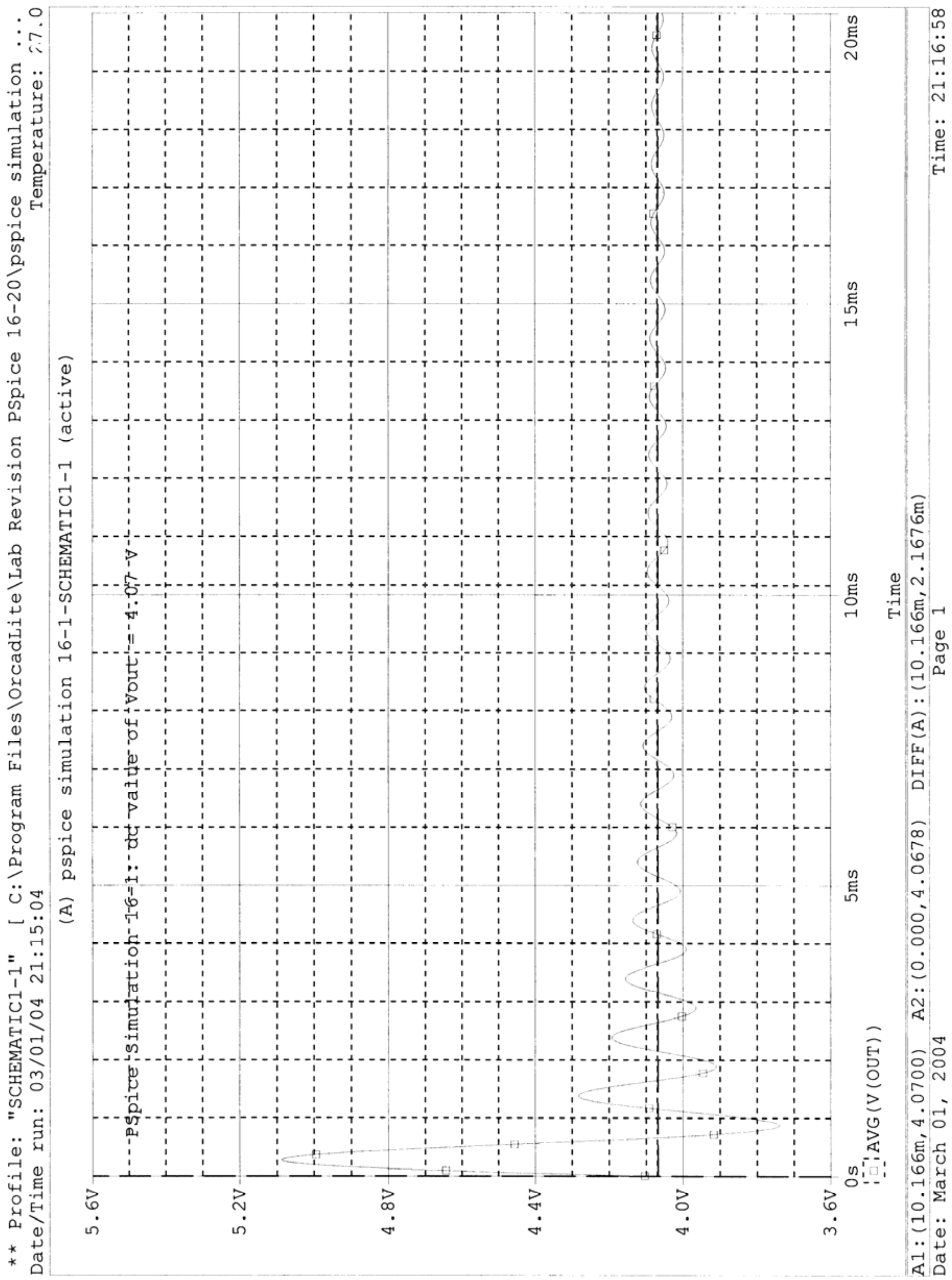
Date/Time run: 03/01/04 20:41:27
Temperature: 27.0
(A) pspice simulation 16-1-SCHEMATIC1-1 (active)
PSpice Simulation 16-1: RMSvoltages
Vin(rms) = 2.8309 volts
Vout(rms) = 1.3165 volts
4.0V
3.0V
2.0V
1.0V
0V
0s
5ms
10ms
15ms
20ms
Time
RMS(V(IN)) RMS(V(OUT))
A1:(11.480m,1.3165) A2:(0.000,0.000) DIFF(A):(11.480m,1.3165)
Date: March 01, 2004
Page 1
Time: 20:44:16


** Profile: "SCHEMATIC1-1" [C:\Program Files\OrcadLite\Lab Revision PSpice 16-20\pspice simulation ...
Date/Time run: 03/01/04 21:15:04
Temperature: 27.0
(A) pspice simulation 16-1-SCHEMATIC1-1 (active)
pspice simulation 16-1: dc value of Vout = 4.07 V
5.6V
5.2V
4.8V
4.4V
4.0V
3.6V
0s
5ms
10ms
15ms
20ms
AVG(V(OUT))
Time
A1:(10.166m,4.0700) A2:(0.000,4.0678) DIFF(A):(10.166m,2.1676m)
Date: March 01, 2004
Page 1
Time: 21:16:58

PSpice Simulation 16-2

1. Using VOM, R2 = 100 kΩ
2. Using DMM, R2 = 1 kΩ
3. For R2 = 1 kΩ
4. Both circuits
5. No

EXPERIMENT 17: COMMON-EMITTER TRANSISTOR AMPLIFIERS

Part 1: Common-Emitter DC Bias

b. $V_{BB} = R_2/(R_1 + R_2) * V_{CC}$ = 10 K/(10 K + 33 K) * 10 = 2.33 V
$V_E = V_{BB} - .7$ = 1.63 V
$V_C = V_{CC} - I_C * R_C$ = 10 – 1.63 mA * 3 K = 5.1 V
$I_E = V_E/R_E$ = 1.63/1 K = 1.63 mA
r_e = 26 mV/I_E = 26 mV/1.63 mA = 16 ohms

c. V_B(measured) = 2.25 V
V_E(measured) = 1.57 V
V_C (measured) = 4.95 V
$I_E = V_E/R_E$ = 1.57/978 = 1.6 mA
r_e = 26 mV/1.6 mA = 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) = $-RC/re$ = 3.2 K/16 = 198
b. V_{sig} = 8.3 mV(rms)
V_O(no load) = 1.47 V (rms)
A_V(no load) = 177

The two values of A_V agree within 10.6 percent of each other.

Part 3: AC Input Impedance, Z_i

$Z_{\text{in}} = R_1 \parallel R_2 \parallel \text{Beta} * r_e$ = 10 K || 33 K || (150 * 16) = 1.8 Kohms
V_i (measured) = 12 mV (rms)
V_{sig} = 20 mV(rms)
Z_{in} = [12 mV/(20 mV – 12 mV)] * 1 K = 1.5 Kohms
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.

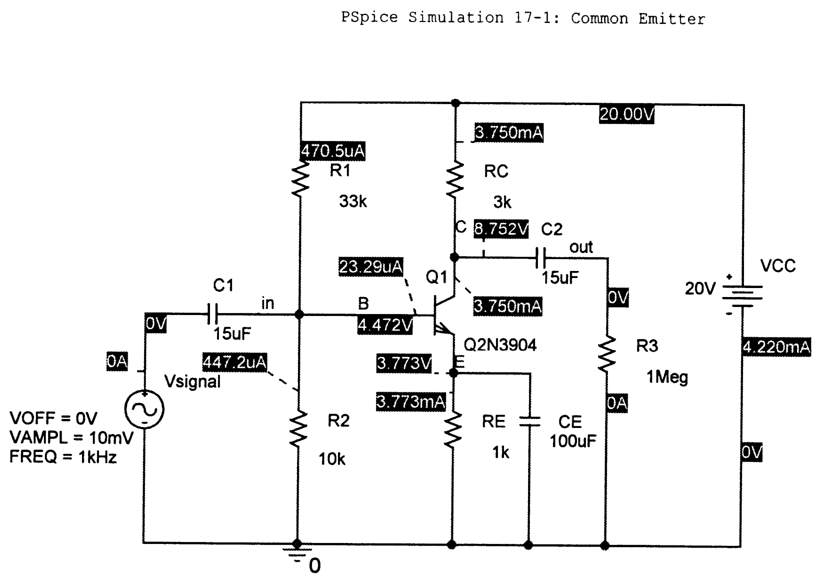
Part 4: Output Impedance

a. Z_O(calculated) = R_C = 3.2 Kohms
b. $V_{\text{sig(rms)}}$ = 10 $\text{mV}_{\text{(rms)}}$
V_O(no load)(rms) = 1.8 V (rms)
V_O(loaded)(rms) = .913 V(rms)
R_L = 3.2 Kohms
$Z_O = [(V_O - V_L)/V_L] * R_L$ = [(1.8 – .913)/.913] * 3.2 K = 3.1 K
The two values for Z_O are within 3.15% of each other.

Part 6: Computer Analysis

PSpice Simulation 17-1

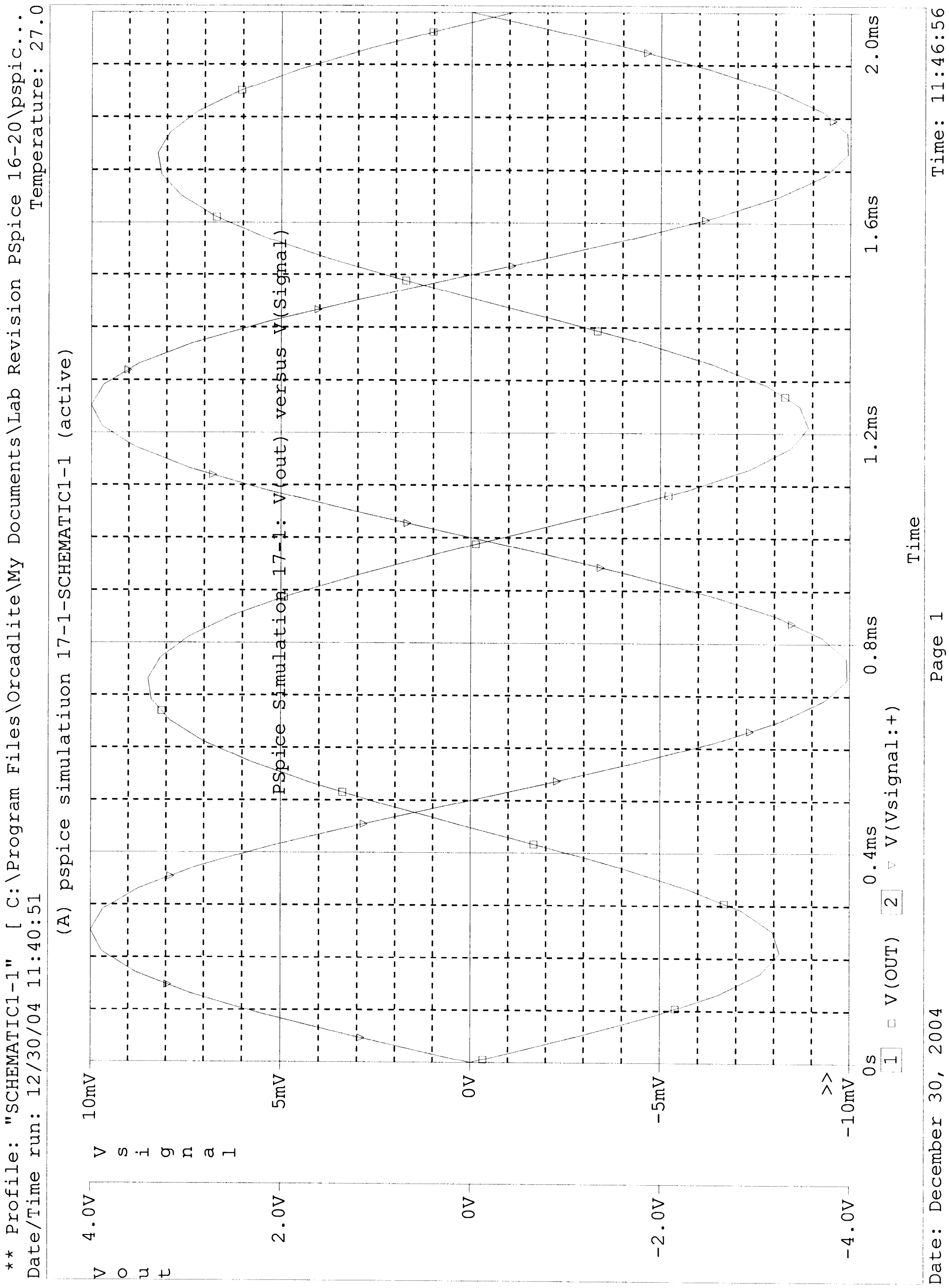
1. See Circuit diagram.



2. $r_e = 6.93\ \Omega$
3. See Probe plot page 271.
4. See Probe plot page 271.
5. 180°
6. As $I(B)$ increases, so does $I(C)$.
   As $I(C)$ increases, so does $V(RC)$ and $V(RE)$. Therefore $V(C)$ decreases.
7. Z_{in} (theoretical) = 937.3 Ω
8. See Probe plot page 272.
9. See Probe plot page 272.
10. Z_{in}(PSpice) = 1.1323 k ≈ Z_{in}(theoretical)

Determining output impedance

1. $Z_{\text{out}} \approx RC = 3$ k
2. See Probe plot page 273.
3. See Probe plot page 273.
4. Z_{out}(PSpice) = 2.6392 k ≈ RC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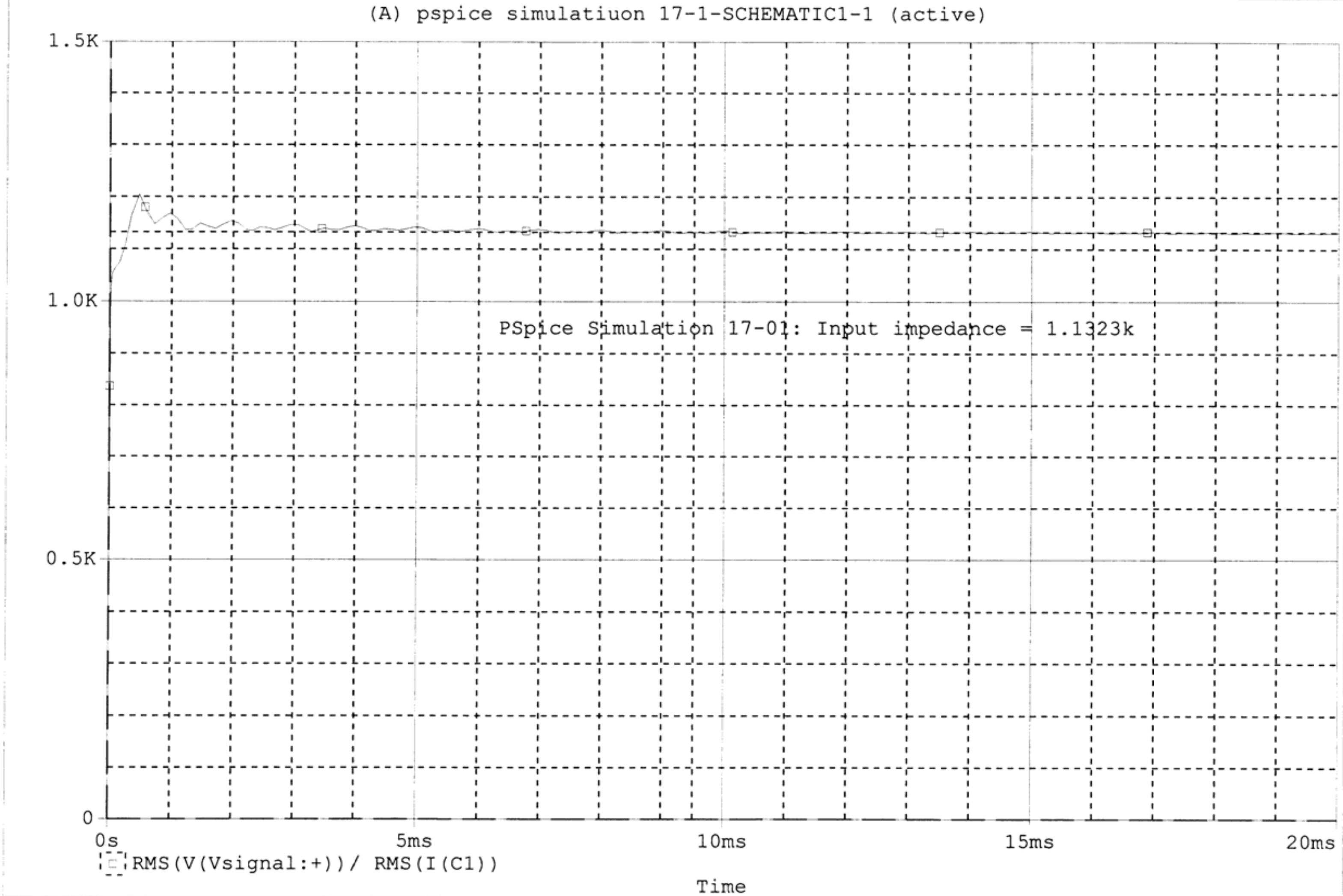
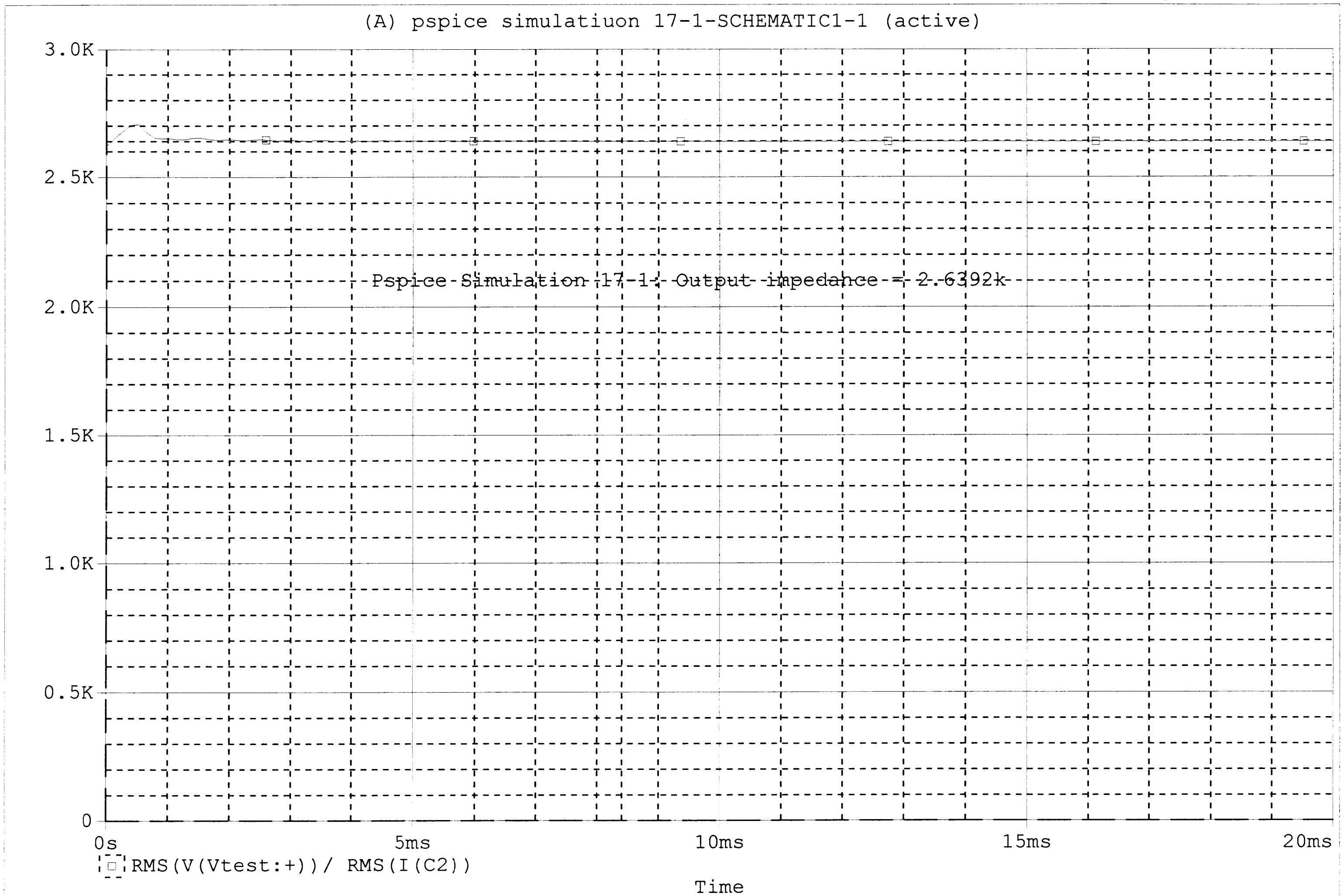
Date/Time run: 12/30/04 11:40:51
Temperature: 27.0
(A) pspice simulatiuon 17-1-SCHEMATIC1-1 (active)
PSpice Simulation 17-1: V(out) versus V(Signal)
4.0V
2.0V
0V
-2.0V
-4.0V
Vout
10mV
5mV
0V
-5mV
-10mV
Vsignal
>>
0s
0.4ms
0.8ms
1.2ms
1.6ms
2.0ms
1 V(OUT) 2 V(Vsignal:+)
Time
Date: December 30, 2004
Page 1
Time: 11:46:56

** Profile: "SCHEMATIC1-1" [C:\Program Files\Orcadlite\My Documents\Lab Revision PSpice 16-20\pspic...
Date/Time run: 12/30/04 12:03:21 Temperature: 27.0



A1:(9.510m,1.1323K) A2:(0.000,0.000) DIFF(A):(9.510m,1.1323K)
Date: December 30, 2004 Page 1 Time: 12:06:53

** Profile: "SCHEMATIC1-1" [C:\Program Files\Orcadlite\My Documents\Lab Revision PSpice 16-20\pspic...
Date/Time run: 12/30/04 12:13:57   Temperature: 27.0



A1:(8.4069m,2.6392K) A2:(0.000,0.000) DIFF(A):(8.4069m,2.6392K)
Date: December 30, 2004   Page 1   Time: 12:16:07

EXPERIMENT 18: COMMON-BASE AND EMITTER-FOLLOWER (COMMON-COLLECTOR TRANSISTOR AMPLIFIERS

Part 1: Common-Base DC Bias

a. V_B(calculated) = 10 K/(10 K + 33 K) * 10 = 2.33 V
$V_E = V_B - .7$ V = 1.63 V
$I_E = I_C = V_E/R_E$ = 1.63 V/1 K = 1.63 mA
$V_C = 10 - I_C * R_C$ = 10 – (1.63 mA) * 3 K = 5.1 V
$r_e = 26$ mV/I_E = 26 mV/1.63 mA = 16 ohms

b. V_B(measured) = 2.26 V
V_E(measured) = 1.57 V
V_C(measured) = 4.95 V
I_E(from measured values) = V_E/R_E = 1.57 V/978 = 1.6 mA
r_e(from measured values) = 26 mV/I_E = 26 mV/1.6 = 16.3 ohms

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 = 3.2 K/16.3 = 197
b. V_{sig} = 50 mV
V_O = 2.43 V
$A_V = 2.43/V_{\text{sig}}$ = 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, Z_{i}

a. $Z_i = r_e$ = 16.3 ohms
b. V_{sig} = 50 mV
V_i = 9.9 mV
R_X = 100 ohms
$Z_i = [V_i/(V_{\text{sig}} - V_i)] * R_X$ = [9.9 mV/(50 mV – 9.9 mV)] * 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. $Z_O = R_C$ = 3.2 K
b. V_{sig} = 20 mV
V_O(measured, no load) = 2.43 V
V_L(measured, loaded) = 1.22 V
$Z_O = [(V_O - V_L)/V_L] * R_L$ = [(2.43 – 1.22)/1.22] * 3 K = 3.18 Kohms

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) = 2.33 V
   V_E(calculated) = 1.63 V
   I_E(calculated) = 1.63 V
   V_C(calculated) = 10 V
   r_e(calculated) = 26 mV/I_E = 26 mV/1.63 mA = 16 ohms

b. V_B(measured) = 2.26 V
   V_E(measured) = 1.78 V
   V_C(measured) = 10.1 V
   $I_E = V_E/R_E$ = 1.78 V/1 K = 1.78 mA
   r_e = 26 mV/1.78 mA = 14.3 ohms

Part 6: Emitter-Follower AC Voltage Gain

a. $A_V = R_E/(R_E + r_e)$ = 1 K/(1 K + 14.3) = .986
b. V_{sig} = 1 V
   V_O(measured) = .987 V
   $A_V = V_O/V_{\text{sig}}$ = .987/1 = .987

   The two values of gain are within .1 percent of each other.

Part 7: Emitter Follower (EF) Input Impedance, Z_i

a. $Z_i = R_1 \| R_2 \|$ (Beta * (1 K + r_e) = 7.31 Kohms
b. V_{sig} = 2 V
   R_X = 10 Kohms
   f = 1 KHz
   V_i(measured) = .85 V
   $Z_i = [V_i/(V_{\text{sig}} - V_i)] * R_X$ = [.85/(2 – .85)] * 10 K = 7.39 Kohms

   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

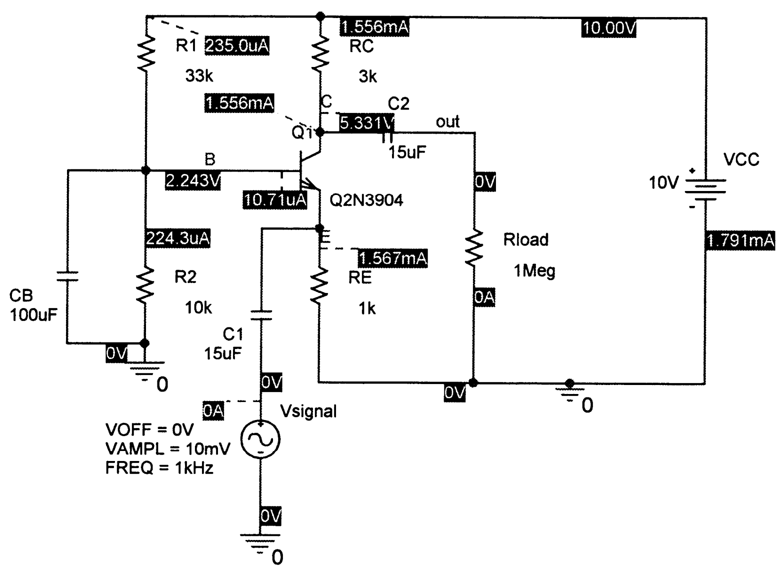
a. $Z_O = r_e$ = 16 ohms
b. V_O(measured) = 19.8 mV
   V_L(measured) = 11.2 mV
   $Z_O = [(V_O - V_L)/V_L]*R_L$ = [(19.8 mV – 11.2 mV)/11.2 mV] * 100 = 76.8 ohms

   In the theoretical formulation, Z_O was equated with r_e, this is an approximation. A better expression for the output impedance is: $Z_O = r_e + (R_G \| R_1 \| R_2)$/Beta. Thus it can be seen that the given formulation was actually a minimum value of the output impedance.

Part 9: Computer Analysis

PSpice Simulation 18-1
Bias Point Analysis
1. See Circuit diagram.

PSpice Simulation 18-1: Common Base Amplifier

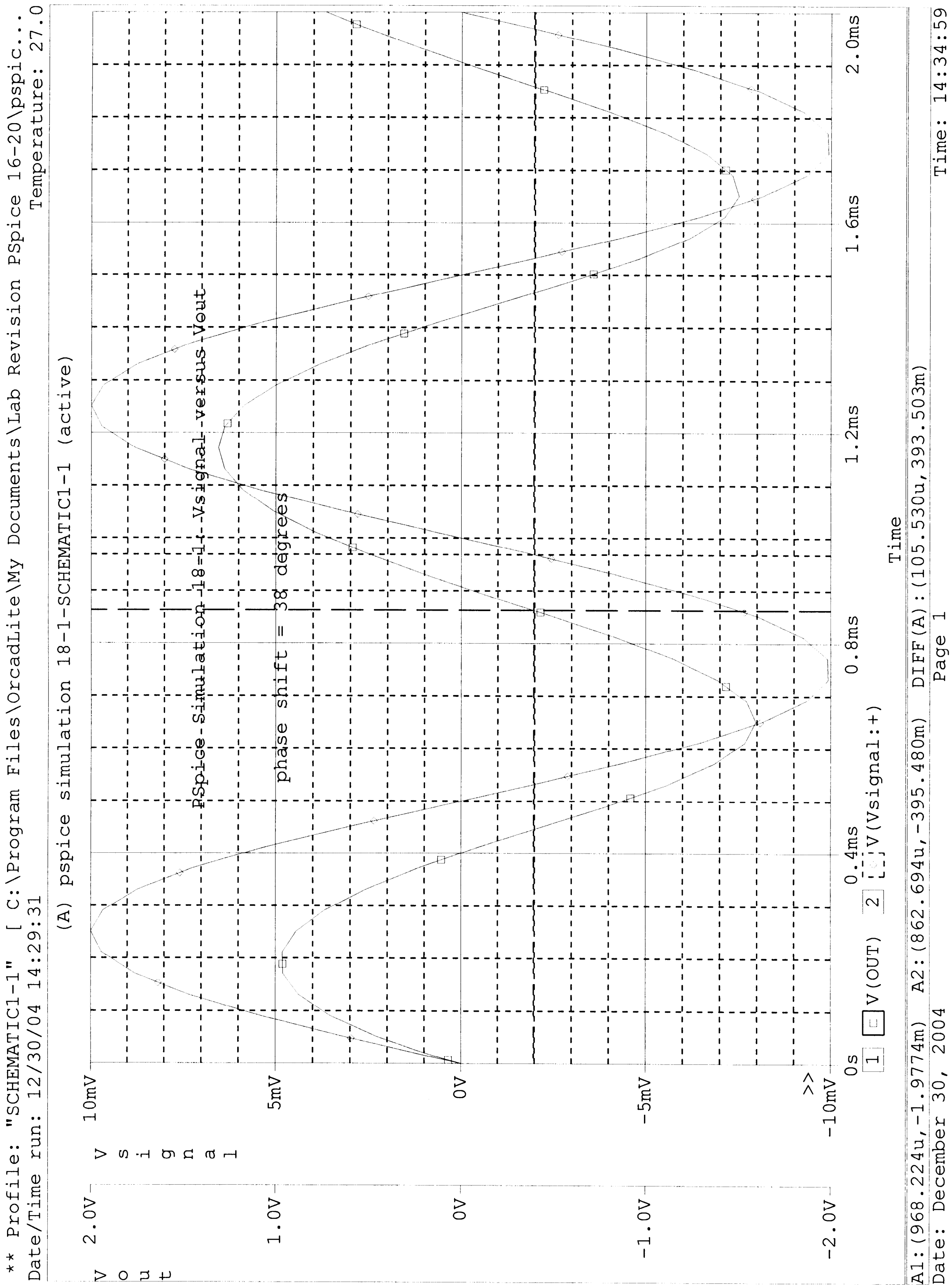


2. See circuit diagram.
4. $r_e = 16.71\ \Omega$
5. $A_v = 179.53$
6. $Z_{in} = r_e = 16.71\ \Omega$
7. $Z_{out} = 3\ \text{k}\Omega$

Transient Analysis
1. See Probe plot page 277.
2. 38°
4. $A_v = 141.59$, see Probe plot page 278.

Input Impedance
1. $Z_{in} = 20.7\ \Omega$, see Probe plot page 279.

Output Impedance
1. $Z_{out} = 2.87\ \text{k}\Omega$, see Probe plot page 280.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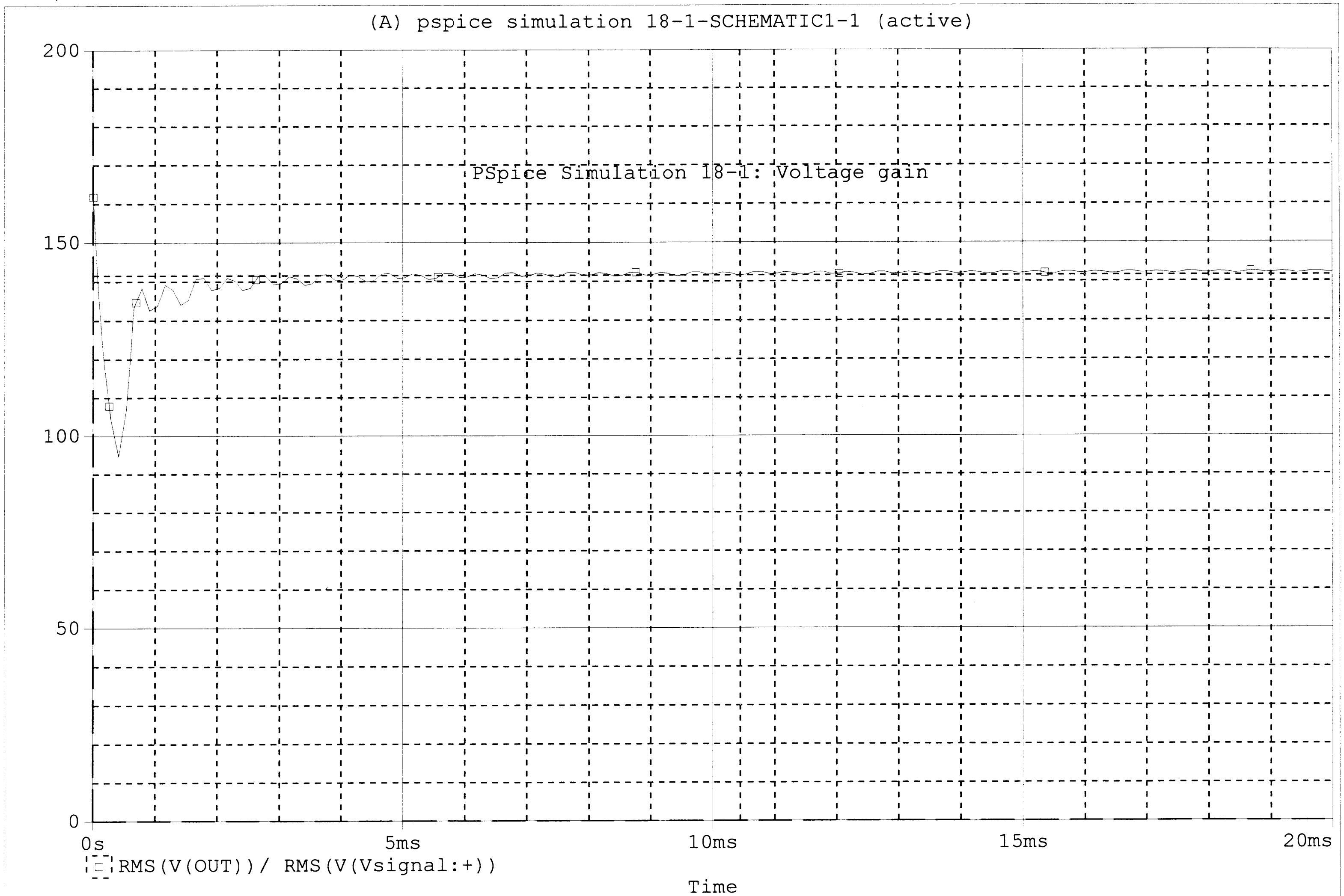
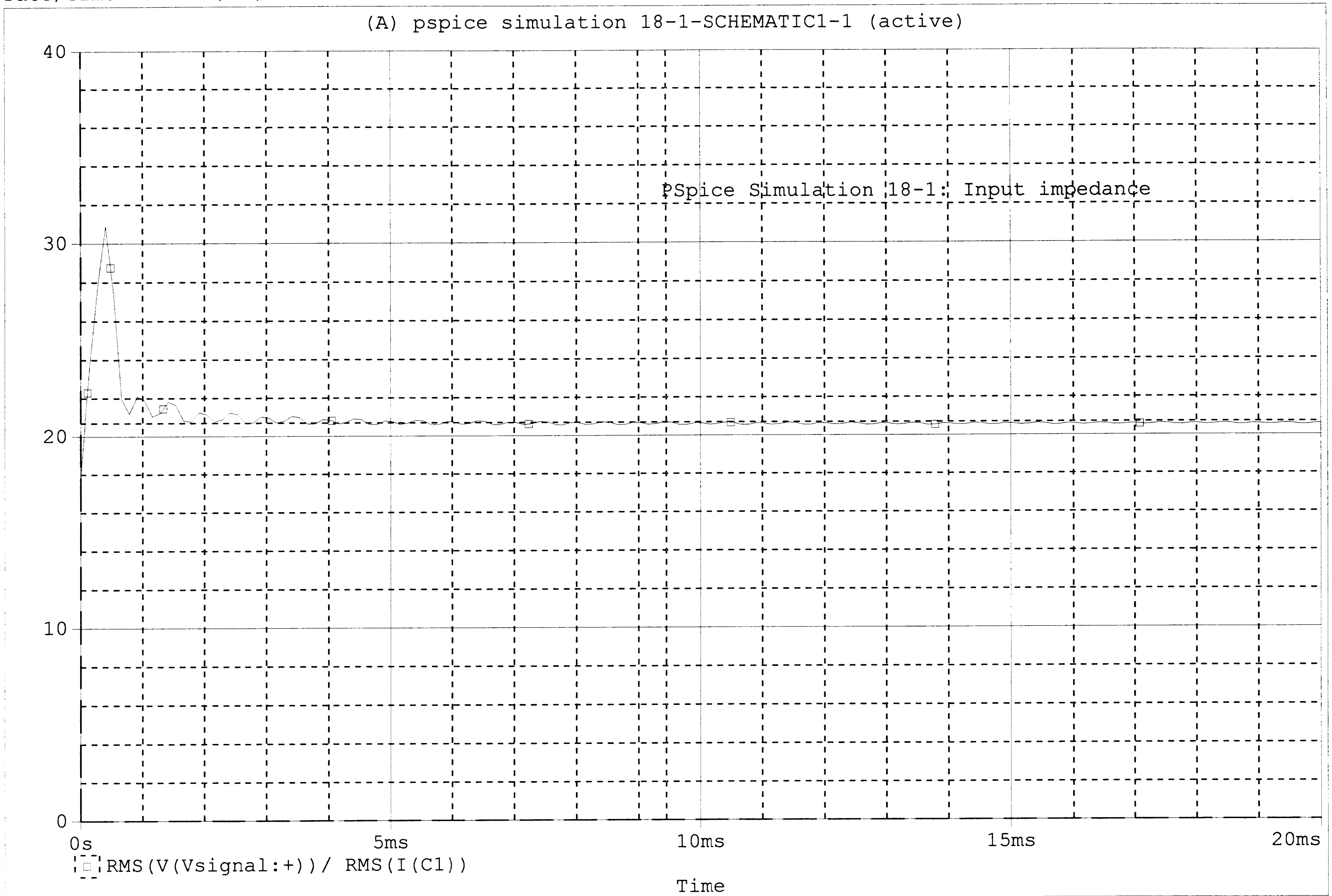
Date/Time run: 12/30/04 14:29:31
Temperature: 27.0
(A) pspice simulation 18-1-SCHEMATIC1-1 (active)
PSpice Simulation 18-1: Vsignal versus Vout
phase shift = 38 degrees
Vout
2.0V
1.0V
0V
-1.0V
-2.0V
Vsignal
10mV
5mV
0V
-5mV
-10mV
0s
0.4ms
0.8ms
1.2ms
1.6ms
2.0ms
Time
V(OUT)
V(Vsignal:+)
A1:(968.224u,-1.9774m) A2:(862.694u,-395.480m) DIFF(A):(105.530u,393.503m)
Date: December 30, 2004
Page 1
Time: 14:34:59

** Profile: "SCHEMATIC1-1" [C:\Program Files\OrcadLite\My Documents\Lab Revision PSpice 16-20\pspic...
Date/Time run: 03/10/04 12:55:16 Temperature: 27.0



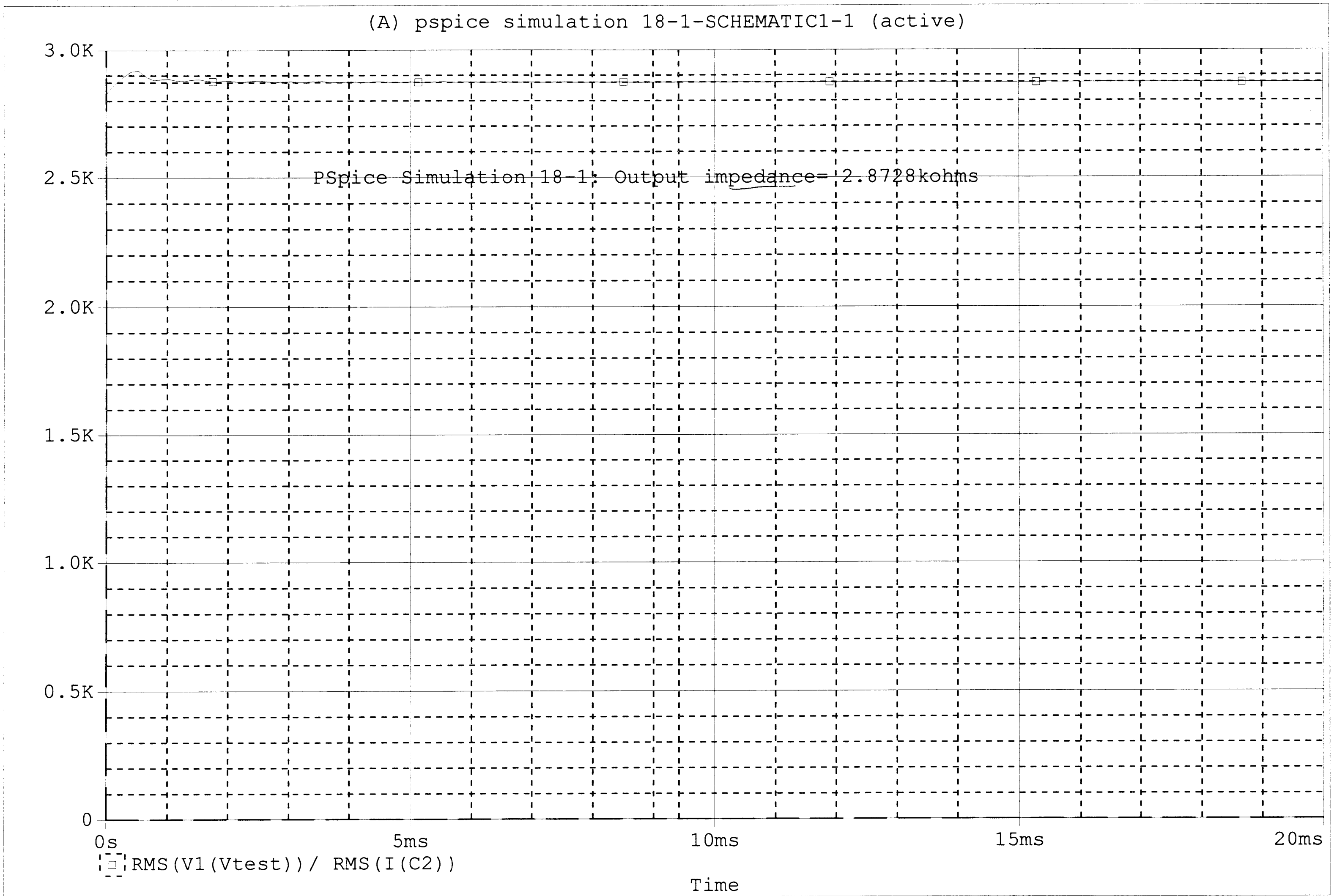
A1:(10.444m,141.590) A2:(0.000,0.000) DIFF(A):(10.444m,141.590)
Date: March 10, 2004 Page 1 Time: 12:59:32

** Profile: "SCHEMATIC1-1" [C:\Program Files\OrcadLite\My Documents\Lab Revision PSpice 16-20\pspic...
Date/Time run: 03/22/04 11:42:05 Temperature: 27.0



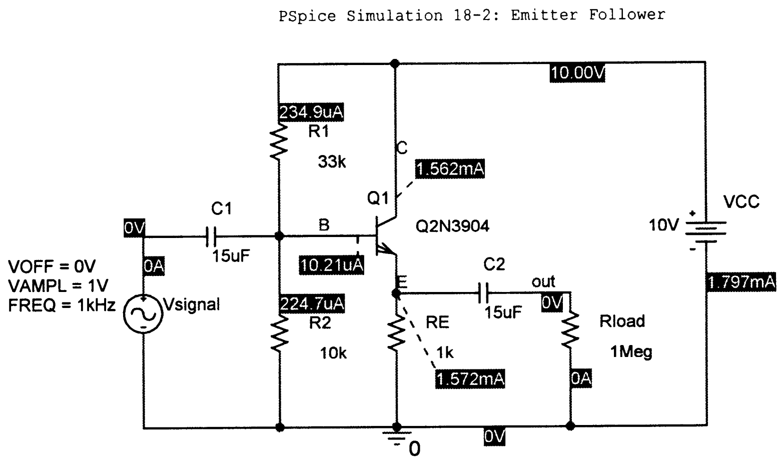
A1:(9.4493m,20.692) A2:(0.000,0.000) DIFF(A):(9.4493m,20.692)
Date: March 22, 2004 Page 1 Time: 11:43:31

** Profile: "SCHEMATIC1-1" [C:\Program Files\OrcadLite\My Documents\Lab Revision PSpice 16-20\pspic...
Date/Time run: 03/22/04 11:55:06   Temperature: 27.0



A1:(9.4170m,2.8728K) A2:(0.000,0.000) DIFF(A):(9.4170m,2.8728K)
Date: March 22, 2004   Page 1   Time: 11:57:21

PSpice Simulation 18-2
Bias Point Analysis
1. See Circuit diagram.

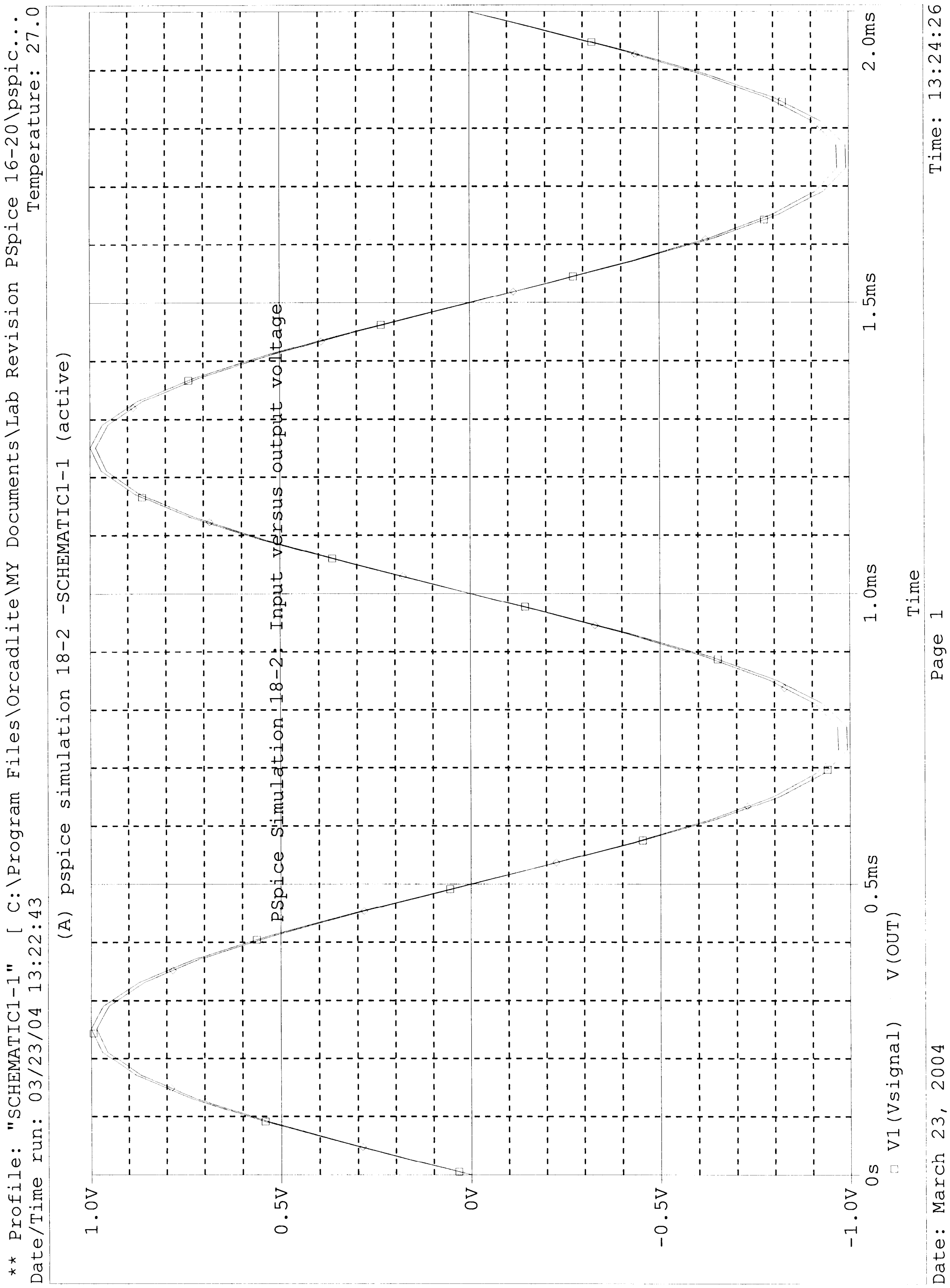


2. See circuit diagram.
4. $r_e = 16.65\ \Omega$
5. $A_v = 0.98$
6. $Z_{in} = 7.31\ k\Omega$
7. $Z_{out} \cong r_e = 16.65\ k\Omega$

Transient Data
1. See Probe plot page 282.
2. 0.0°
4. 0.981

Input Impedance
1. 7.35 kΩ

Output Impedance
1. 58.63 Ω

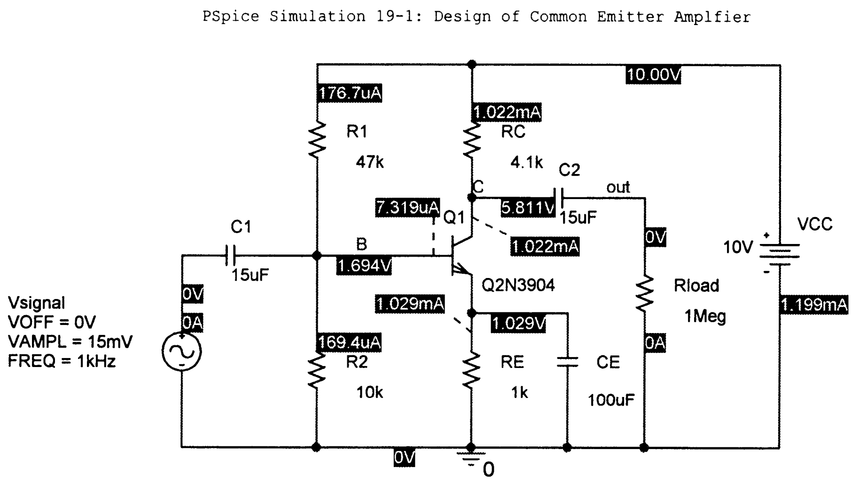

** Profile: "SCHEMATIC1-1" [C:\Program Files\Orcadlite\MY Documents\Lab Revision PSpice 16-20\pspic...
Date/Time run: 03/23/04 13:22:43
Temperature: 27.0
(A) pspice simulation 18-2 -SCHEMATIC1-1 (active)
PSpice Simulation 18-2: Input versus output voltage
1.0V
0.5V
0V
-0.5V
-1.0V
0s
0.5ms
1.0ms
1.5ms
2.0ms
V1(Vsignal)
V(OUT)
Time
Date: March 23, 2004
Page 1
Time: 13:24:26

EXPERIMENT 19: DESIGN OF COMMON-EMITTER AMPLIFIERS

Part 2. Computer Analysis

PSpice Simulation 19-1

1. See Circuit diagram.



3. $\beta = 139.6$
4. $V_{CE} = 4.78$ V
5. Yes

Transient Analysis
1. $A_V = 147.9$
2. Yes
4. $Z_{in} = 2.78$ kΩ
5. Yes
8. $Z_{out} = 3.893$ kΩ
9. Yes

Part 3: Build and Test CE Circuit

b. V_B(measured) = 1.54 V
V_E(measured) = .87 V
V_C(measured) = 7.15 V
$I_C = I_E = V_E/R_E$ = .87 V/979 = .89 mA
$r_e = 26$ mV/I_E = 26 mV/.89 mA = 29.3 ohms

c. V_{sig} = 10 mV
V_L(measured) = .815 V
$A_V = (R_C \parallel R_L)/r_e$ = (3.2 K || 10.2 K)/29.3 = 80.7

d. V_{sig} = 20.5 mV
R_X = 3.17 Kohms
V_i(measured) = 8.8 mV
$Z_i = (R_1 \parallel R_2 \parallel \text{Beta}*r_e)$ = (100.2 K || 21.6 K || 100 * 29.3 = 2.4 Kohms

e. V_O(measured) = 1.08 V
$Z_O = (V_O - V_L)/V_L*R_L$ = (1.08 – .82)/.82 * 10.2 K = 3.25 Kohms

f.

	Design parameter	Measured value
A_V	100 min.	80.7
Z_i (Kohms)	1 Kmin.	2.38 K
Z_O (Kohms)	10 Kmax.	3.35 K
$V_O$max(p–p)	3 Vp–p min.	7.1 Vp–p

The design of the circuit was successful 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 AMPLIFIERS

Part 1: Measurement of I_{DSS} and V_P

a. I_{DS} = 9.1 mA
b. V_P = –2.9 V

Part 2: DC Bias of Common-Source Circuit

a. V_{GS} = –1.33 V
I_D = 2.55 mA
$V_D = V_{DD} – I_D * R_D$ = 20 – 2.55 mA * 2.2 K = 13.8 V

c. V_G(measured) = 0 V
V_S(measured) = 1.46 V
V_D(measured) = 13.8 V
V_{GS}(measured) = –1.37 V
$I_D = V_D/R_S$ = 13.8/488 = 2.99 mA

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 * 9.1 mA/2.9 * (1 – 1.33/2.9) = 3.4 mS

therefore: A_V = –3.4 mS * 2.2 K = 7.48

b. V_{sig} = 10 mV
f = 1 KHz
V_O(measured) = 758 mV
$A_V = V_O/V_{\text{sig}}$ = 758 mV/100 mV = 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) = 1 Megohm
b. $Z_O = R_D$
Z_O(expected) = 2.25 Kohms
c. V_i(measured) = 37.2 mV
Z_i(calculated) = $V_i * R_X(V_{\text{sig}} – V_i)$ = 592 Kohms

d. V_O(measured) = 760 mV
R_L(measured) = 9.9 Kohms
V_L(measured) = 620 mV
$Z_O = (V_O - V_L) * R_L/V_L$ = (760 mV – 620 mV) * 9.9 K/620 mV = 2.24 Kohms

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.

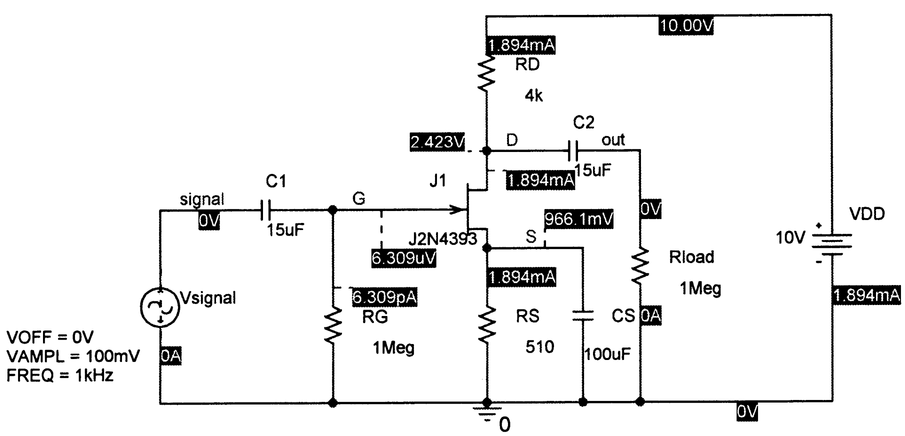
The two values of the output impedance are in far better agreement. They differ only by .44 percent.

Part 5: Computer Exercises

PSpice Simulation 20-1

1. See Circuit diagram.

PSpice Simulation 20-1: Common Source amplifier



3. g_{mo} = 21.15 mS; g_m = 7.48 mS
4. A_v = –17.9
6. A_v = –19.47
8. Z_{in} = 954.64 kΩ
11. Z_{out} = 2.34 kΩ
13. A_v
14. $A_v|_{R_D}$ = 4 kΩ = 21.93

EXPERIMENT 21: MULTISTAGE AMPLIFERS: RC COUPLING

Part 1: Measurement of I_{DSS} and V_P

I_{DSS} = 10.4 mA
V_P = –3.2 V

Part 2: DC Bias of Common-Source Circuit

a. V_{GS1}(calculated) = –1.36 V
I_{D1}(calculated) = 3.1 mA
V_{D1}(calculated) = $V_{DD} - I_{D1} * R_{D1}$ = 20 V – 3.1 mA * 2.2 K = 13.2 V
V_{GS2}(calculated) = –1.38 V
I_{D2}(calculated) = 3.54 mA
V_{D2}(calculated) = $V_{DD} - I_{D2} * R_{D2}$ = 20 V – 3.54 mA * 2.2 K = 12.2 V

c. V_{G1}(measured) = 0 V
V_{S1}(measured) = 1.49
V_{D1}(measured) = 13.81 V
V_{GS1}(measured) = –1.04 V
$I_{D1} = V_{S1}/R_{S1}$ = 1.49 V/496 = 3 mA
V_{G2}(measured) = 0 V
V_{S2}(measured) = 1.52 V
V_{D2}(measured) = 11.3 V
V_{GS2}(measured) = –.8 V
$I_{D2} = V_{S2}/R_{S2}$ = 1.52 V/468 = 3.25 mA

The theoretical and the measured bias values were consistently in close agreement.

Part 3: AC Voltage Gain of Amplifier

a. For stage 2:
$A_{V2} = -g_{m2}(R_{D2} \parallel R_L)$ = (–3.64 mS)(2.2 K || 10 K) = 6.6

For stage 1:
$A_{V1} = -g_{m1}(R_{D1} \parallel Z_{i2})$ = (–3.51 mS)(2.2 K || 1 M) = 7.72
note: $Z_{i2} = R_{G2}$ = 1 Megohm

$A_V = A_{V1} * A_{V2}$ = 6.6 * 7.72 = 50.7

b. V_{sig}(measured) = 20 mV
V_L(measured) = 945 mV
$A_V = V_L/V_{\text{sig}}$ = 945 mV/20 mV = 47.3
V_{O1}(measured) = 145 mV
V_{sig}(measured) = 20 mV
$A_{V1} = V_{O1}/V_{\text{sig}}$ = 145 mV/20 mV = 7.25
$A_{V2} = V_L/V_{O1}$ = 945 mV/145 mV = 6.52

The voltage gains differed by less than 10 percent from each other.

Part 4: Input and Output Impedance Measurements

a. $Z_i = R_{G1}$ = 1 Megohm

b. $Z_O = R_{D2}$ = 2.2 Kohms

c. V_{i1}(measured) = 7.5 mV
V_{sig} = 20 mV
R_X = 1 Megohm
$Z_i = V_{i1} * R_X/(V_{sig} - V_{i1})$ = 7.5 mV * 1 M/(20 mV – 7.5 mV) = 600 Kohms

d. V_L(measured) = 330 mV
V_O(measured) = 410 mV
$Z_O = (V_O - V_L) * R_L/V_L$ = (410 mV – 330 mV) * 10 K/330 mV = 2.42 Kohms

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.

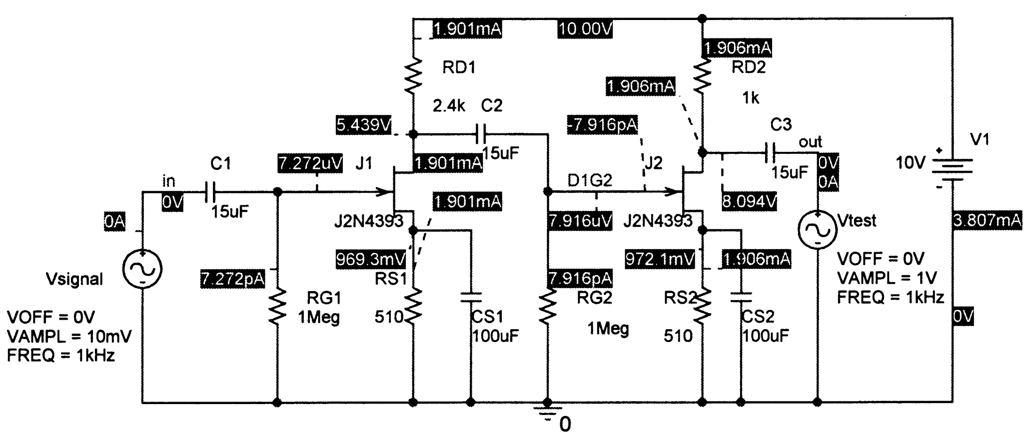
The output impedances again are in reasonable agreement, differing by no more than 9 percent from each other.

Part 5: Computer Exercise

Pspice Simulation 21-1

1. See circuit diagram.

PSpice Simulation 21-1: Multistage Common Source Circuit



3. g_{mo} = 21.15 mS
g_{mJ1} = 7.48 mS
g_{mJ2} = 7.48 mS
4. A_{v1} = 17.95 A_{v2} = 7.48
6. A_{v1} = 19.498

7. $A_{v2} = 8.275$
10. $(A_{v1})(A_{v2}) = 161.35$
11. $(A_{v1})(A_{v2}) = 161.35$
14. Yes
16. Interchange J1 with J2
17. $Z_{in} = 956.89\ k\Omega$
20. $Z_{out} = 989.74\ \Omega$

EXPERIMENT 22: CMOS CIRCUITS

Part 1: CMOS Inverter Circuit

Table 22.1

IN	OUT
0V	5V
5V	.3V

Table 22.2

IN	OUT
0V	5V
5 V	.3 V

Part 2: CMOS Gate

Table 22.3

A	B	OUTPUT
0 V	0 V	5 V
0 V	5 V	0 V
5 V	0 V	0 V
5 V	5 V	0 V

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

Part 4: Computer Exercise

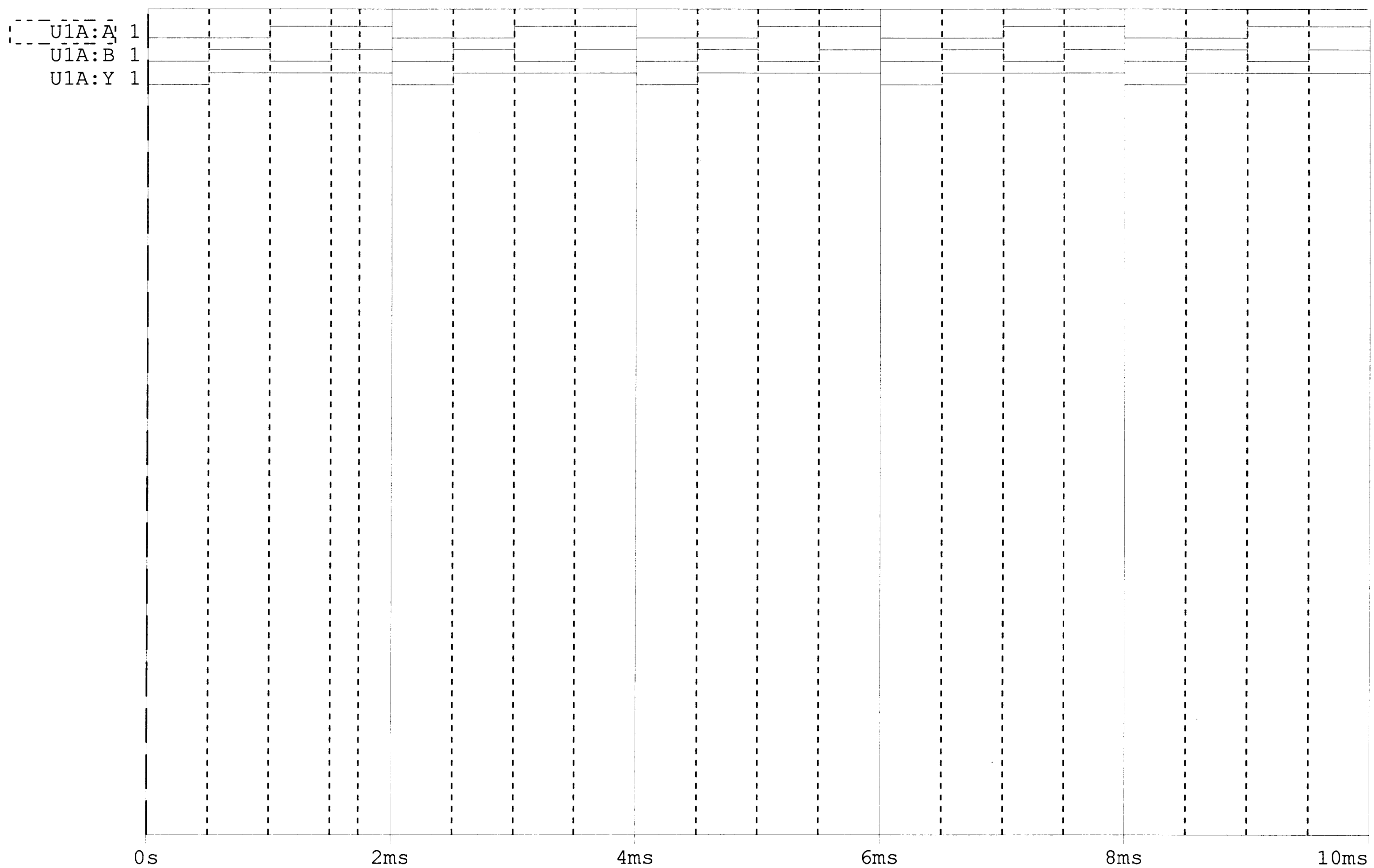
1. See Probe plot page 291.
2. No

VPlot data

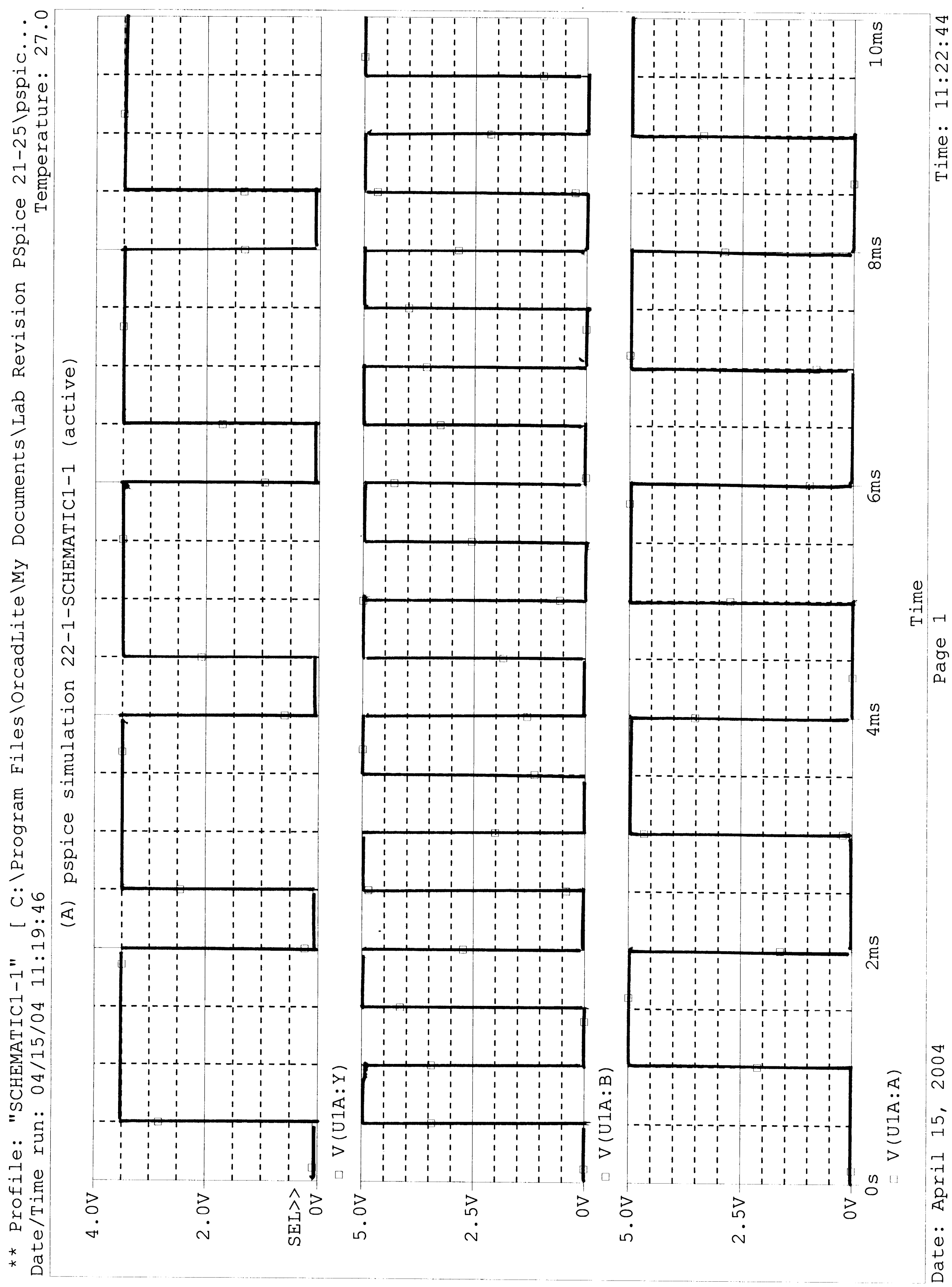
1. See Probe plot page 292.

** Profile: "SCHEMATIC1-1" [C:\Program Files\OrcadLite\My Documents\Lab Revision PSpice 21-25\pspic...
Date/Time run: 04/14/04 14:11:45 Temperature: 27.0

(A) pspice simulation 22-1-SCHEMATIC1-1 (active)



A1:(1.7341m),1 A2:(0.000),0 DIFF(A):(1.7341m)
Date: April 14, 2004 Page 1 Time: 14:13:20


** Profile: "SCHEMATIC1-1" [C:\Program Files\OrcadLite\My Documents\Lab Revision PSpice 21-25\pspic...
Date/Time run: 04/15/04 11:19:46
Temperature: 27.0
(A) pspice simulation 22-1-SCHEMATIC1-1 (active)
4.0V
2.0V
SEL>>
0V
V(U1A:Y)
5.0V
2.5V
0V
V(U1A:B)
5.0V
2.5V
0V
0s
2ms
4ms
6ms
8ms
10ms
V(U1A:A)
Time
Date: April 15, 2004
Page 1
Time: 11:22:44

EXPERIMENT 23: DARLINGTON AND CASCODE AMPLIFIER CIRCUITS

Part 1: Darlington Emitter-Follower Circuit

a. V_B(calculated) = 2.21 V
V_E(calculated) = 1.01 V
$A_V = R_E/(R_E + r_e)$ = 47/(47 + 10) = .83

b. V_B(measured) = 5.9 V
V_E(measured) = 4.94 V
I_B(calculated) = 199 μA
I_E(calculated) = 106 mA
β(calculated) = 106 mA/199 μA = 535

c. V_i(measured) = 350 mV
V_O(measured) = 340 mV
$A_V = V_O/V_i$ = 340 mV/350 mV = .97

Part 2: Darlington Input and Output Impedance

a. Z_i(calculated) = 20.6 K || (535 * 47) = 11.3 Kohms
$Z_O = r_e + (R_G \| R_B)/\beta$ = 9 ohms

b. V_{sig} = 500 mV
V_i(measured) = 55.6 mV
$Z_i = [V_i/(V_{\text{sig}} - V_i) * Rx$ = [55.6 mV/(500 mV – 55.6 mV)] * 100 K = 12.5 Kohms

c. V_O(measured) = 492 mV
V_L(measured) = 476 mV
R_L = 100 ohms
$Z_O = [(V_O - V_L)/V_L] * R_L$ = [(492 mV – 476 mV)/476 mV] * 100 = 4.2 ohms

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) = 5.5 V
V_{E1} (calculated) = 4.8 V
V_{C1} (calculated) = 11 V
V_{B2} (calculated) = 12 V
V_{E2} (calculated) = 11.3 V
V_{C2} (calculated) = 12.5 V
$I_{E1} = V_{E1}/R_{E1}$ = 4.8 V/1 k = 4.8 mA
I_{E2} = 11.3/1.8 K = 6.24 mA
$r_{e1} = 26\text{ mV}/I_{E1}$ = 26 mV/4.8 mA = 5.4 ohms
$r_{e2} = 26\text{ mV}/I_{E2}$ = 26 mV/6.24 mA = 4.2 ohms

b. V_{B1} (measured) = 4.69 V
V_{E1} (measured) = 4.0 V

V_{C1} (measured) = 10.7 V
V_{B2} (measured) = 12.0 V
V_{E2} (measured) = 10.5 V
V_{C2} (measured) = 12.3 V
I_{E1} (calculated) = V_{E1}/R_{E1} = 4 V/1 K = 4 mA
I_{E2} (calculated) = V_{E2}/R_{E2} = 10.5/1.8 K = 5.2 mA
r_{e1} = 26 mV/I_{E1} = 26 mV/4 mA = 6 ohms
r_{e2} = 26 mV/I_{E2} = 26 mV/5.2 mV = 5 ohms

c. A_{V1} = –1 (as per equation 23.5)
A_{V2} = R_C/r_{e2} = 1.8 K/5 = 360

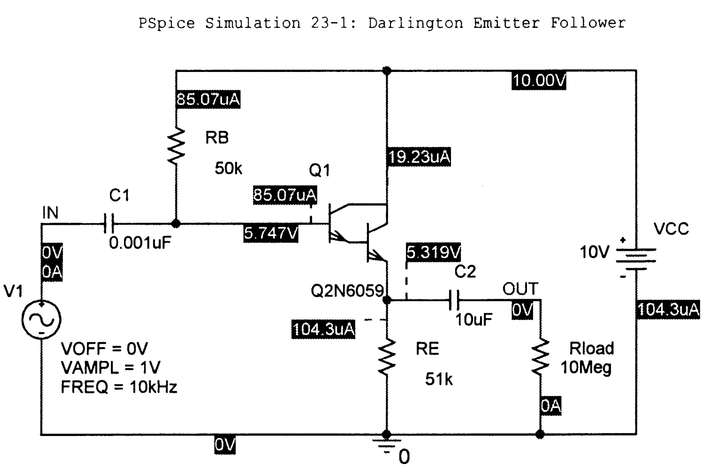
d. V_{sig} = 10 mV
V_i (measured) = 8 mV
V_{O2} (measured) = 7.91 mV
V_{O1} (measured) = 948 mV
A_{V1} (calculated) = $-V_{O1}/V_i$ = 7.91/8 mV = –.98
A_{V2} (calculated) = V_{O2}/V_{O1} = 948 mV/7.91 mV = 120
A_V = V_{O2}/V_i = –948 mV/8 mV = –119

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.

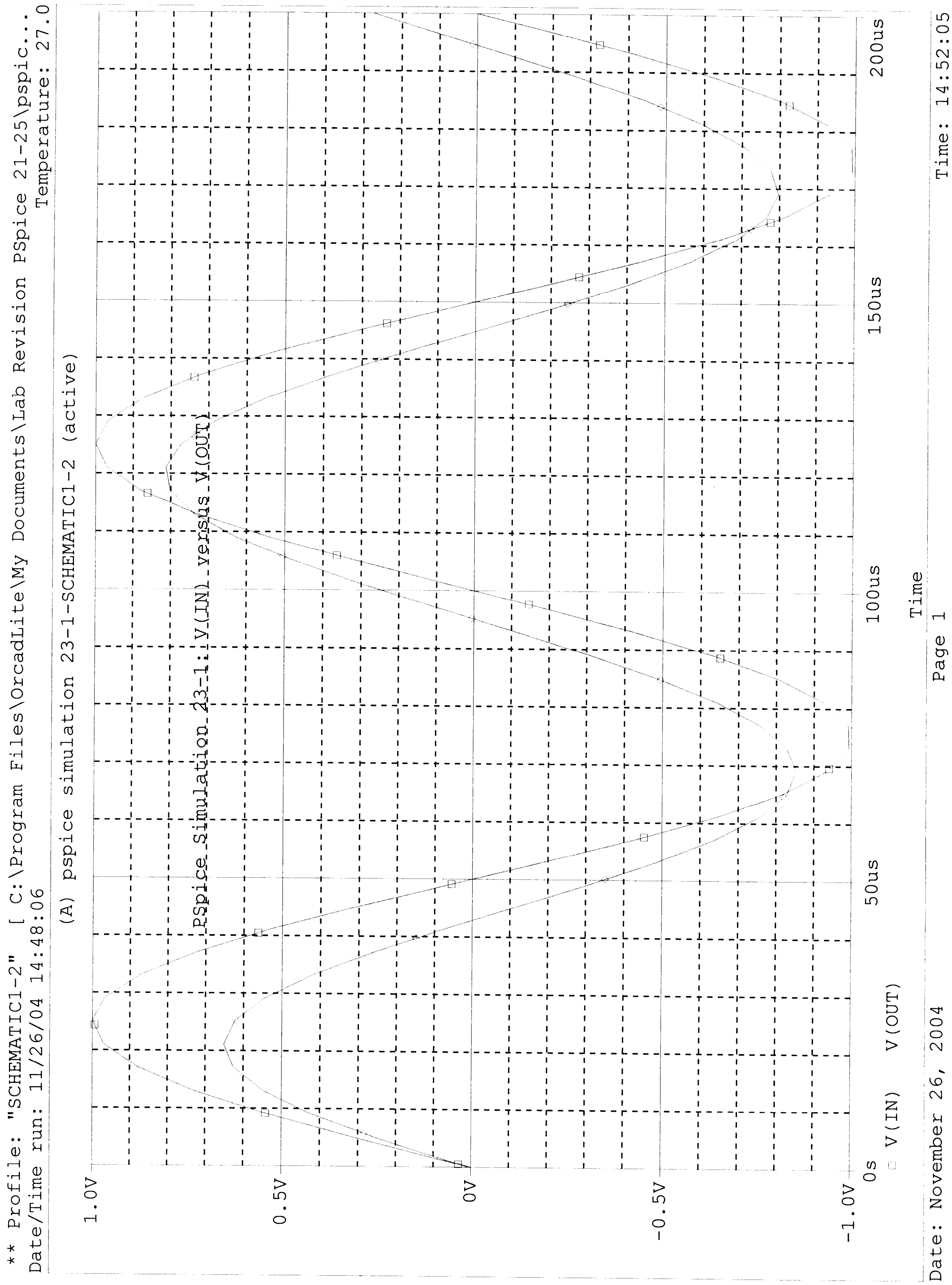
Part 4: Computer Exercises

PSpice Simulation 23-1

1. See circuit diagram.

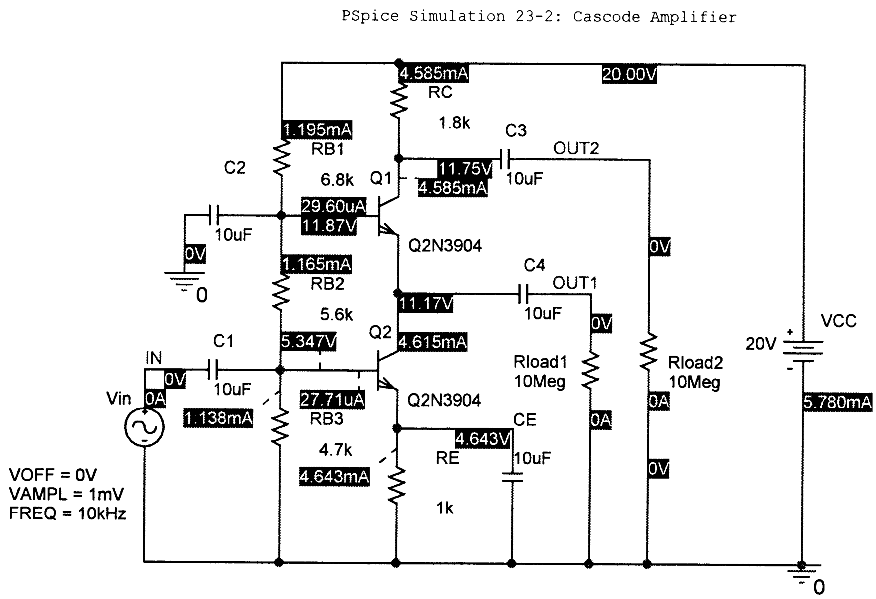


2. r_e = 249 Ω
3. See Probe plot page 295.
4. See Probe plot page 295.
5. See Probe plot page 295.
6. A_V = 0.787
9. Z_{in} = 47.123 kΩ
Z_{out} = 2.04 kΩ


** Profile: "SCHEMATIC1-2" [C:\Program Files\OrcadLite\My Documents\Lab Revision PSpice 21-25\pspic...
Date/Time run: 11/26/04 14:48:06
Temperature: 27.0
(A) pspice simulation 23-1-SCHEMATIC1-2 (active)
PSpice Simulation 23-1: V(IN) versus V(OUT)
1.0V
0.5V
0V
-0.5V
-1.0V
0s
50us
100us
150us
200us
V(IN) V(OUT)
Time
Date: November 26, 2004
Page 1
Time: 14:52:05

PSpice Simulation 23-2

1. See circuit diagram.



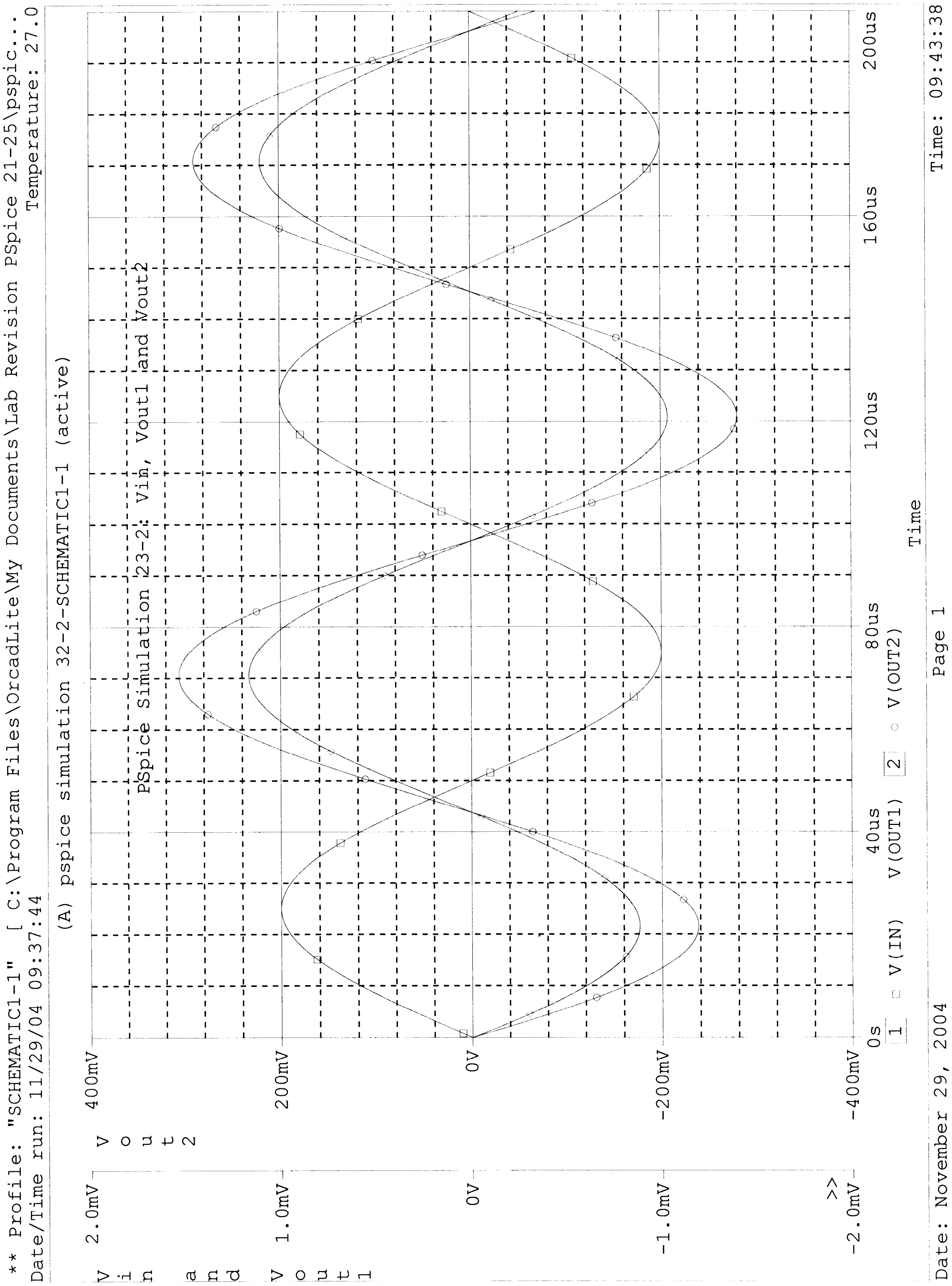
2. $r_{e_{Q1}} = 5.63\ \Omega$ $r_{e_{Q2}} = 5.6\ \Omega$

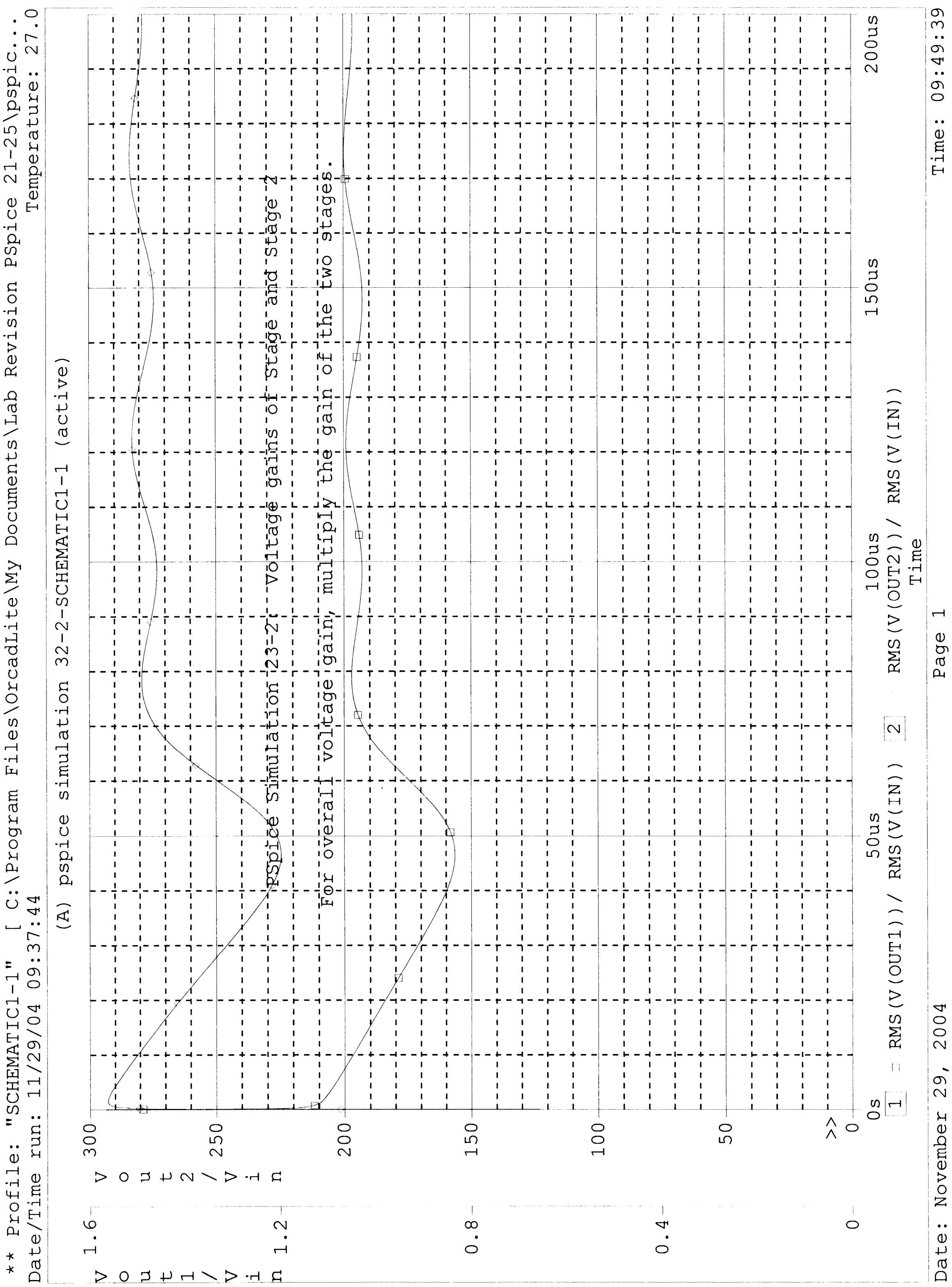
5. See Probe plot page 297.

7. See Probe plot page 298.

8. For Q_1; $A_V = \dfrac{R_C}{r_e} = \dfrac{1.8\text{ k}}{5.63\ \Omega} = 319$

For Q_2; $A_V = \dfrac{r_e}{r_e} = \dfrac{5.6\ \Omega}{5.6\ \Omega} = 1$


** Profile: "SCHEMATIC1-1" [C:\Program Files\OrcadLite\My Documents\Lab Revision PSpice 21-25\pspic...
Date/Time run: 11/29/04 09:37:44
Temperature: 27.0
(A) pspice simulation 32-2-SCHEMATIC1-1 (active)
PSpice Simulation 23-2: Vin, Vout1 and Vout2
Vin and Vout1
2.0mV
1.0mV
0V
-1.0mV
-2.0mV
Vout2
400mV
200mV
0V
-200mV
-400mV
0s
40us
80us
120us
160us
200us
1 V(IN) V(OUT1) 2 V(OUT2)
Time
Date: November 29, 2004
Page 1
Time: 09:43:38



** Profile: "SCHEMATIC1-1" [C:\Program Files\OrcadLite\My Documents\Lab Revision PSpice 21-25\pspic...
Date/Time run: 11/29/04 09:37:44
Temperature: 27.0
(A) pspice simulation 32-2-SCHEMATIC1-1 (active)
PSpice Simulation 23-2: Voltage gains of Stage and Stage 2
For overall voltage gain, multiply the gain of the two stages.
Vout1/Vin
1.6
1.2
0.8
0.4
0
Vout2/Vin
300
250
200
150
100
50
0
0s
50us
100us
150us
200us
1 RMS(V(OUT1))/ RMS(V(IN))
2 RMS(V(OUT2))/ RMS(V(IN))
Time
Date: November 29, 2004
Page 1
Time: 09:49:39

EXPERIMENT 24: CURRENT SOURCE AND CURRENT MIRROR CIRCUITS

Part 1: JFET Current Source

a. V_{DS} (measured) = 9.64 V

b. $I_L = (V_{DD} - V_{DS})/R_L = (10 - 9.64)/51.2 = 7.03$ mA

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 = 1.9 mA

b. V_E (measured) = –.68 V
V_C (measured) = .404 V

c. I_E (calculated) = 2.13 mA
I_L (calculated) = 1.88 mA

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 = .9 mA

b. V_{B1} = .669 V
V_{C2} = 2.24 V
I_X = .89 mA
I_L = 1.0 mA

c. I_X (calculated) = 1 mA
V_{B1} (measured) = .669 V
V_{C2} (measured) = 4.1 V
I_X = .9 mA
I_L = 1.5 mA

Part 4: Multiple Current Mirrors

a. I_X (calculated) = 1 mA

b. V_{B1} (measured) = .672 V
V_{C2} (measured) = 1.67 V
V_{C3} (measured) = 1.65 V
I_X = 1.01 mA
I_{L1} = 1.58 mA
I_{L2} = 1.78 mA

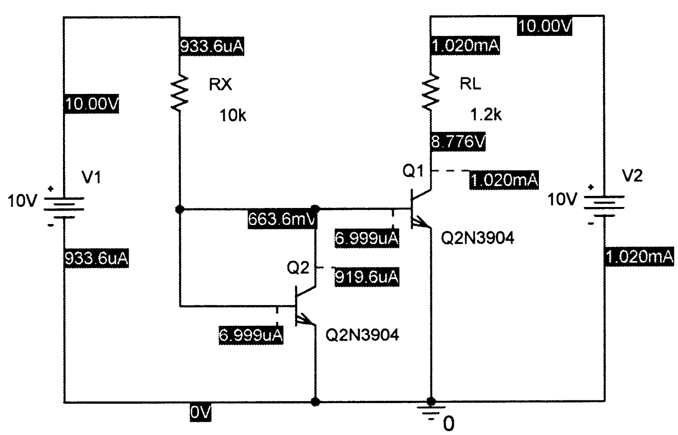
c. I_X (calculated) = 1 mA
V_{B1} (measured) = .672 V
V_{C2} (measured) = 3.81 V
V_{C3} (measured) = 2.87 V
I_X = 1.02 mA
I_{L1} = 1.73 mA
I_{L2} = 1.44 mA

Part 5: Computer Exercise

PSpice Simulation 24-1

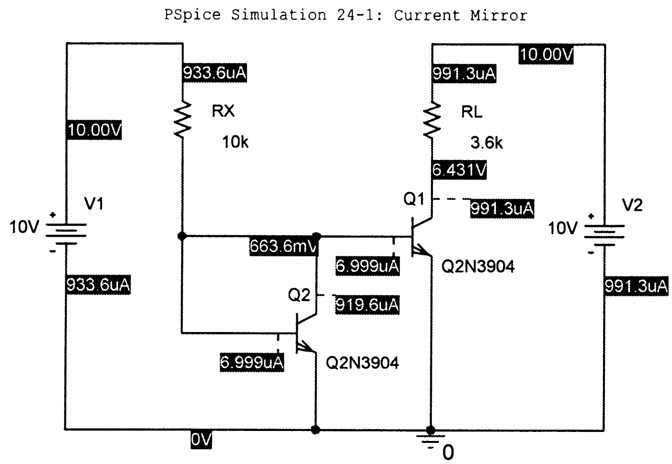
1. See circuit diagram.

PSpice Simulation 24-1: Current Mirror



2. $I(R_X)$ = 933.6 μA
$I(R_L)$ = 1.020 mA
3. Yes

4. See Circuit diagram.



5. $I(R_X) = 933.6\ \mu A$

   $I(R_L) = 991.3\ \mu A$

6. Yes
8. Yes
10. Yes
11. No
12. Yes

EXPERIMENT 25: FREQUENCY RESPONSE OF COMMON-EMITTER AMPLIFIERS

Résumé

$f_{L,1}$ = 1/(2 * 3.24 * 1.39 K * 10 μf) = 11.5 Hz
$f_{L,2}$ = 1/(2 * 3.24 * 6.1 K * 1 μf) = 26 Hz
$f_{L,E}$ = 1/(2 * 3.14 * 2.2 K * 20 μf) = 3.62 Hz
$f_{H,i}$ = 1/(2 * 3.14 * 1.68 K * 960 μf) = 98.7 KHz
$f_{H,O}$ = 1/(2 * 3.14 * 1.43 K * 45 pf) = 2.43 MHz

Part 1: Low-Frequency Response Calculations

a. C_{be} (specified) = 100 pf
C_{bc} (specified) = 10 pf
C_{ce} (specified) = 15 pf
$C_{W,i}$ (approximated) = 20 pf
$C_{W,o}$ (approximated) = 30 pf

b. β(measured) = 126

c. V_B (calculated) = 4.08 V
V_E (calculated) = 3.38 V
V_C (calculated) = 14 V
I_E (calculated) = 1.54 mA
r_e = 26 mV/I_E = 26 mV/1.54 mA = 16.9 ohms

d. A_V (mid) = (R_C || R_L)/r_e = (3.9 K || 2.2 K)/16.9 = 83.2

e. $f_{L,1}$ (calculated) = 11.5 Hz
$f_{L,2}$ (calculated) = 26.2 Hz
$f_{L,E}$ (calculated) = 3.62 Hz

Part 2: Low Frequency Response Measurements

b. V_{sig} (measured) = 30 mV
V_O (measured) = 2.1 V
A_V (mid) = 70

Table 25.1

f (Hz)	50	100	200	400	600	800	1 K	2 K	3 K	5 K	10 K
$V_{O(p-p)}$	.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	1 K	2 K	3 K	5 K	10 K
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) = 98.7 KHz
$f_{H,O}$ (calculated) = 2.47 MHz

b.

Table 25.3

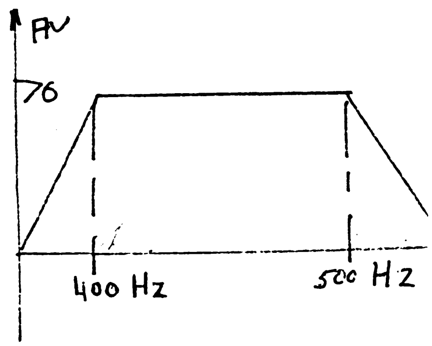
f (KHz)	10	50	100	300	500	600	700	900	1000	2000
$V_{O(p-p)}$	2.2	2.2	2.1	1.9	1.6	1.5	1.4	1.3	1.3	.8

Table 25.4

f (KHz)	10	50	100	300	500	600	700	900	1000	2000
A_V	73	73	70	63	53	20	46	40	40	27

Part 4: Plotting Bode Plot and Frequency Response

Fig 25.2



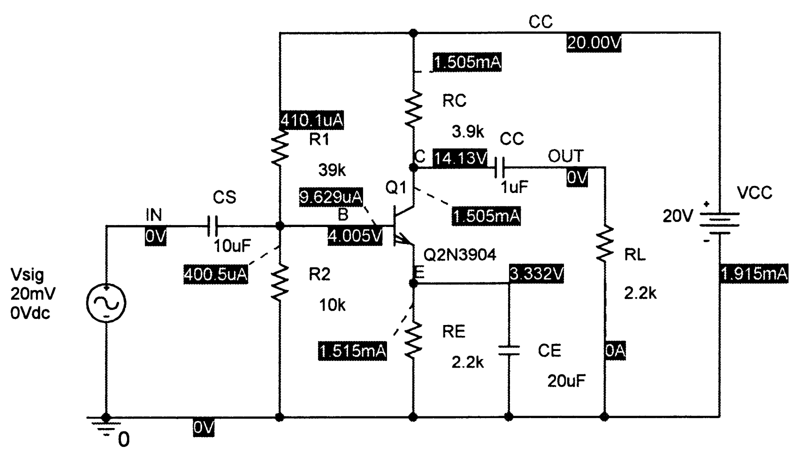
from plot: f_1 = 400 Hz
f_2 = 500 Hz

Part 5: Computer Exercise

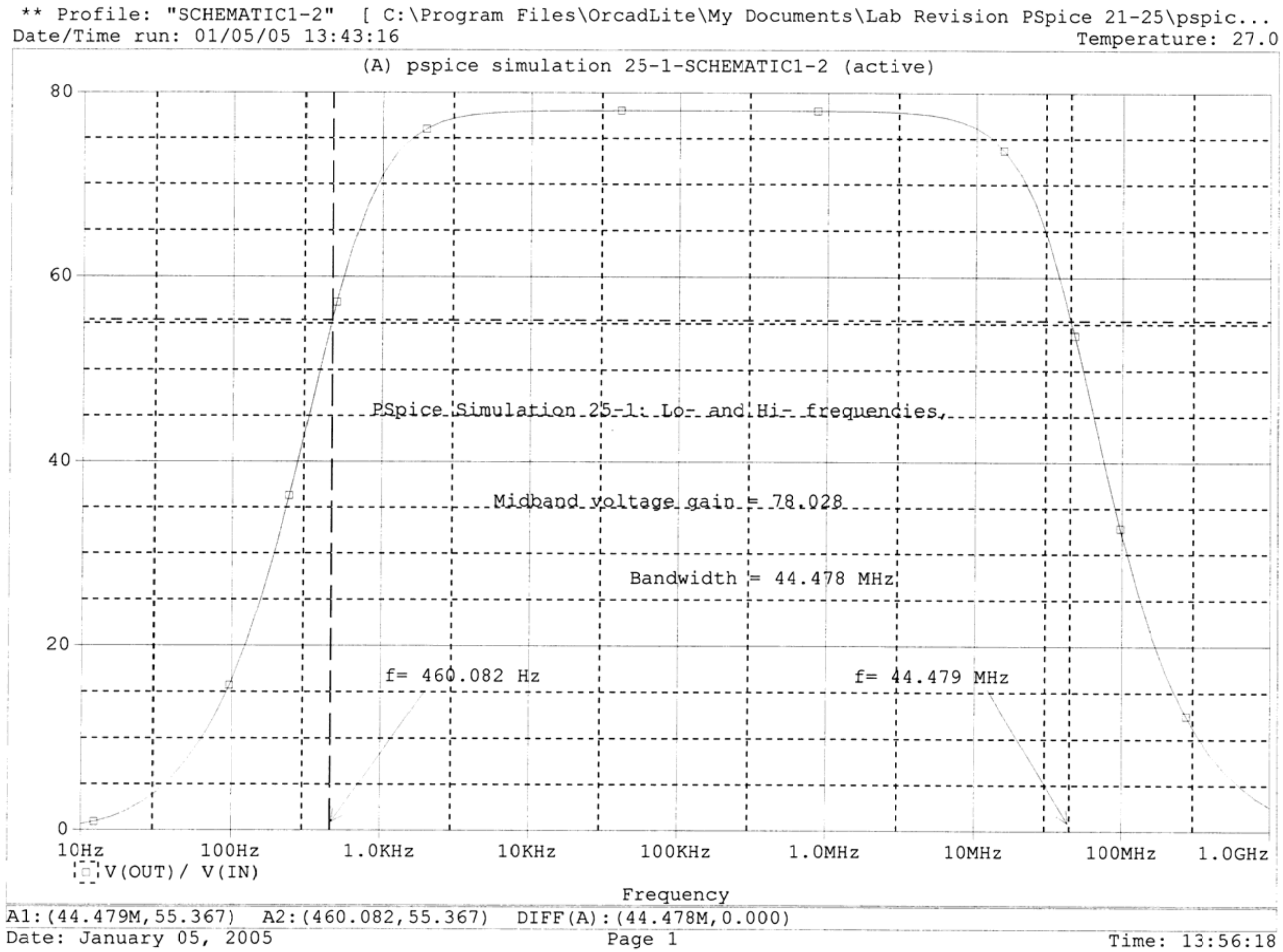
PSpice Simulation 25-1

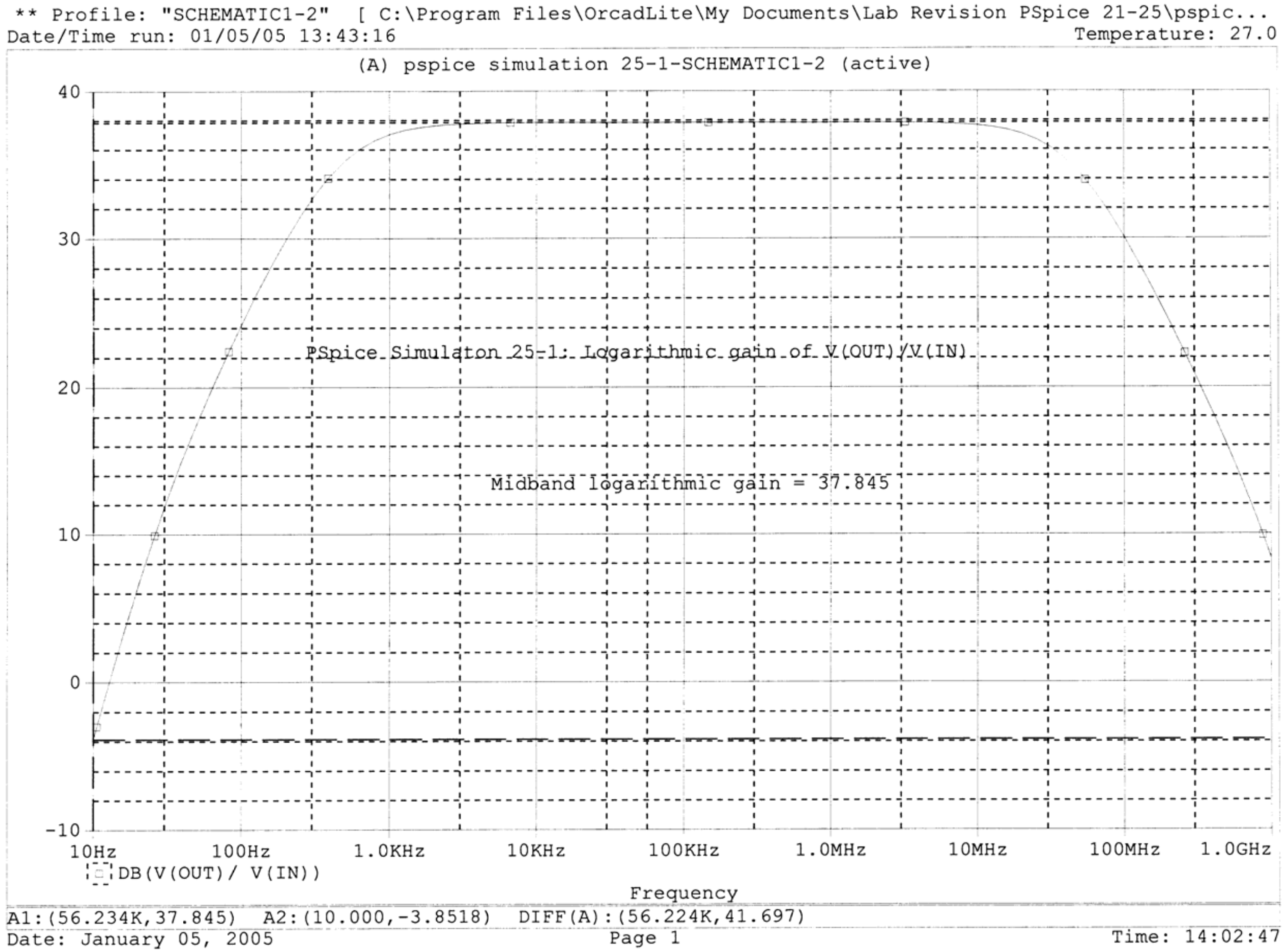
1. See circuit diagram.

PSpice Simulation 25-1: Frequency Response of Common Emitter Amplifier



2. r_e = 17.2 Ω; $A_{V\,\text{mid}}$ = 81.3
4. See Probe plot 346.
5. Almost identical
6. See Probe plot page 346.
7. See Probe plot page 347.
8. 20 log(78.028) = 37.84 both gains agree


** Profile: "SCHEMATIC1-2" [C:\Program Files\OrcadLite\My Documents\Lab Revision PSpice 21-25\pspic...
Date/Time run: 01/05/05 13:43:16
Temperature: 27.0
(A) pspice simulation 25-1-SCHEMATIC1-2 (active)
PSpice Simulation 25-1: Lo- and Hi- frequencies,
Midband voltage gain = 78.028
Bandwidth = 44.478 MHz
f= 460.082 Hz
f= 44.479 MHz
80
60
40
20
0
10Hz
100Hz
1.0KHz
10KHz
100KHz
1.0MHz
10MHz
100MHz
1.0GHz
V(OUT) / V(IN)
Frequency
A1:(44.479M,55.367) A2:(460.082,55.367) DIFF(A):(44.478M,0.000)
Date: January 05, 2005
Page 1
Time: 13:56:18


** Profile: "SCHEMATIC1-2" [C:\Program Files\OrcadLite\My Documents\Lab Revision PSpice 21-25\pspic...
Date/Time run: 01/05/05 13:43:16
Temperature: 27.0
(A) pspice simulation 25-1-SCHEMATIC1-2 (active)
40
30
20
10
0
-10
PSpice Simulaton 25-1: Logarithmic gain of V(OUT)/V(IN)
Midband logarithmic gain = 37.845
10Hz
100Hz
1.0KHz
10KHz
100KHz
1.0MHz
10MHz
100MHz
1.0GHz
DB(V(OUT)/ V(IN))
Frequency
A1:(56.234K,37.845) A2:(10.000,-3.8518) DIFF(A):(56.224K,41.697)
Date: January 05, 2005
Page 1
Time: 14:02:47

EXPERIMENT 26: CLASS A AND CLASS B POWER AMPLIFIERS

Part 1: Class A Amplifier: DC Bias

a. V_B (calculated) = 1.53 V
V_E (calculated) = .83 V
I_E (calculated) = I_C = V_E/R_E = .83/20 = 41 mA
V_C (calculated) = 5.1 V

b. V_B (measured) = 1.59 V
V_E (measured) = .88 V
V_C (measured) = 5.3 V
I_E (calculated) = I_C = V_E/R_E = .88/20 = 44 mA

Part 2: Class-A Amplifier: AC Operation

a. P_i (calculated) = 400 mW
V_O (calculated) = 5.3 Vp–p
P_O (calculated) = 29.3 mW
% efficiency (calculated) = 7.3 percent

b. V_i (measured) = 65 mV
V_o (measured) = 5 Vp–p

c. P_i = 400 mW
P_O = 26 mW
% 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) = 32.5 mVp–p
V_O (measured) = 3 Vp–p

e. P_i (calculated) = 400 mW
P_O (calculated) = 9.38 mW
% efficiency (calculated) = 2.3 percent

f. P_i = 400 mW
P_O = 93 mW
% efficiency = 2.3 percent

As stated previously, while the data is consistent, the values of the efficiency makes this not a practical circuit.

Part 3: Class-B Amplifier Operation

a. for V_O = 1 V_{peak}
P_i (calculated) = 1.59 W
P_O (calculated) = 50 mW
% efficiency (calculated) = 3.1 percent

for V_O = 2 V_{peak}
P_i = 1.59 W
P_O = 200 mW
% efficiency (calculated) = 12.6 percent

b. V_i (measured) = 2.9 Vp–p
V_O (measured) = 2.7 Vp–p
P_i = 890 mW
P_O = 91 mW
% efficiency = 10.2%

c. V_i (measured) = 5 Vp–p
V_O (measured) = 4 Vp–p
I_{dc} (measured) = 159 mA
P_i = 1.27 W
P_O = 637 mW
% efficiency = 50.2%

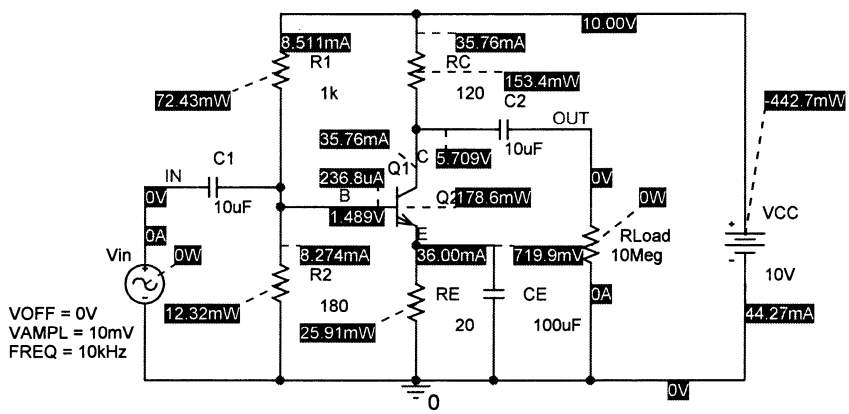
Note that the efficiency of the Class B amplifier increases with increasing input signal and consequent increasing output signal. Also observe that the two stages of the Class B amplifier shown in Figure 26.2 are in the emitter follower configuration. Thus, the voltage gain for each stage is near unity. 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.

Part 4: Computer Exercises

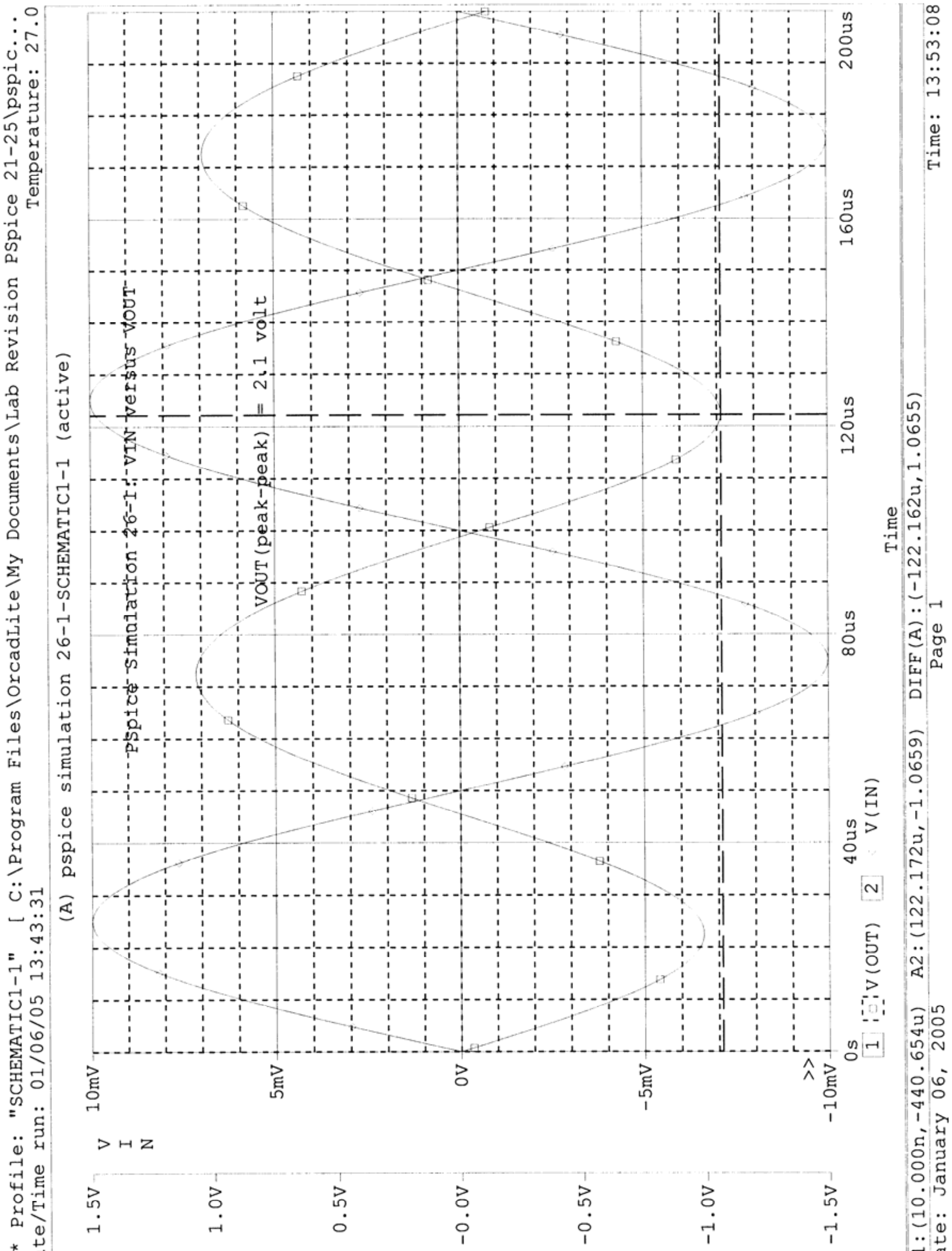
PSpice Simulation 26-1

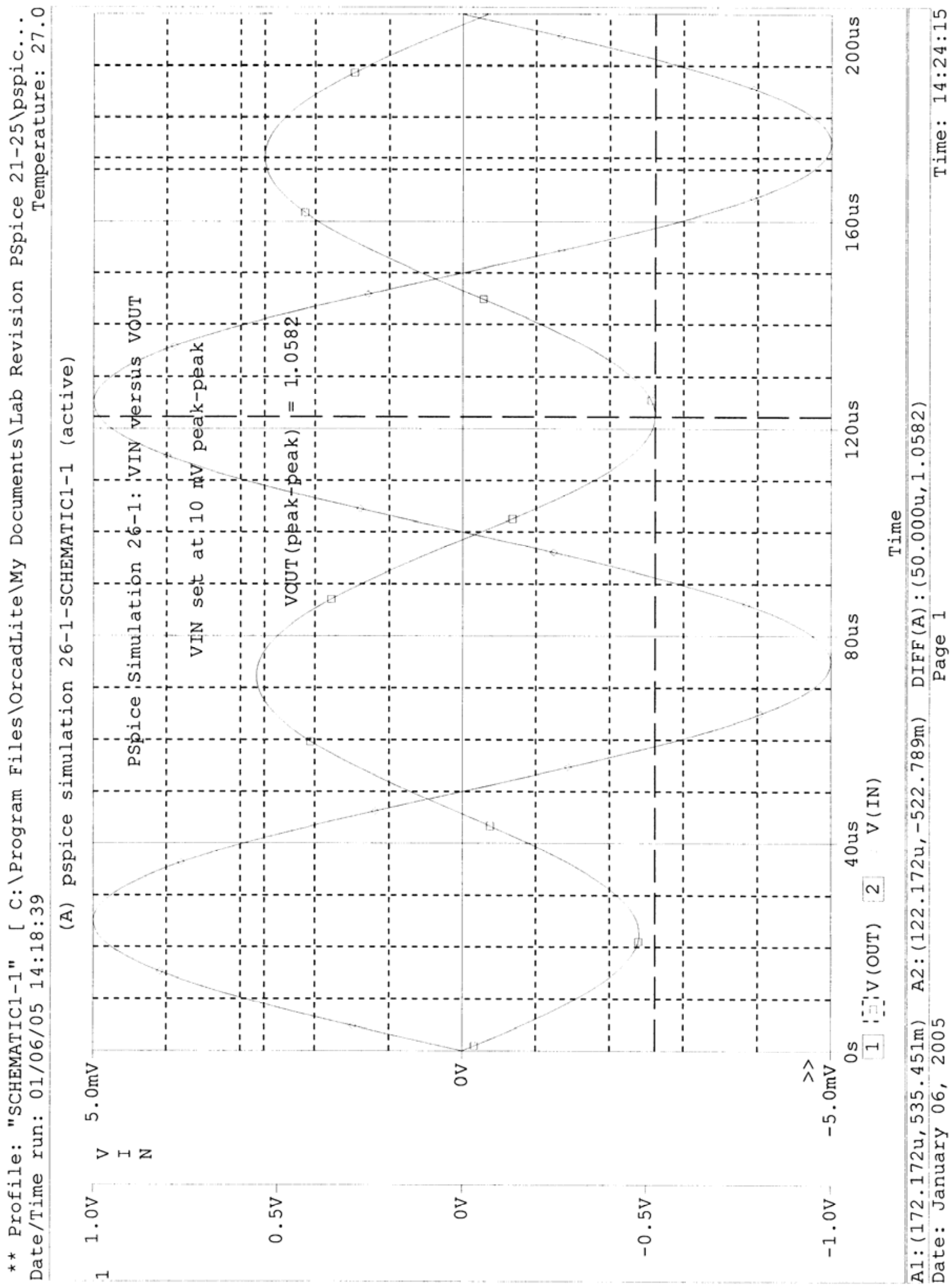
1. See Circuit diagram.

PSpice Simulation 26-1: Class- A Amplifier



2. Yes.
3. $V_{CE} = 5.709 \text{ V} - 0.719 \text{ V} = 4.98 \text{ V} \cong \frac{1}{2}(10 \text{ V})$
4. 442.7 mW
5. Q_1
7. See Probe plot page 309.
8. Yes
9. No
10. 180°
11. $P_o(\text{AC}) = 4.59$ mW
12. $\%\eta = 1.04\%$
13. DC values remain the same
    $P_o(\text{AC}) = 1.16$ mW
    $\%\eta = 0.26\%$
    See Probe plot page 310.

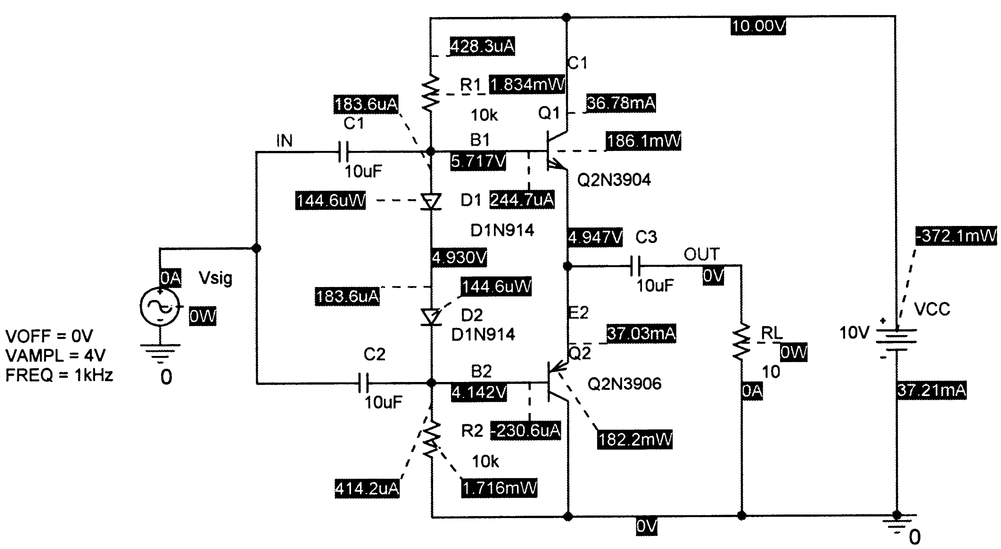

** Profile: "SCHEMATIC1-1" [C:\Program Files\OrcadLite\My Documents\Lab Revision PSpice 21-25\pspic...
Date/Time run: 01/06/05 13:43:31
Temperature: 27.0
(A) pspice simulation 26-1-SCHEMATIC1-1 (active)
PSpice Simulation 26-1: VIN versus VOUT
VOUT(peak-peak) = 2.1 volt
1.5V
1.0V
0.5V
-0.0V
-0.5V
-1.0V
-1.5V
VOUT
VIN
10mV
5mV
0V
-5mV
-10mV
0s
40us
80us
120us
160us
200us
Time
V(OUT)
V(IN)
A1:(10.000n,-440.654u) A2:(122.172u,-1.0659) DIFF(A):(-122.162u,1.0655)
Date: January 06, 2005
Page 1
Time: 13:53:08


** Profile: "SCHEMATIC1-1" [C:\Program Files\OrcadLite\My Documents\Lab Revision PSpice 21-25\pspic...
Date/Time run: 01/06/05 14:18:39
Temperature: 27.0
(A) pspice simulation 26-1-SCHEMATIC1-1 (active)
PSpice Simulation 26-1: VIN versus VOUT
VIN set at 10 mV peak-peak
VOUT(peak-peak) = 1.0582
1.0V
0.5V
0V
-0.5V
-1.0V
VIN
5.0mV
0V
-5.0mV
>>
0s
40us
80us
120us
160us
200us
1 V(OUT) 2 V(IN)
Time
A1:(172.172u,535.451m) A2:(122.172u,-522.789m) DIFF(A):(50.000u,1.0582)
Date: January 06, 2005
Page 1
Time: 14:24:15

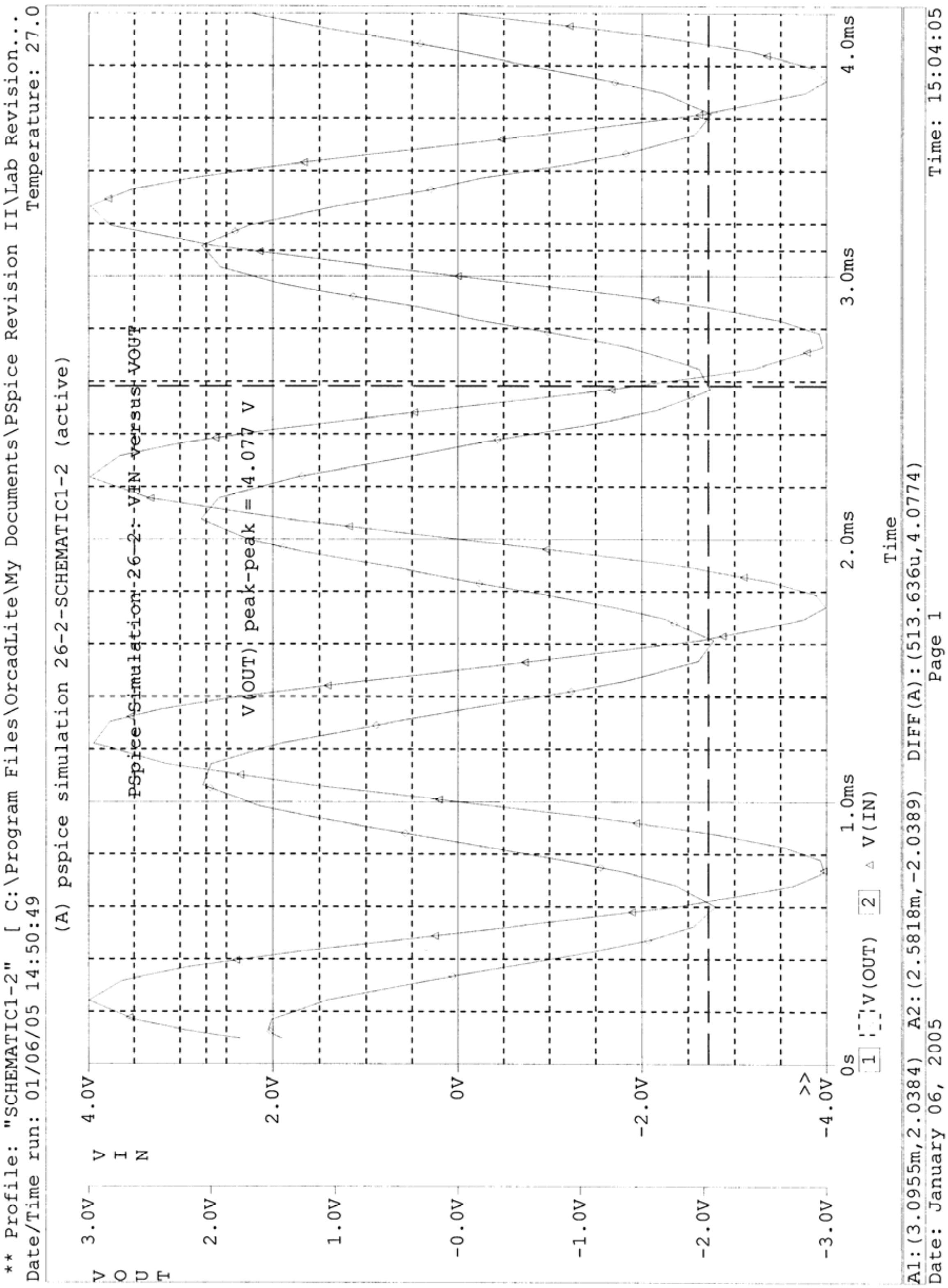
PSpice Simulation 26-2

1. See circuit diagram.
   P_i(DC) = 372.1 mW

Spice Simulation 26-2: Class B Amplifier



2. Q_1 and Q_2
3. Yes.
4. $V(E2) = 4.947\text{ V} \cong \frac{1}{2}(10\text{ V})$
5. $V(BE)_{Q1} = 0.77$ V
   $V(BE)_{Q2} = -0.81$ V
6. Maintain proper bias across Q_1 and Q_2.
7. 0.7 V
9. See Probe plot page 312.
10. $V(\text{OUT})_{p-p} = 4.077$ V
11. $\%\eta = 55.8\%$
14. $V(\text{OUT})_{p-p} = 2.187$ V
    $\%\eta = 16.1\%$


** Profile: "SCHEMATIC1-2" [C:\Program Files\OrcadLite\My Documents\PSpice Revision II\Lab Revision...
Date/Time run: 01/06/05 14:50:49
Temperature: 27.0
(A) pspice simulation 26-2-SCHEMATIC1-2 (active)
PSpice Simulation 26-2: VIN versus VOUT
V(OUT) peak-peak = 4.077 V
VIN
VOUT
4.0V
2.0V
0V
-2.0V
-4.0V
3.0V
2.0V
1.0V
-0.0V
-1.0V
-2.0V
-3.0V
0s
1.0ms
2.0ms
3.0ms
4.0ms
1 V(OUT) 2 V(IN)
Time
A1:(3.0955m,2.0384) A2:(2.5818m,-2.0389) DIFF(A):(513.636u,4.0774)
Date: January 06, 2005
Page 1
Time: 15:04:05

EXPERIMENT 27: DIFFERENTIAL AMPLIFIER CIRCUITS

Part 1: DC Bias of BJT Differential Amplifier

a. V_B (calculated) = 0V
V_E (calculated) = –.7 V
V_C (calculated) = 5.43 V
I_E (calculated) = 457 μA
r_e (calculated) = 57 ohms

b.

	$Q1$	$Q2$
V_B (measured)	–.10 V	0 V
V_E (measured)	–.65 V	–.65 V
V_C (measured)	5.10 V	4.9 V
I_E (calculated)	490 μA	510 μA
r_e	53 ohms	51 ohms

Part 2: AC Operation of BJT Differential Amplifier

a. $A_{V,d}$ (calculated) = 179
$A_{V,c}$ (calculated) = .5

b. V_{O1} (measured) = 1.48 V
V_{O2} (measured) = 1.43 V
$V_{O,d} = (V_{O,1} + V_{O,2})/2 = (1.48 + 1.43)/2 = 1.46$ V
$A_{V,d} = V_{O,d}/V_i = 72.8$

c. $V_{O,c}$ (measured) = .55 V
$A_{V,c} = V_{O,c}/V_i = .55$

Part 3: DC Bias of BJT Differential Amplifier with Current Source

a. For either $Q1$ or $Q2$:
V_B (calculated) = 0 V
V_E (calculated) = –.7 V
V_C (calculated) = 9 V
I_E (calculated) = .5 mA
r_e (calculated) = 52 ohms

For $Q3$:
V_B (calculated) = –5 V
V_E (calculated) = –5.7 V
V_C (calculated) = –.7 V
I_E (calculated) = 1 mA
r_e (calculated) = 26 ohms

b. For $Q1$, $Q2$, and $Q3$:

	Q_1	Q_2	Q_3
V_B (measured)	47 mV	0 mV	–4.69 V
V_E (measured)	–.64 V	–.64 V	–5.35 V
V_C (measured)	7.91 V	2.97 V	–.64 V
I_E (calculated)	110 μA	612 μA	783 μA
r_e (calculated)	236 ohms	42.5 ohms	33.2 ohms

Part 4: AC Operation of Differential Amplifier with Transistor Current Source

a. $A_{V,d} = R_C/(2 * r_e) = 10\text{ K}/(2 * 57.8) = 173$

Part 5: JEFT Differential Amplifier

a. For $Q1$: $I_{DSS} = 7.9$ mA
$V_P = –3.1$ V

For $Q2$: $I_{DSS} = 8.1$ mA
$V_P = –3.4$ V

For $Q3$: $I_{DSS} = 11.2$ mA
$V_P = –4.2$ V

b. $V_{D,1}$ (calculated) = 9.84 V
$V_{D,2}$ (calculated) = 9.84 V
$V_{S,1}$ (calculated0 = .845 V

c. $V_{G,1}$ (measured) = 0 V
$V_{D,1}$ (measured) = 9.71 V
$V_{D,2}$ (measured) = 9.72 V
$V_{D,3}$ (measured) = .84 V

d. $A_{V,d} = .184$

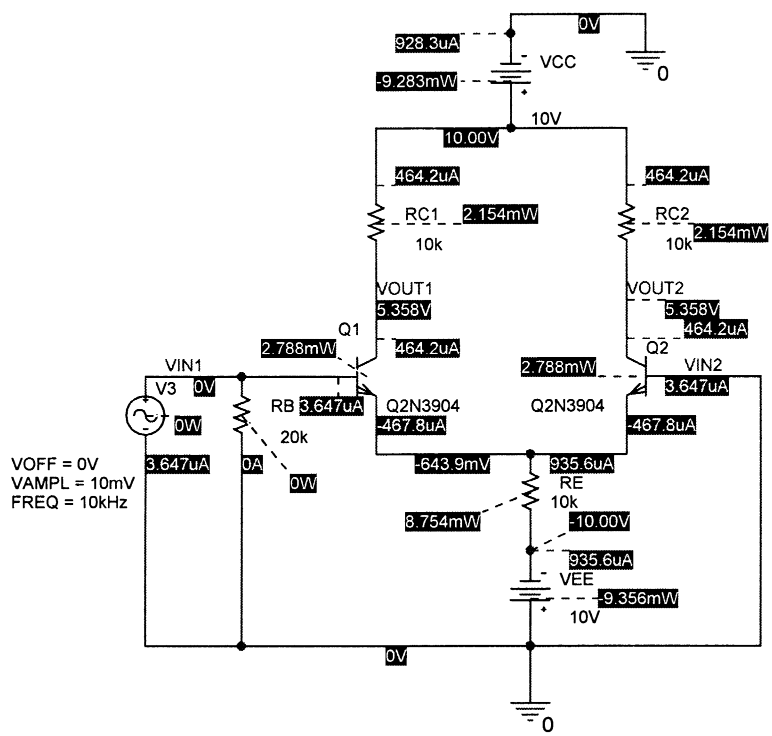
e. $V_{O,1}$ (measured) = 50 mV
$V_{O,2}$ (measured) = 46 mV
$A_{V1,d} = .5$
$A_{V2,d} = 4.6$

Part 6: Computer Exercises

Pspice Simulations 27-1

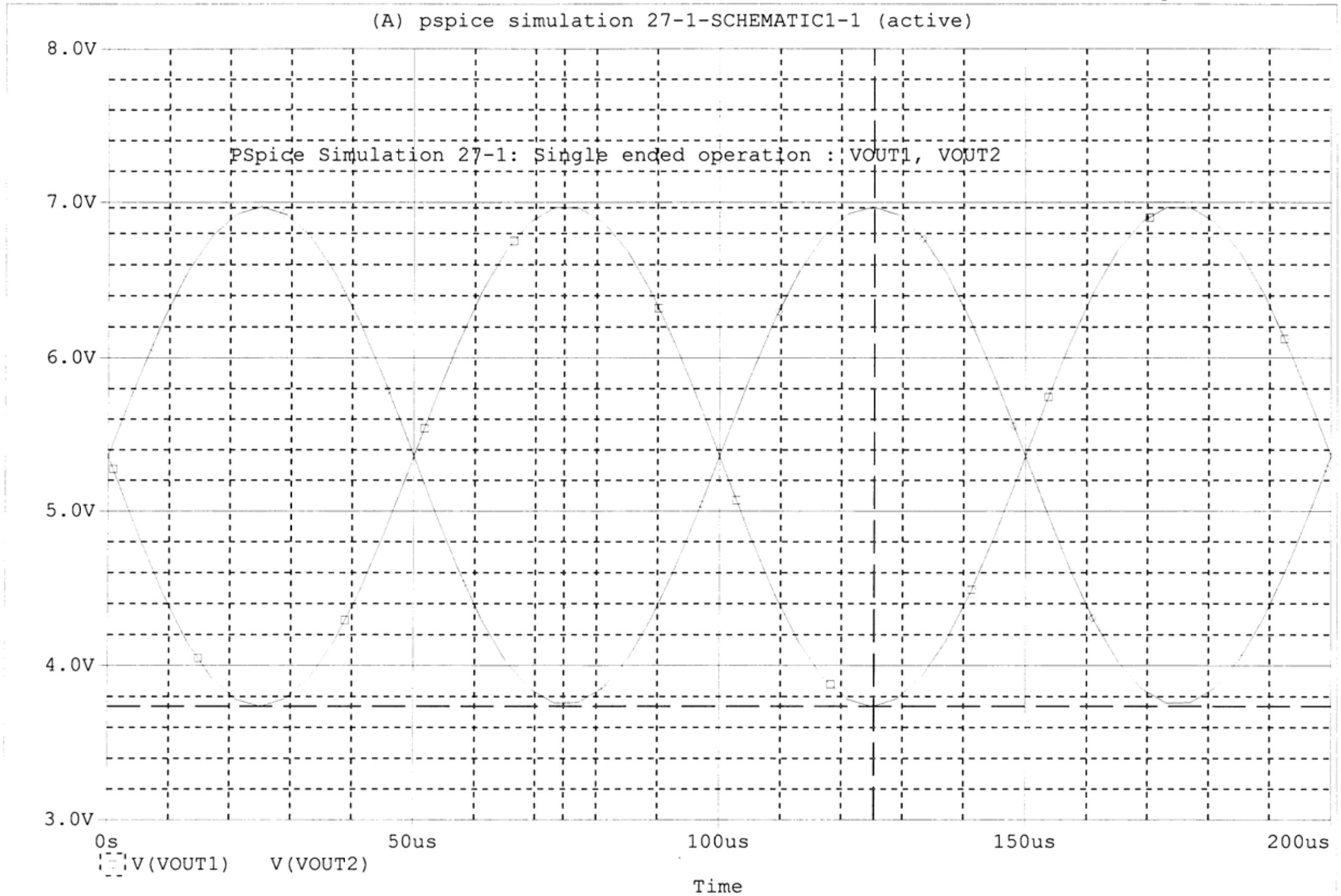
1. See circuit diagram.
   $P(\text{DC})_{VCC}$ = 9.283 mW
   $P(\text{DC})_{VEE}$ = 9.356 mW

PSpice Simulation 27-1: Differential Amplifier

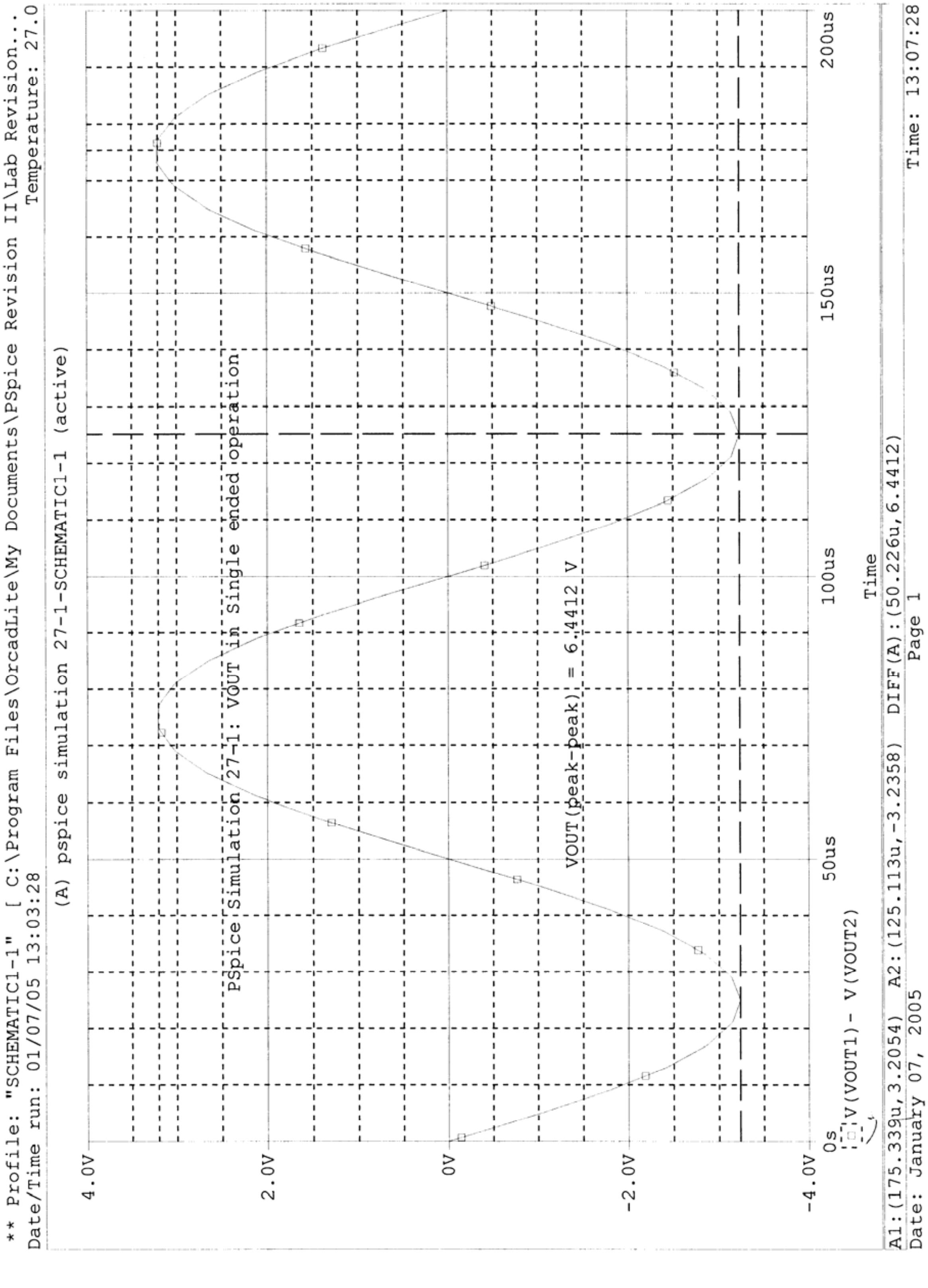


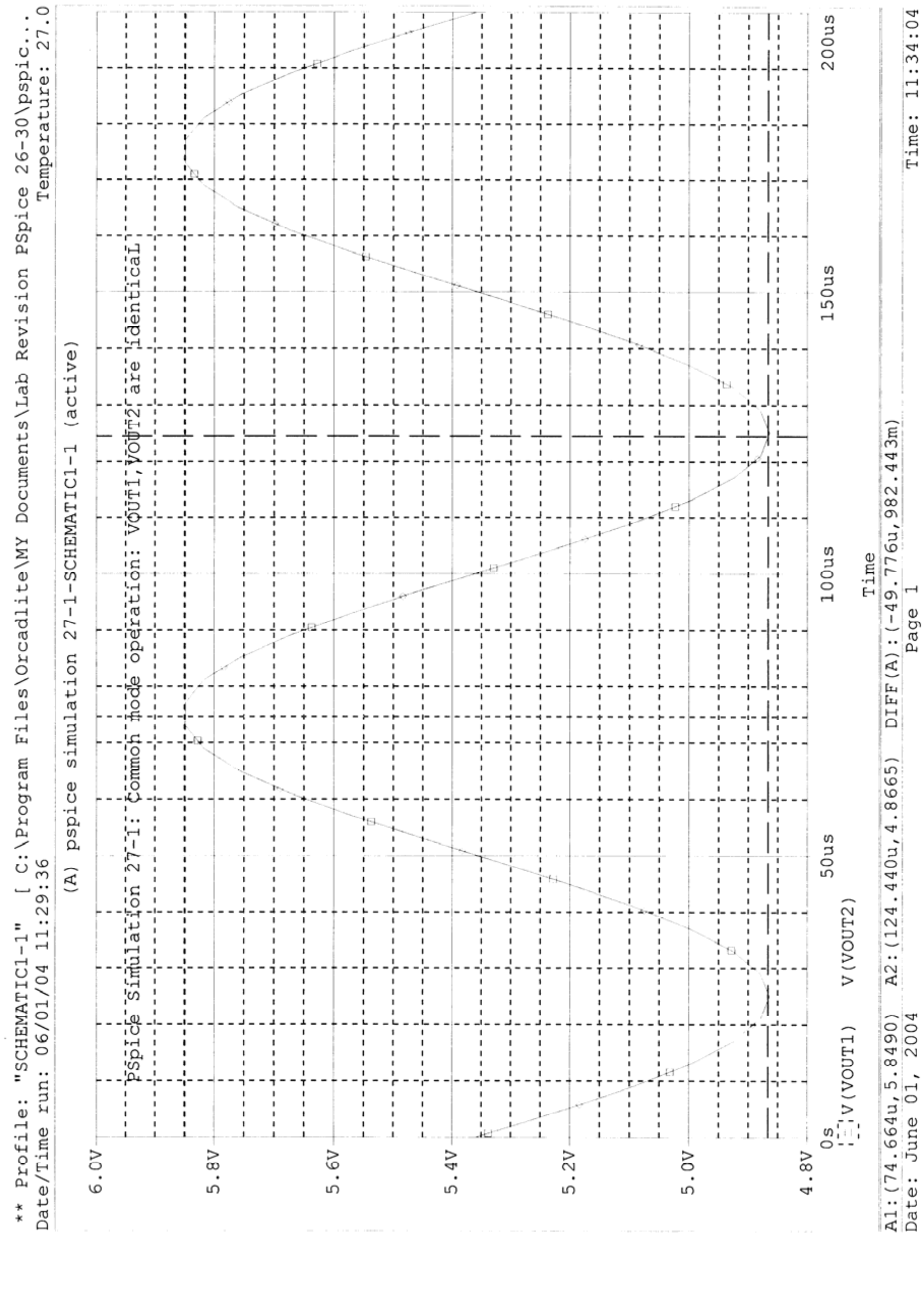
2. Practically yes
3. $V(CE)_{Q_1} = V(CE)_{Q_2}$ = 6 V
4. Yes.
5. $I(Q_1) = 464.2\ \mu\text{A}$
   $I(Q_2) = 464.2\ \mu\text{A}$
6. Yes
9. See Probe plot page 316.
10. $(\text{VOUT1})_{p-p} = (\text{VOUT2})_{p-p}$ = 3.23 V
    phase shift = 180°
11. See Probe plot page 317.
    $A_V = 114$
14. See Probe plot page 318.
15. $(\text{VOUT1})_{p-p} = (\text{VOUT2})_{p-p}$ = 0.98 V
    phase shift = 0°
16. See Probe plot page 319.
    $A_V = 0$

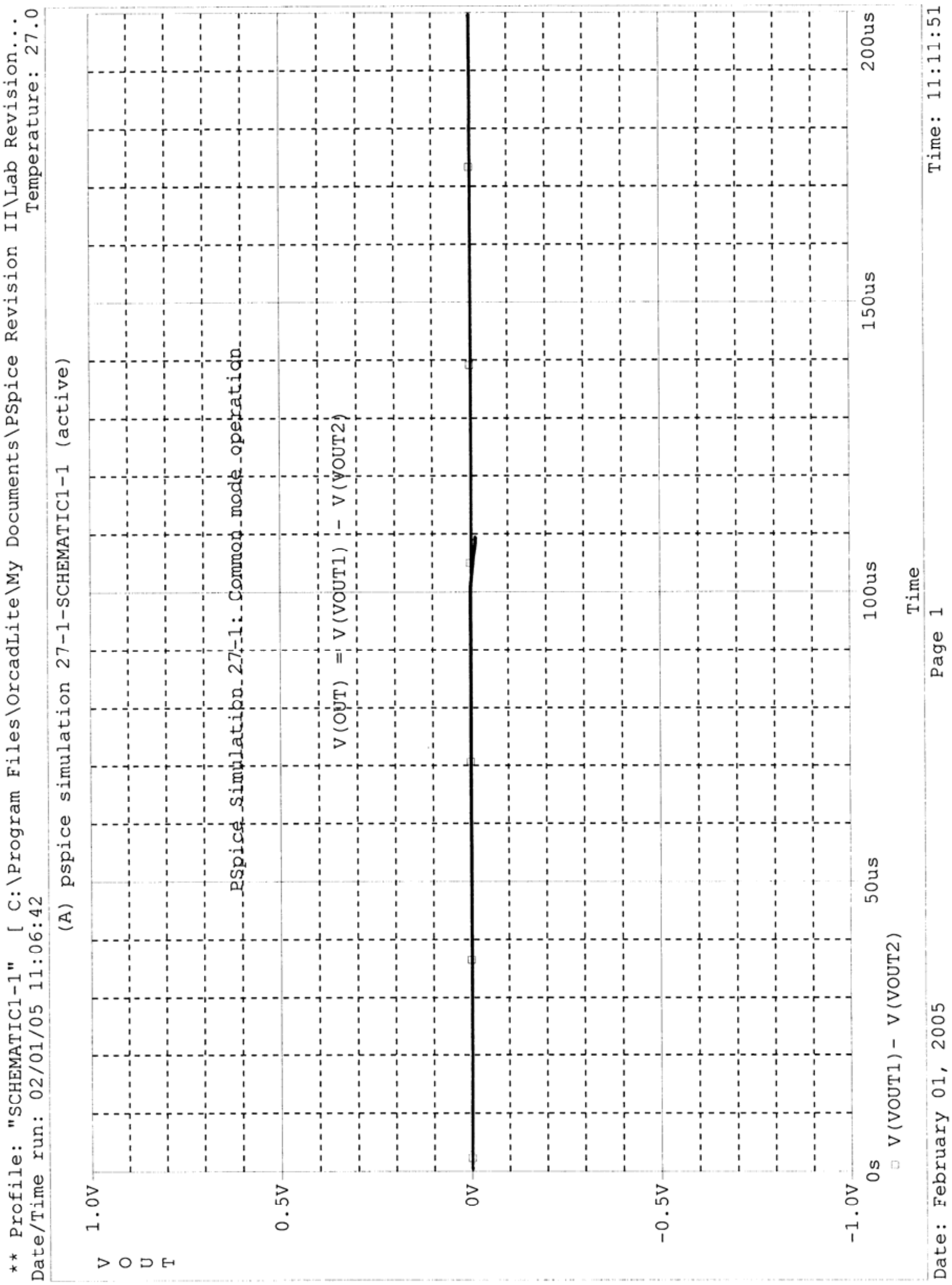
** Profile: "SCHEMATIC1-1" [C:\Program Files\Orcadlite\MY Documents\Lab Revision PSpice 26-30\pspic...
Date/Time run: 06/01/04 11:18:04   Temperature: 27.0



A1:(74.664u,6.9656) A2:(125.336u,3.7375) DIFF(A):(-50.673u,3.2281)
Date: June 01, 2004   Page 1   Time: 11:21:41


** Profile: "SCHEMATIC1-1" [C:\Program Files\OrcadLite\My Documents\PSpice Revision II\Lab Revision...
Date/Time run: 01/07/05 13:03:28
Temperature: 27.0
(A) pspice simulation 27-1-SCHEMATIC1-1 (active)
PSpice Simulation 27-1: VOUT in Single ended operation
VOUT(peak-peak) = 6.4412 V
4.0V
2.0V
0V
-2.0V
-4.0V
0s
50us
100us
150us
200us
V(VOUT1) - V(VOUT2)
Time
A1:(175.339u,3.2054) A2:(125.113u,-3.2358) DIFF(A):(50.226u,6.4412)
Date: January 07, 2005
Page 1
Time: 13:07:28

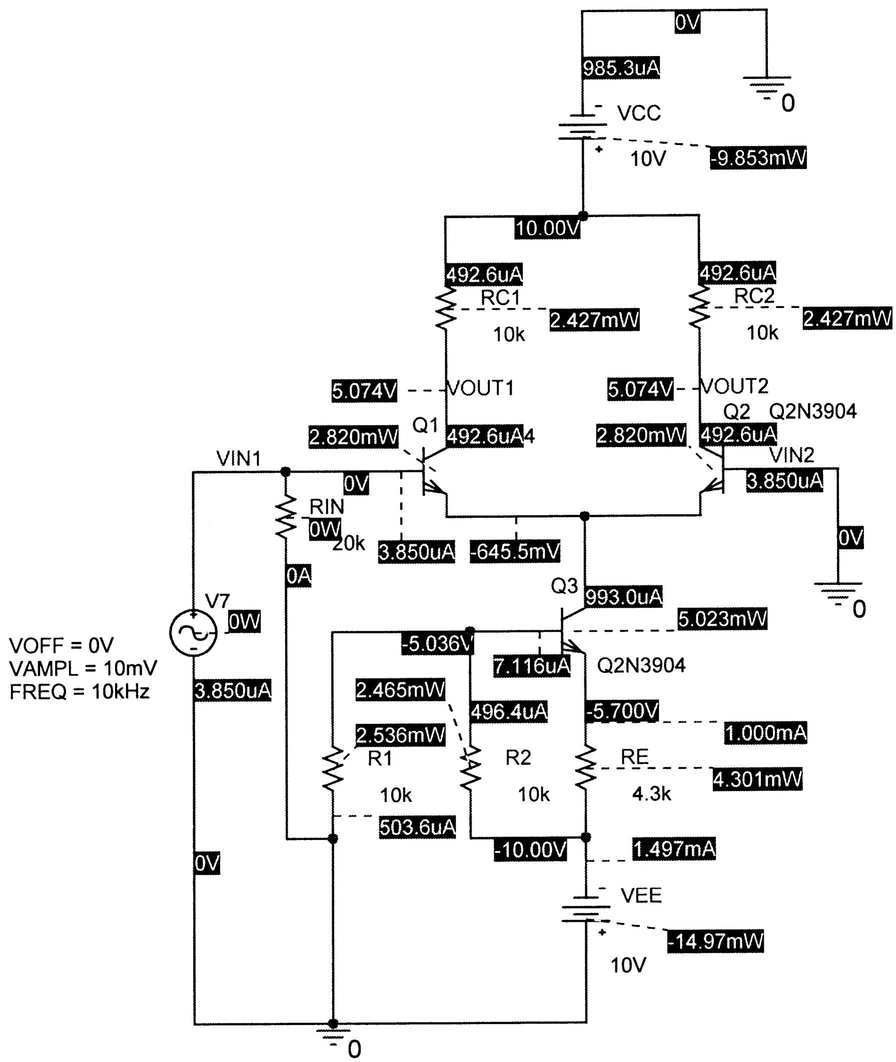

** Profile: "SCHEMATIC1-1" [C:\Program Files\Orcadlite\MY Documents\Lab Revision PSpice 26-30\pspic...
Date/Time run: 06/01/04 11:29:36
Temperature: 27.0
(A) pspice simulation 27-1-SCHEMATIC1-1 (active)
PSpice Simulation 27-1: Common mode operation: VOUT1, VOUT2 are identicaL
6.0V
5.8V
5.6V
5.4V
5.2V
5.0V
4.8V
0s
50us
100us
150us
200us
V(VOUT1) V(VOUT2)
Time
A1:(74.664u,5.8490) A2:(124.440u,4.8665) DIFF(A):(-49.776u,982.443m)
Date: June 01, 2004
Page 1
Time: 11:34:04


** Profile: "SCHEMATIC1-1" [C:\Program Files\OrcadLite\My Documents\PSpice Revision II\Lab Revision...
Date/Time run: 02/01/05 11:06:42
Temperature: 27.0
(A) pspice simulation 27-1-SCHEMATIC1-1 (active)
PSpice Simulation 27-1: Common mode operation
V(OUT) = V(VOUT1) - V(VOUT2)
VOUT
1.0V
0.5V
0V
-0.5V
-1.0V
0s
50us
100us
150us
200us
V(VOUT1)- V(VOUT2)
Time
Date: February 01, 2005
Page 1
Time: 11:11:51

Pspice Simulations 27-2

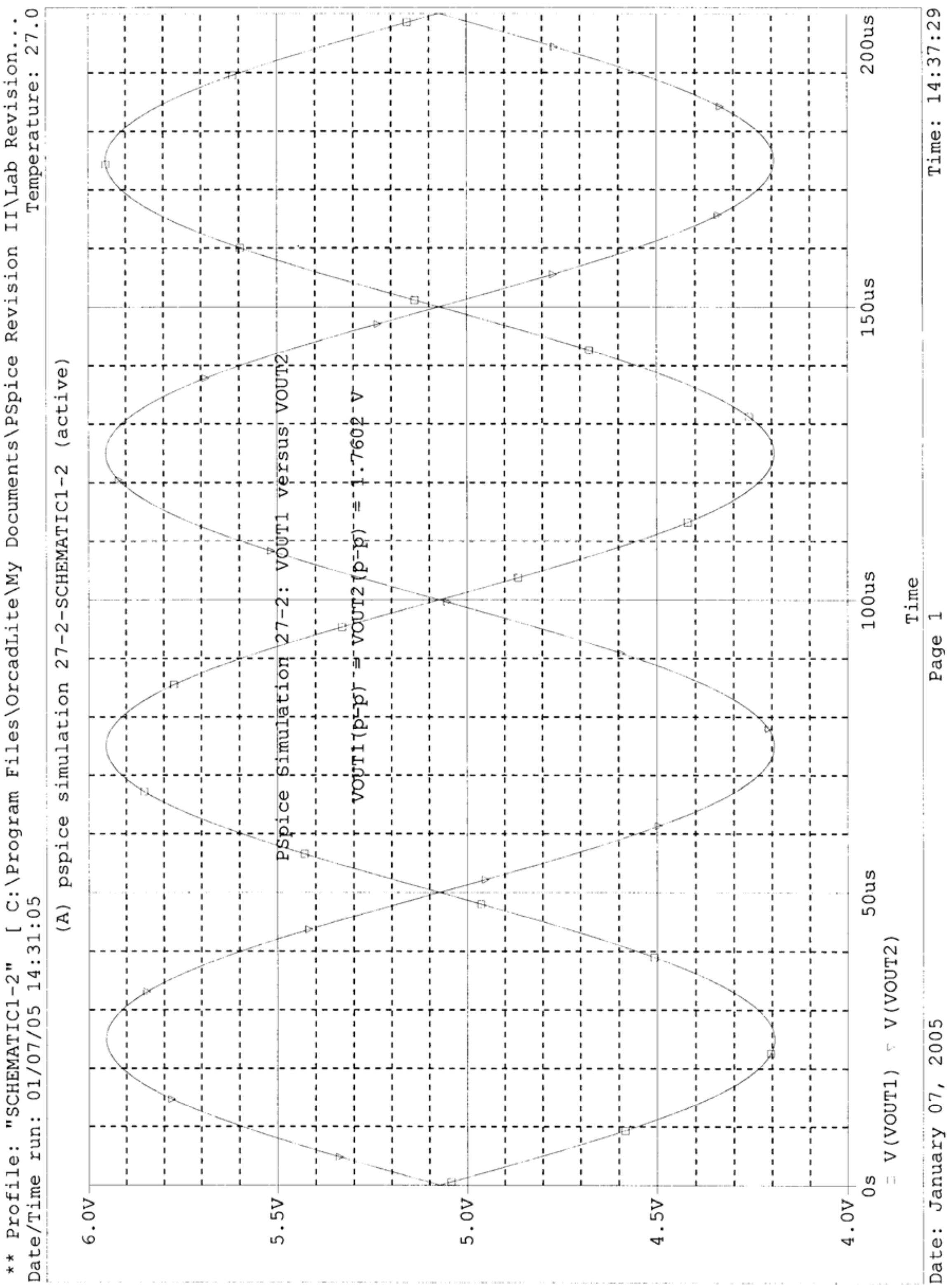
1. See circuit diagram.
   $P(\mathrm{DC})_{VCC}$ = 9.853 mW
   $P(\mathrm{DC})_{VEE}$ = 14.97 mW

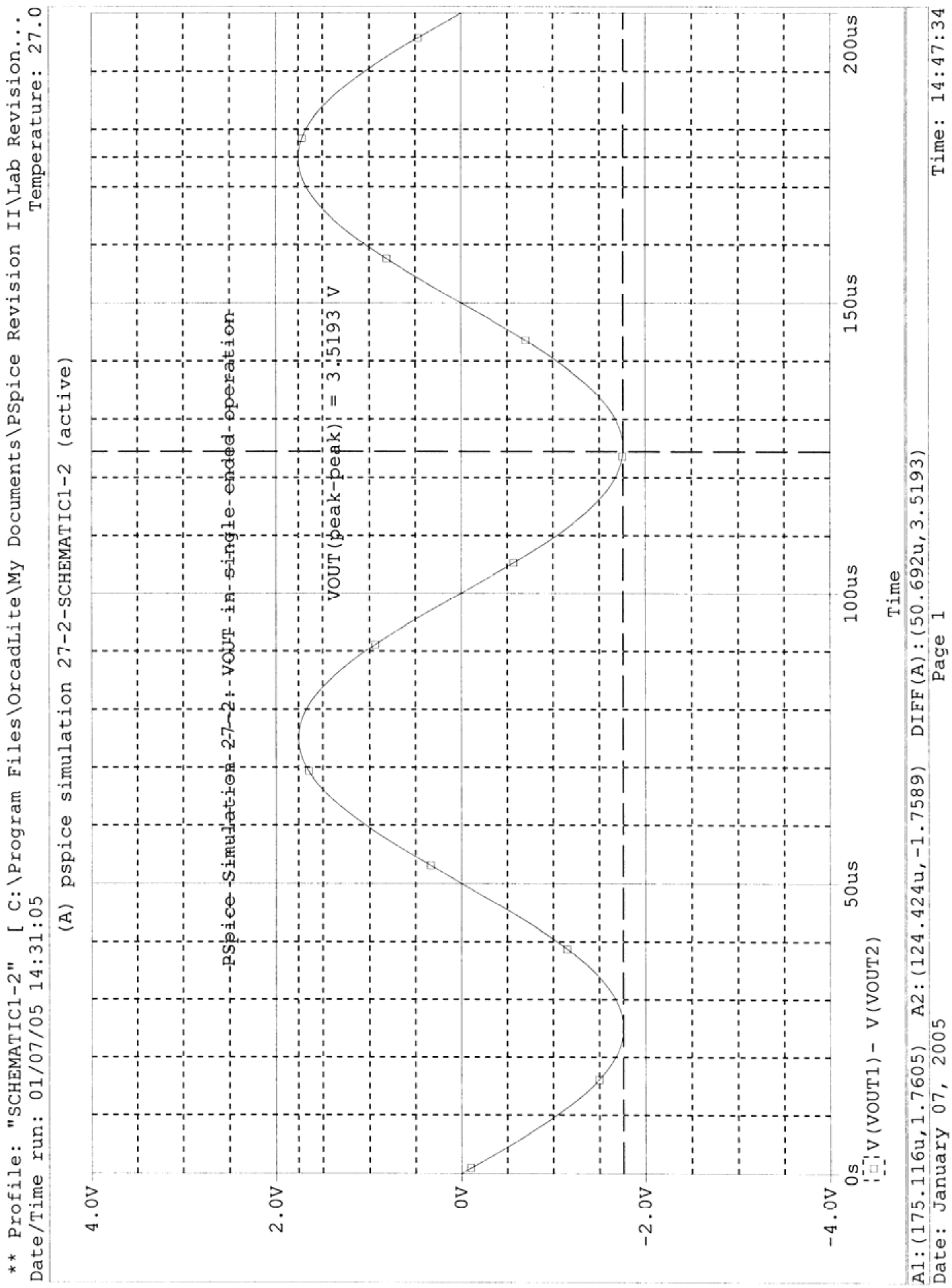
PSpice Simulation 27-2: Differential Amplifier with Current Source

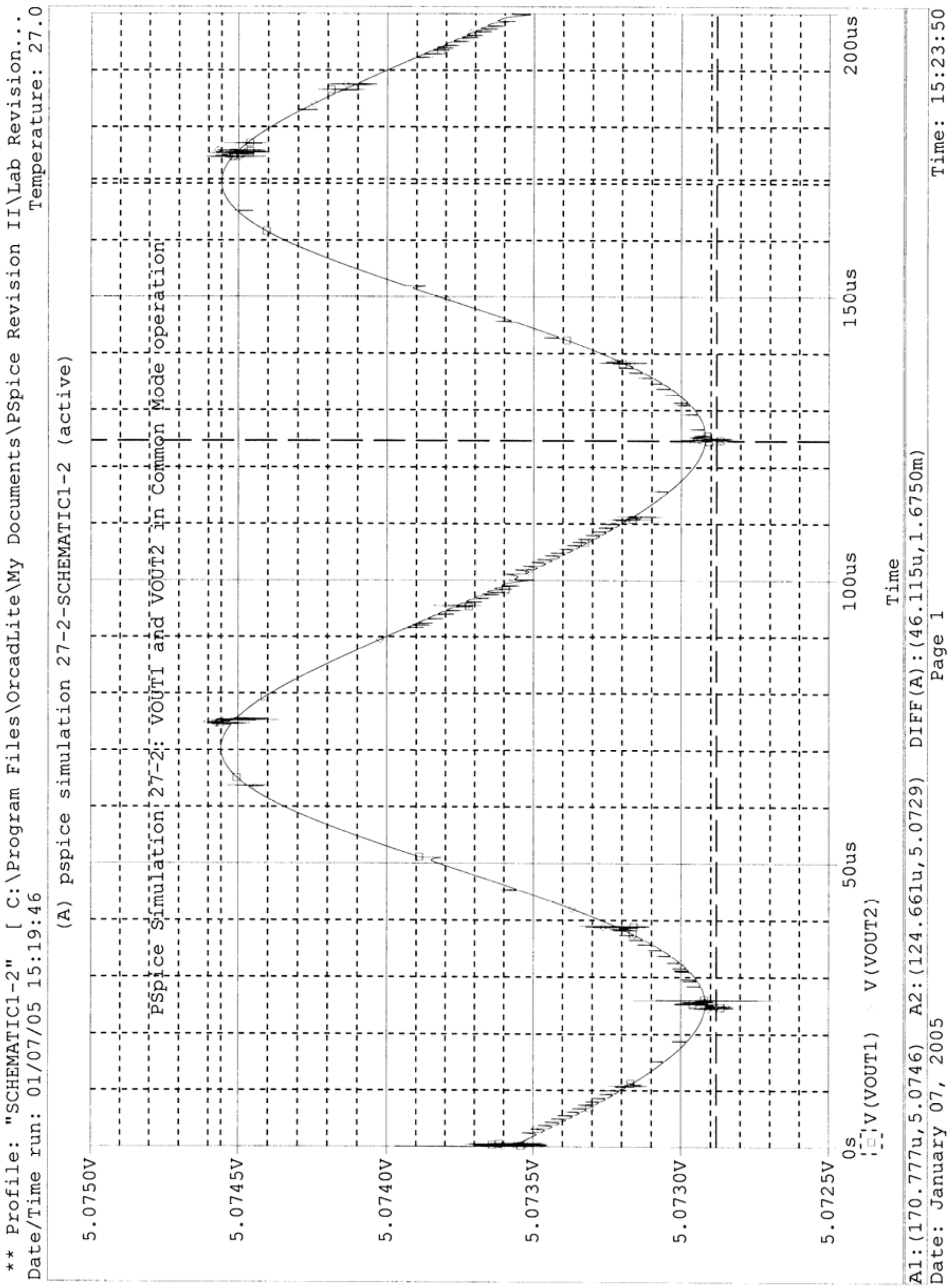


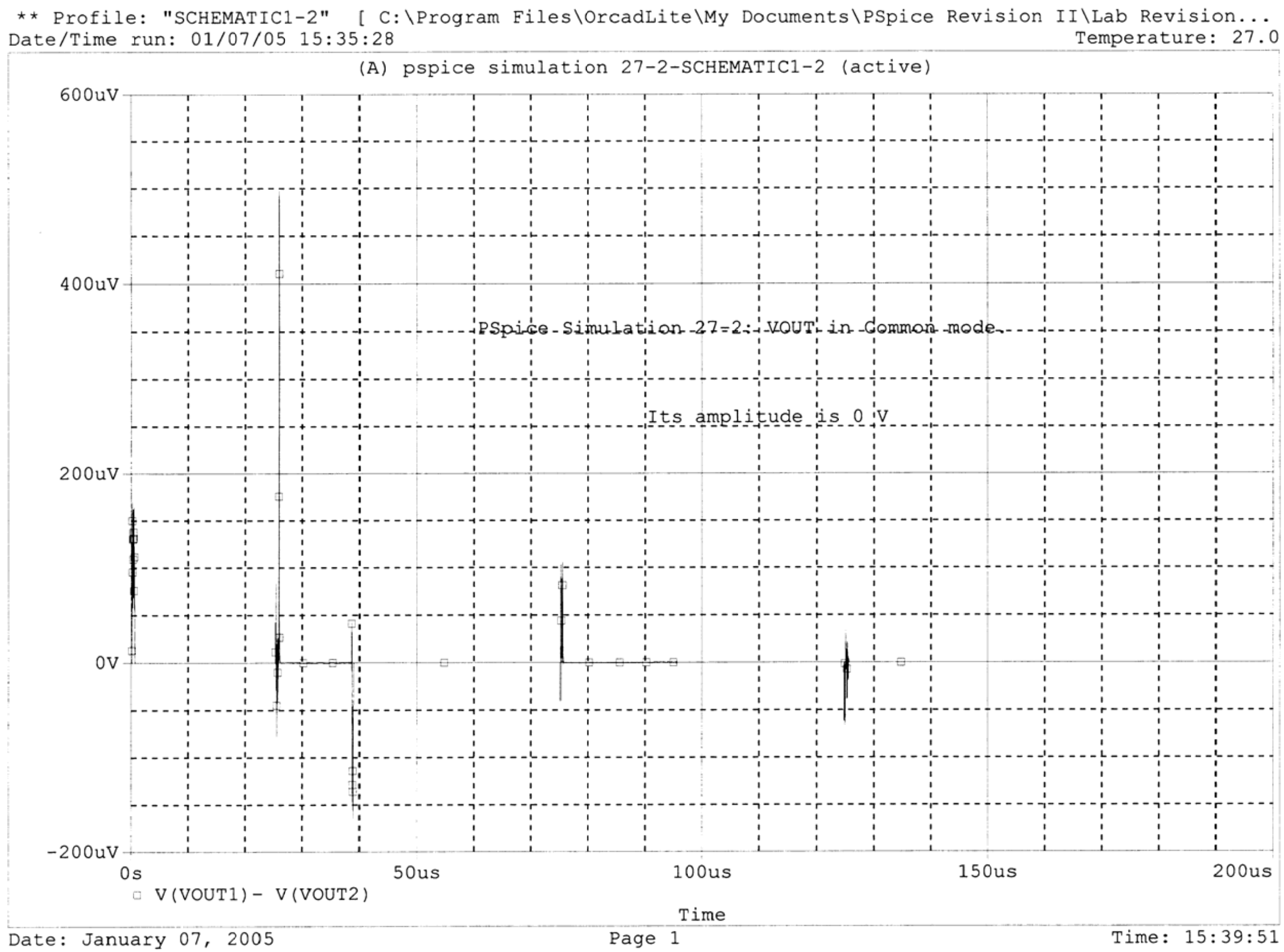
2. $V(C)_{Q_1}$ = 5.074 V
   $V(C)_{Q_2}$ = 5.074 V
   Yes
3. $I(Q_1)$ = 492.6 μA
   $I(Q_2)$ = 492.6 μA
   $I(Q_3($ = 993.0 μA
4. $|I(Q_1)| = |I(Q_2)|$
   $|I(Q_3)| = 2|I(Q_1)| = 2|I(Q_2)|$

7. See Probe plot page 322.
8. Both voltages are 1.7602 $V_{p\text{–}p}$
   phase shift = 180°
9. See Probe plot page 323.
   A_V = 125
12. See Probe plot page 324.
13. 1.6 $mV_{p\text{–}p}$ phase shift = 0°
14. See probe plot page 325.
   A_V = 0


** Profile: "SCHEMATIC1-2" [C:\Program Files\OrcadLite\My Documents\PSpice Revision II\Lab Revision...
Date/Time run: 01/07/05 14:31:05
Temperature: 27.0
(A) pspice simulation 27-2-SCHEMATIC1-2 (active)
PSpice Simulation 27-2: VOUT1 versus VOUT2
VOUT1(p-p) = VOUT2(p-p) = 1.7602 V
6.0V
5.5V
5.0V
4.5V
4.0V
0s
50us
100us
150us
200us
V(VOUT1)
V(VOUT2)
Time
Date: January 07, 2005
Page 1
Time: 14:37:29


** Profile: "SCHEMATIC1-2" [C:\Program Files\OrcadLite\My Documents\PSpice Revision II\Lab Revision...
Date/Time run: 01/07/05 14:31:05
Temperature: 27.0
(A) pspice simulation 27-2-SCHEMATIC1-2 (active)
PSpice Simulation 27-2: VOUT in single-ended operation
VOUT(peak-peak) = 3.5193 V
4.0V
2.0V
0V
-2.0V
-4.0V
0s
50us
100us
150us
200us
V(VOUT1)- V(VOUT2)
Time
A1:(175.116u,1.7605) A2:(124.424u,-1.7589) DIFF(A):(50.692u,3.5193)
Date: January 07, 2005
Page 1
Time: 14:47:34


** Profile: "SCHEMATIC1-2" [C:\Program Files\OrcadLite\My Documents\PSpice Revision II\Lab Revision...
Date/Time run: 01/07/05 15:19:46
Temperature: 27.0
(A) pspice simulation 27-2-SCHEMATIC1-2 (active)
PSpice Simulation 27-2: VOUT1 and VOUT2 in Common Mode operation
5.0750V
5.0745V
5.0740V
5.0735V
5.0730V
5.0725V
0s
50us
100us
150us
200us
V(VOUT1) V(VOUT2)
Time
A1:(170.777u,5.0746) A2:(124.661u,5.0729) DIFF(A):(46.115u,1.6750m)
Date: January 07, 2005
Page 1
Time: 15:23:50



** Profile: "SCHEMATIC1-2" [C:\Program Files\OrcadLite\My Documents\PSpice Revision II\Lab Revision...
Date/Time run: 01/07/05 15:35:28
Temperature: 27.0
(A) pspice simulation 27-2-SCHEMATIC1-2 (active)
600uV
400uV
200uV
0V
-200uV
0s
50us
100us
150us
200us
PSpice Simulation 27-2: VOUT in Common mode.
Its amplitude is 0 V
V(VOUT1)- V(VOUT2)
Time
Date: January 07, 2005
Page 1
Time: 15:39:51

EXPERIMENT 28: OP-AMP CHARACTERISTICS

Part 1: Determining the Slew Rate

f. 5 V p-p

g. 12 us

h. 0.41 V/us

Part 2: Determining the Common Mode Rejection Ratio

g. Vout(rms) = 0.263 V   Vin(rms)= 8.7 V

h. A(cm) = V(out)/V(in) = 0.0302

i. A(dif)=R1/R2=1000

j. CMR(dB)= 90.4 dB

k. Published values: 90-95 dB

Part 3: Computer Exercises
PSpice Simulation: Determining the Slew Rate

b. V(Vout) max= 5 V   V(Vout)min= 0 V

c. Time interval = 12 us

d. SR= 0.40 us

e. Published values: 0.3-0.7 us

PSpice Simulation: Determining the Common Mode Rejection Ratio

b. A(cm) = V(out)/V(in) = 0.26 V/8.7 V = 0.03

c. A(dif) = R1/R2 = 1000

d. CMR(dB) = 90.4

e. Published values: 90-95 dB

EXPERIMENT 29: LINEAR OP-AMP CIRCUITS

Part 1: Inverting Amplifier

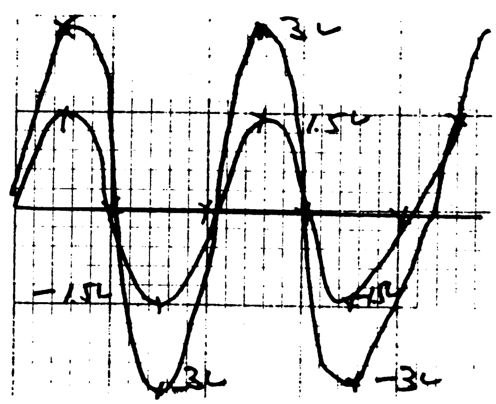
a. V_O/V_i (calculated) = $-R_O/R_i$ = 100 K/20 K = –5

b. V_O (measured) = –4.87
$A_V = -V_O/V_i$ = 4.87/1 = –4.87

c. V_O/V_i (calculated) = $-R_O/R_i$ = –100 K/100 K = –1
V_O (measured) = 1 V
$A_V = -V_O/V_i$ = –1.06/1 = –1.06

d.

Fig 29.6



Part 2: Noninverting Amplifier

a. A_V (calculated) = $(1 + R_O/R_i)$ = (1 + 100 K/20 K) = 6

b. V_O (measured) = 5.24 V
$A_V = V_O/V_i$ = 5.25/1 = 5.25
The two gains are within 12.5 percent of agreement.

c. A_V (calculated) = (1 + 100 K/100 K) = 2
V_O (measured) = 2.17 V
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) = 2.06 V
V_O (measured) = 2.05 V

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) = –[100 K/100 K * 1 + 100 K/20 K * 1] = –6 V
b. V_O (measured) = –5.02 V

The difference between the two values of V_O is equal to 16.3 percent.

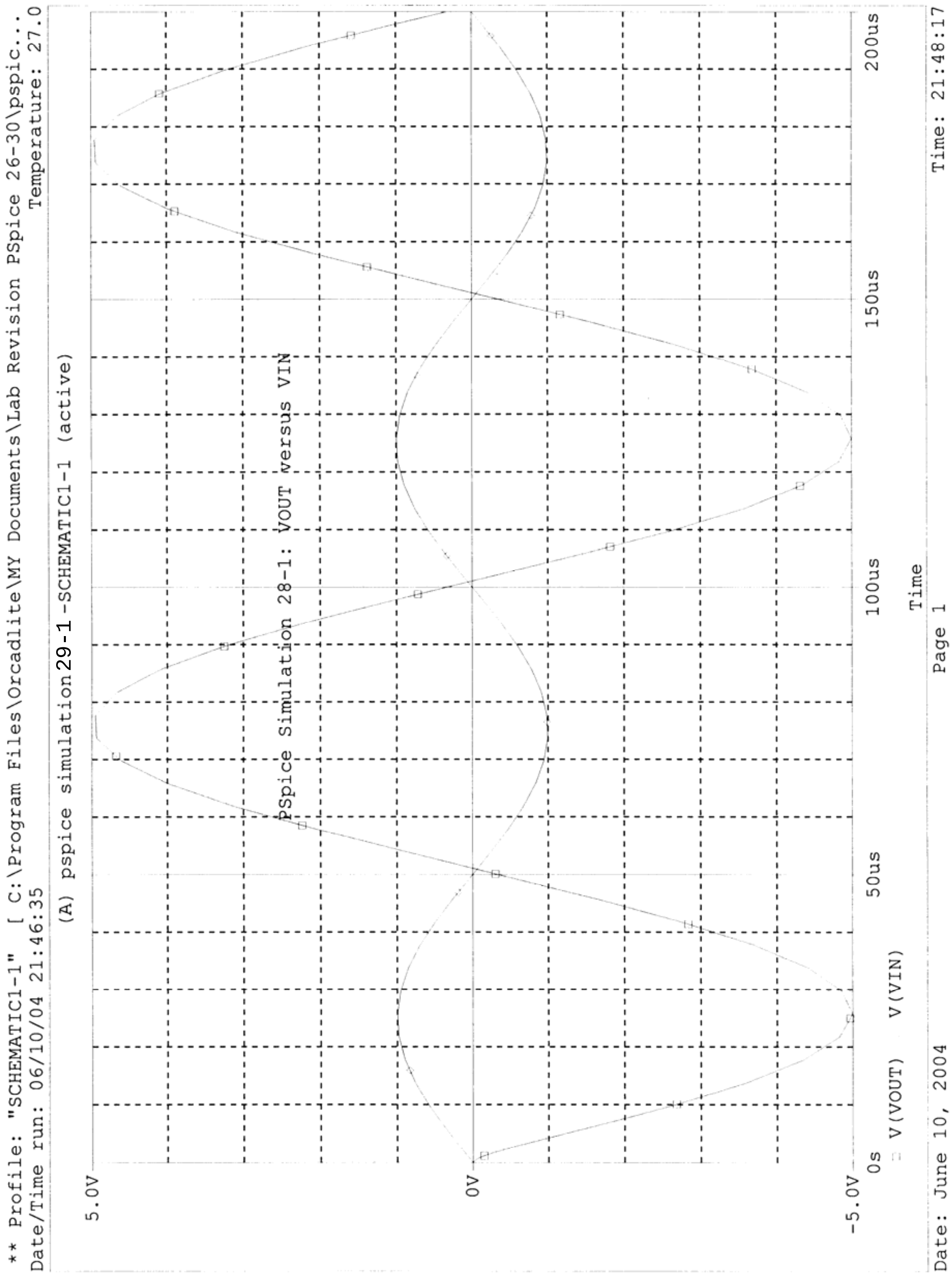
c. V_O (calculated) = –[100 K/100 K * 1 + 100 K/100 K*1] = –2 V
V_O (measured) = –2.01 V

The difference between the two values of V_O is equal to .5 percent.

Part 5: Computer Exercises

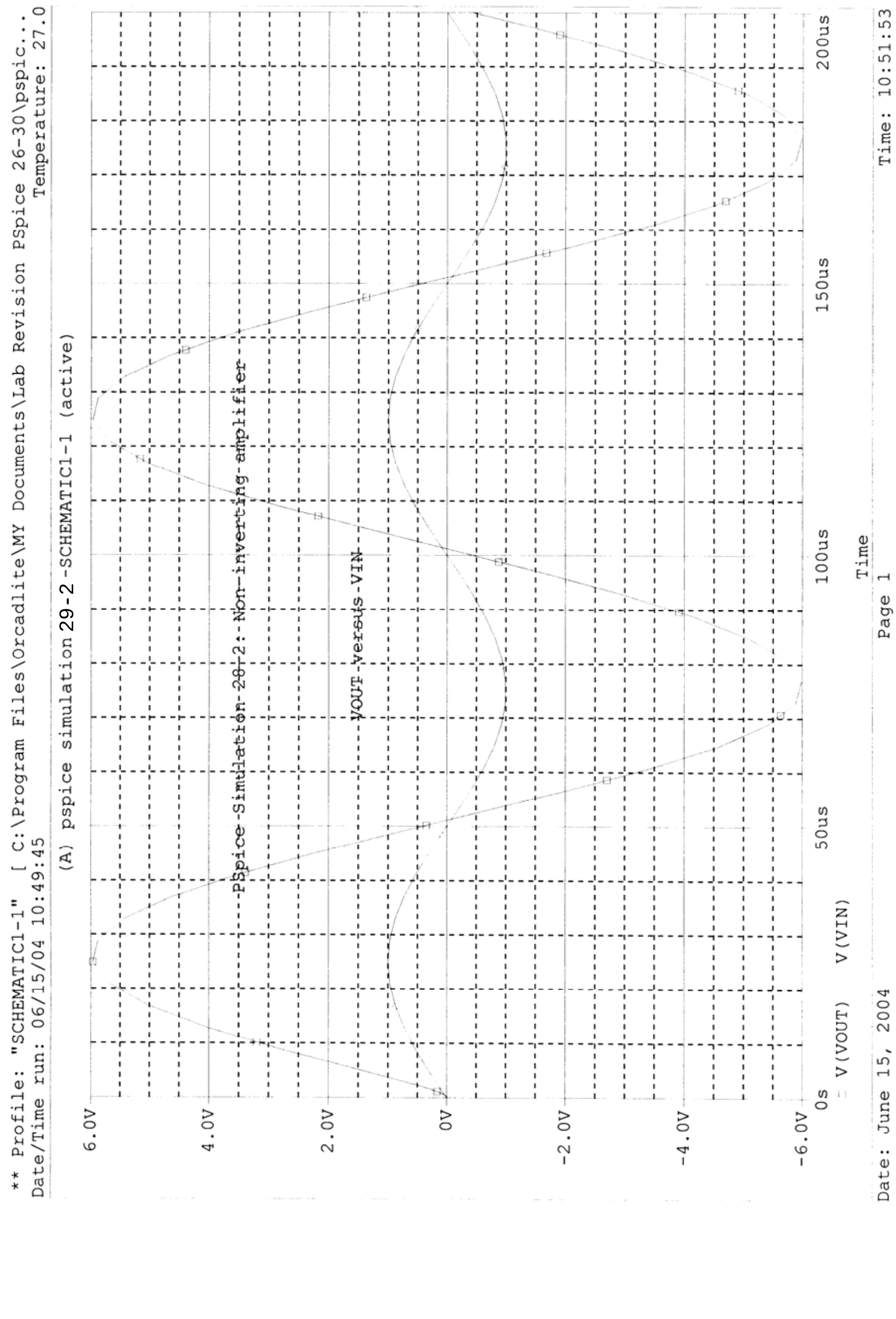
PSpice Simulation 29-1

1. See Probe plot page 329.
2. $(\text{VOUT})_{\text{peak}} = 5$ V
   $(\text{VIN})_{\text{peak}} = 1$ V
3. $A_V = \frac{V_o}{V_{\text{in}}} = -\frac{R_{\text{out}}}{R_{\text{in}}} = -5$
4. $\frac{\text{VOUT}}{\text{VIN}} = -\frac{5\text{ V}}{1\text{ V}} = -5$
5. Yes
6. 180°
7. Yes


** Profile: "SCHEMATIC1-1" [C:\Program Files\Orcadlite\MY Documents\Lab Revision PSpice 26-30\pspic...
Date/Time run: 06/10/04 21:46:35
Temperature: 27.0
(A) pspice simulation 29-1-SCHEMATIC1-1 (active)
PSpice Simulation 28-1: VOUT versus VIN
5.0V
0V
-5.0V
0s
50us
100us
150us
200us
V(VOUT) V(VIN)
Time
Date: June 10, 2004
Page 1
Time: 21:48:17

PSpice Simulation 29-2

1. See Probe plot page 331.
2. $(VOUT)_{peak} = 6$ V
   $(VIN)_{peak} = 1$ V
3. $\frac{V_o}{V_{in}} = \left(1 + \frac{R_{out}}{R_{in}}\right) = \left(1 + \frac{100\ k\Omega}{20\ k\Omega}\right) = 6$
4. $\frac{V_{out}}{V_{in}} = \frac{6\ V}{1\ V} = 6$
5. Yes
6. 0°
7. Yes


** Profile: "SCHEMATIC1-1" [C:\Program Files\Orcadlite\MY Documents\Lab Revision PSpice 26-30\pspic...
Date/Time run: 06/15/04 10:49:45
Temperature: 27.0
(A) pspice simulation 29-2-SCHEMATIC1-1 (active)
PSpice Simulation 28-2: Non-inverting amplifier
VOUT versus VIN
6.0V
4.0V
2.0V
0V
-2.0V
-4.0V
-6.0V
0s
50us
100us
150us
200us
V(VOUT) V(VIN)
Time
Date: June 15, 2004
Page 1
Time: 10:51:53

EXPERIMENT 30: ACTIVE FILTER CIRCUITS

Part 1: Low-Pass Active Filter

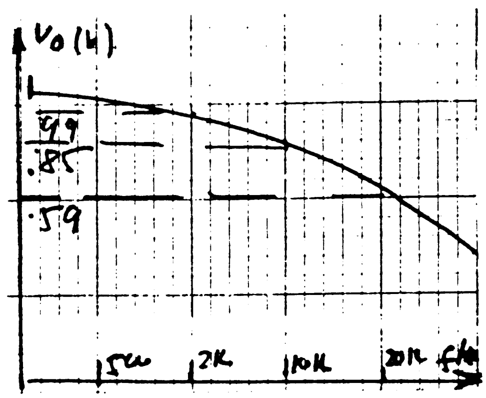
a. f_L (calculated) = 1/(2 * 3.14 * 10 K * .001 μF) = 15.9 KHz

b.

Table 30.1 Low Pass Filter

f (Hz)	100	500	1 K	2 K	5 K	10 K	15 K	20 K	30 K
V_O (V)	1.0	1.0	1.0	.99	.95	.85	.74	.59	.52

c. **Fig 30.4**



d. f_L (from graph) = 15 KHz

Part 2: High-Pass Filter

a. $f_H = 1/(2 * 3.14 * R_2 * C_2)$ = 1/(2 * 3.14 * 10 K*.001 μF) = 15.9 KHz

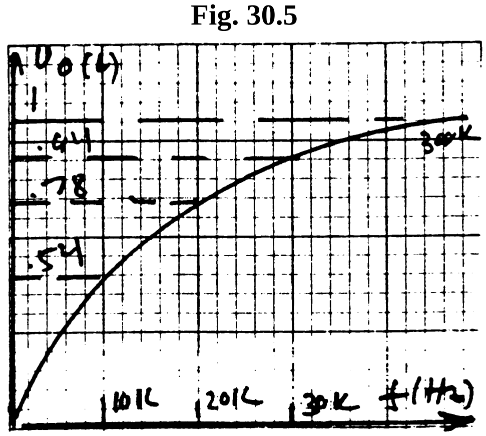
b.

Table 30.2 High-Pass Filter

f (Hz)	1 K	2 K	5 K	10 K	20 K	30 K	50 K	100 K	300 K
V_O (V)	.06	.13	.31	.54	.78	.94	1.0	1.0	1.0

c.

Fig. 30.5



d. f_H (from graph) = 15 KHz

Part 3: Band-Pass Active Filter

c.

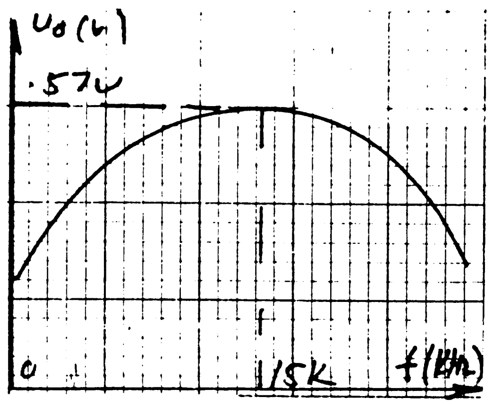
Table 30.3 Band-Pass Filter

f (Hz)	100	500	1 K	2 K	5 K	10 K	15 K	20 K	30 K
V_O (V)	.01	.035	.07	.15	.32	.51	.57	.57	.49

f (Hz)	50 K	100 K	200 K	300 K
V_O (V)	.35	.10		

d.

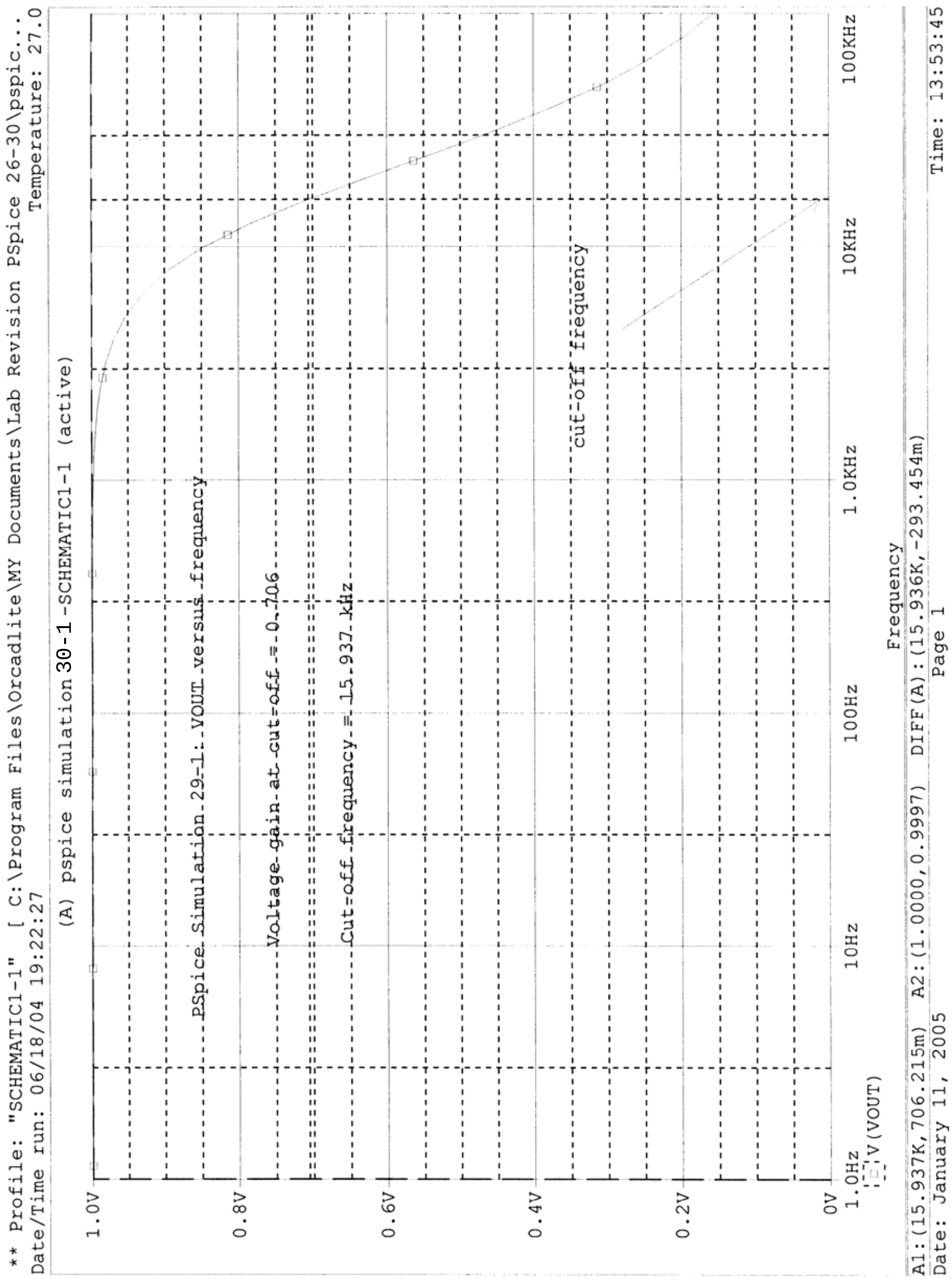
Fig 30.6



Part 4: Computer Exercises

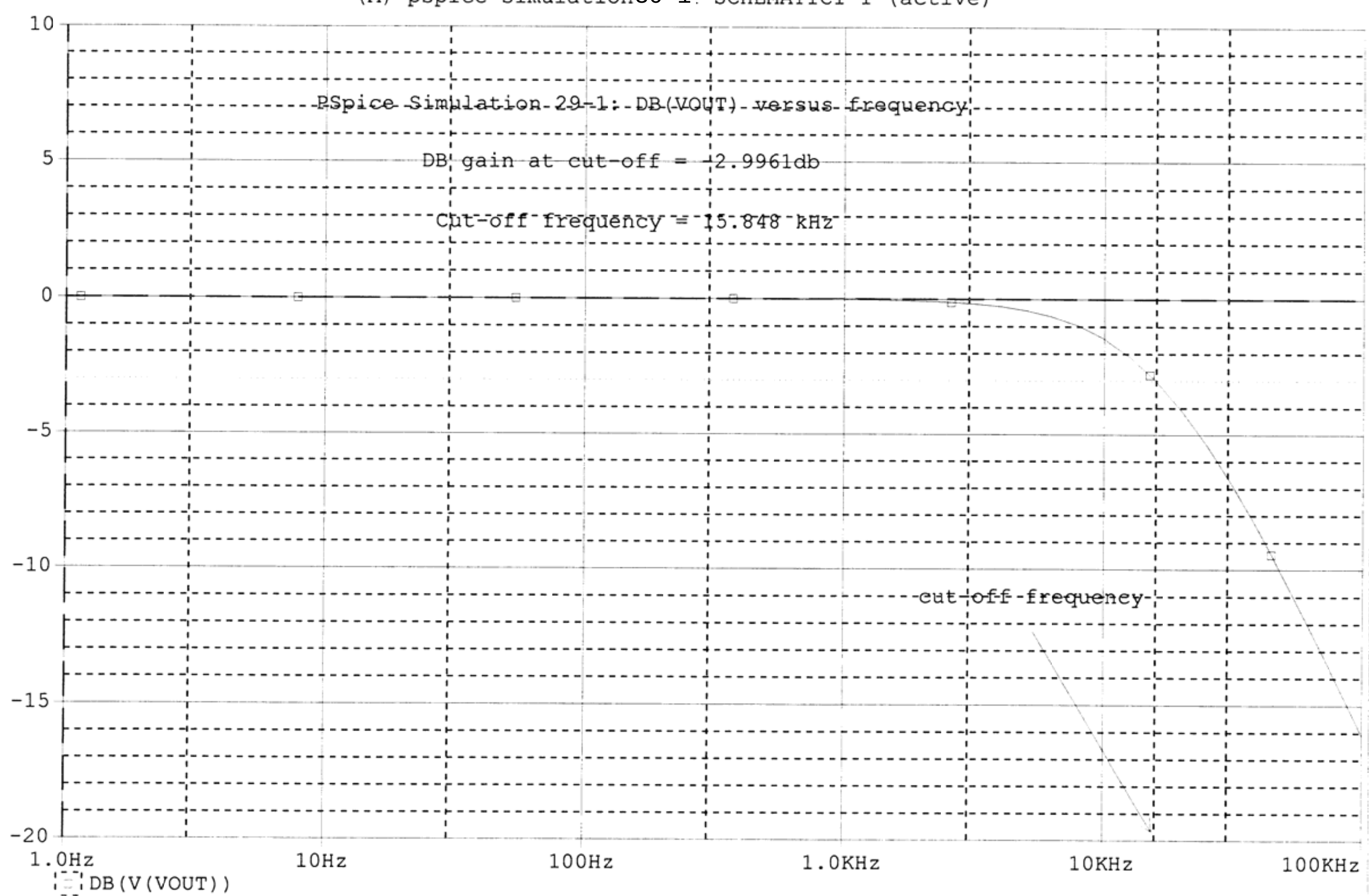
PSpice Simulation 30-1

1-2. See Probe plot page 334.
3-4. See Probe plot page 335.
5. Slight variance due to PSpice cursor position.
6. f_C (calculated) = 15.923 KHz
f_C (numeric gain) = 15.937 KHz
f_C (log. gain) = 15.848 KHz


** Profile: "SCHEMATIC1-1" [C:\Program Files\Orcadlite\MY Documents\Lab Revision PSpice 26-30\pspic...
Date/Time run: 06/18/04 19:22:27
Temperature: 27.0
(A) pspice simulation 30-1 -SCHEMATIC1-1 (active)
PSpice Simulation 29-1: VOUT versus frequency
Voltage gain at cut-off = 0.706
Cut-off frequency = 15.937 kHz
cut-off frequency
1.0V
0.8V
0.6V
0.4V
0.2V
0V
1.0Hz
10Hz
100Hz
1.0KHz
10KHz
100KHz
V(VOUT)
Frequency
A1:(15.937K,706.215m) A2:(1.0000,0.9997) DIFF(A):(15.936K,-293.454m)
Date: January 11, 2005
Page 1
Time: 13:53:45

** Profile: "SCHEMATIC1-1" [C:\Program Files\Orcadlite\MY Documents\Lab Revision PSpice 26-30\pspic...
Date/Time run: 06/18/04 19:22:27   Temperature: 27.0

(A) pspice simulation30-1.-SCHEMATIC1-1 (active)



A1:(15.849K,-2.9961) A2:(1.0000,-2.8759m) DIFF(A):(15.848K,-2.9932)
Date: January 11, 2005   Page 1   Time: 14:00:56

PSpice Simulation 30-2

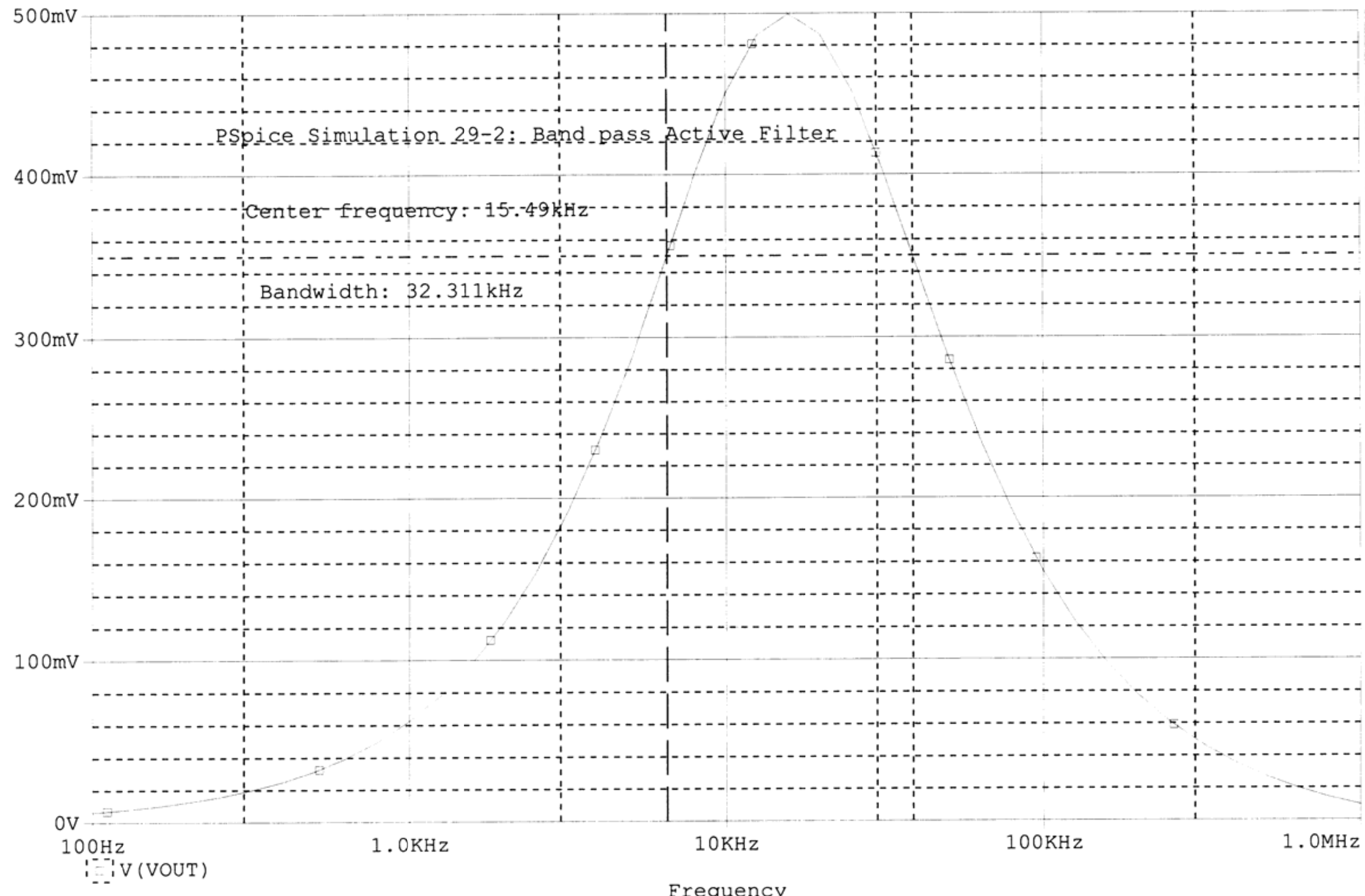
1-5. See Probe plot page 337.
6-8. See Probe plot page 338.
9.

Numeric	Logarithmic
f_C (low): 6.5151 KHz	6.6408 KHz
f_C (high): 38.826 KHz	38.214 KHz
Bandwidth: 32.311 KHz	31.573 KHz

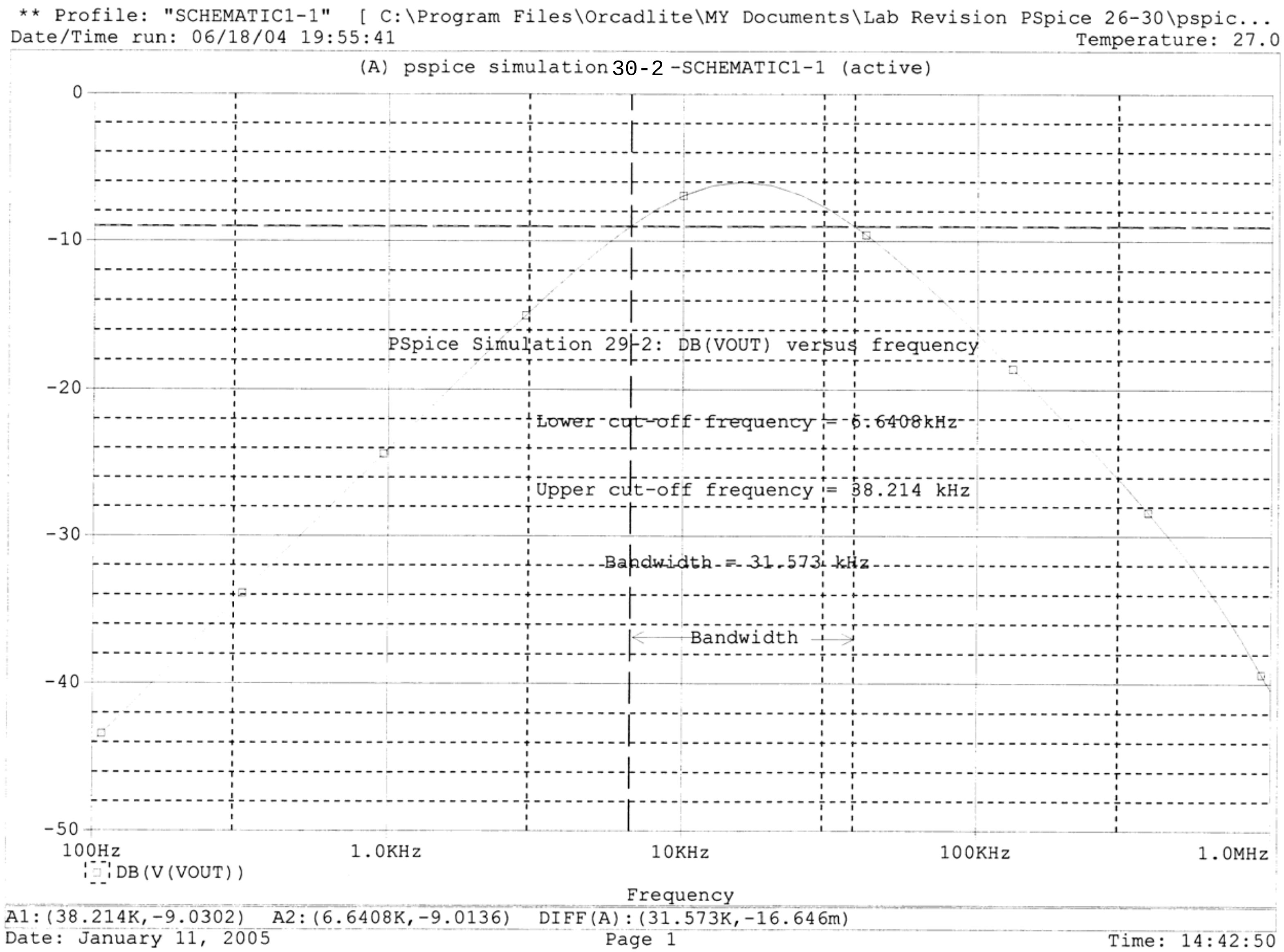
10. See tabulation in #9.

** Profile: "SCHEMATIC1-1" [C:\Program Files\Orcadlite\MY Documents\Lab Revision PSpice 26-30\pspic...
Date/Time run: 06/18/04 19:55:41 Temperature: 27.0

(A) pspice simulation 30-2 -SCHEMATIC1-1 (active)



A1:(38.826K,350.283m) A2:(6.5151K,350.283m) DIFF(A):(32.311K,0.000)
Date: June 18, 2004 Page 1 Time: 19:59:14


** Profile: "SCHEMATIC1-1" [C:\Program Files\Orcadlite\MY Documents\Lab Revision PSpice 26-30\pspic...
Date/Time run: 06/18/04 19:55:41
Temperature: 27.0
(A) pspice simulation 30-2 -SCHEMATIC1-1 (active)
PSpice Simulation 29-2: DB(VOUT) versus frequency
Lower cut-off frequency = 6.6408kHz
Upper cut-off frequency = 38.214 kHz
Bandwidth = 31.573 kHz
Bandwidth
0
-10
-20
-30
-40
-50
100Hz
1.0KHz
10KHz
100KHz
1.0MHz
DB(V(VOUT))
Frequency
A1:(38.214K,-9.0302) A2:(6.6408K,-9.0136) DIFF(A):(31.573K,-16.646m)
Date: January 11, 2005
Page 1
Time: 14:42:50

EXPERIMENT 31: COMPARATOR CIRCUITS OPERATION

Part 1: Comparator with 74IC Used as a Level Detector

a. R_3 = 10 Kohms, V_{ref} = 5 V
R_3 = 20 Kohms, V_{ref} = 6.7 V

c. V_{ref} (measured) = 4.97 V

d. V_i (measured) (LED goes on) = 5.01 V
V_i (measured) (LED goes off) = 4.98 V

e. V_{ref} (measured) = 6.63 V
V_i (measured) (LED goes on) = 6.65 V
V_i (mesasured) (LED goes off) = 6.61 V

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 = 10 Kohms V_{ref} (calculated) = 4.98 V
R_3 = 20 Kohms V_{ref} (calculated) = 6.63 V

c. V_{ref} (measured) = 4.97 V (R_3 = 10 Kohms)

d. V_i (measured) (LED goes on) = 5.01 V
V_i (measured) (LED goes off) = 4.97 V

e. Replace R_1 with 20 Kohm resistor.
V_{ref} (measured) = 6.67 (R_3 = 20 Kohms)
V_i (measured) (LED goes on) = 6.69 V
V_i (measured) (LED) goes off) = 6.65 V

f. V_i (measured) (LED goes on) = 6.65 V
V_i (measured) (LED goes off) = 6.67 V

The agreement between calculated and measured values in every case was near perfect.

Part 3: Window Comparator

a. V^+(pin5, calculated) = 7.5 V
V^- (pin6, calculated) = 2.5 V

c. V_i (pin1, measured) = 7.6 V
V^+ (pin5, measured) = 7.36 V
V^- (pin6, measured) = 2.3 V

d. V_{i} (measured) (LED goes on) = 7.6 V
V_i (measured) (LED goes off) = 2.6 V

e. V_i (measured) (LED goes on) = 7.46 V
V_i (measured) (LED goes off) = 2.2 V

f. V_i (measured) (LED goes on) = 7.46 V
V_i (measured) (LED goes off) = 5.01 V

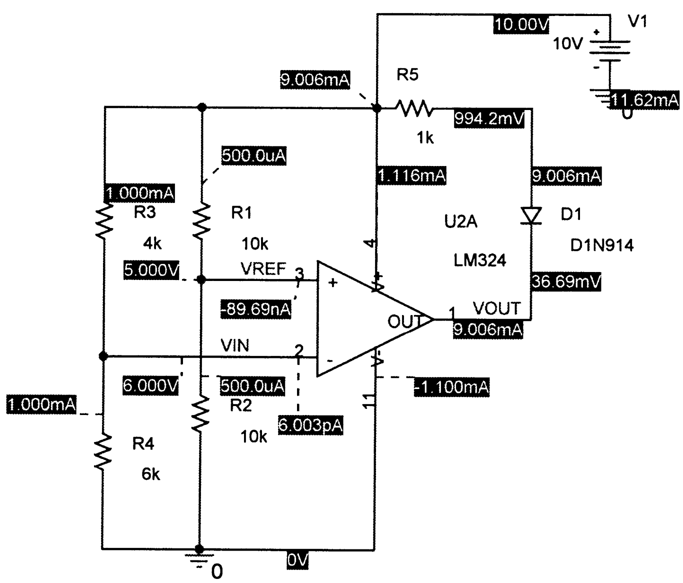
Again as in the previous case, the agreement between measured and calculated values was excellent.

Part 4: Computer Exercises

PSpice Simulation 31-1

1. See circuit diagram.

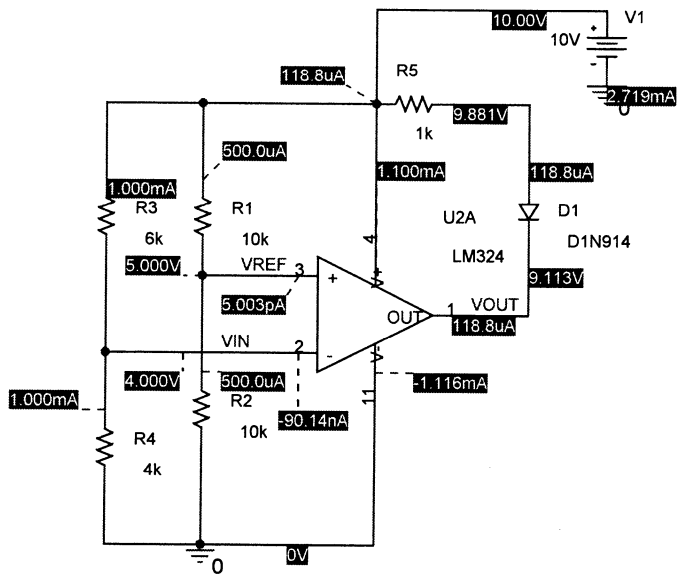
PSpice Simulation 31-1: Comparator Circuit



2. V_{in} = 6 V; V_{ref} = 5 V
3. Yes. I(D1) = 9.006 mA

4-6. See circuit diagram.

PSpice Simulation 31-1: Comparator Circuit



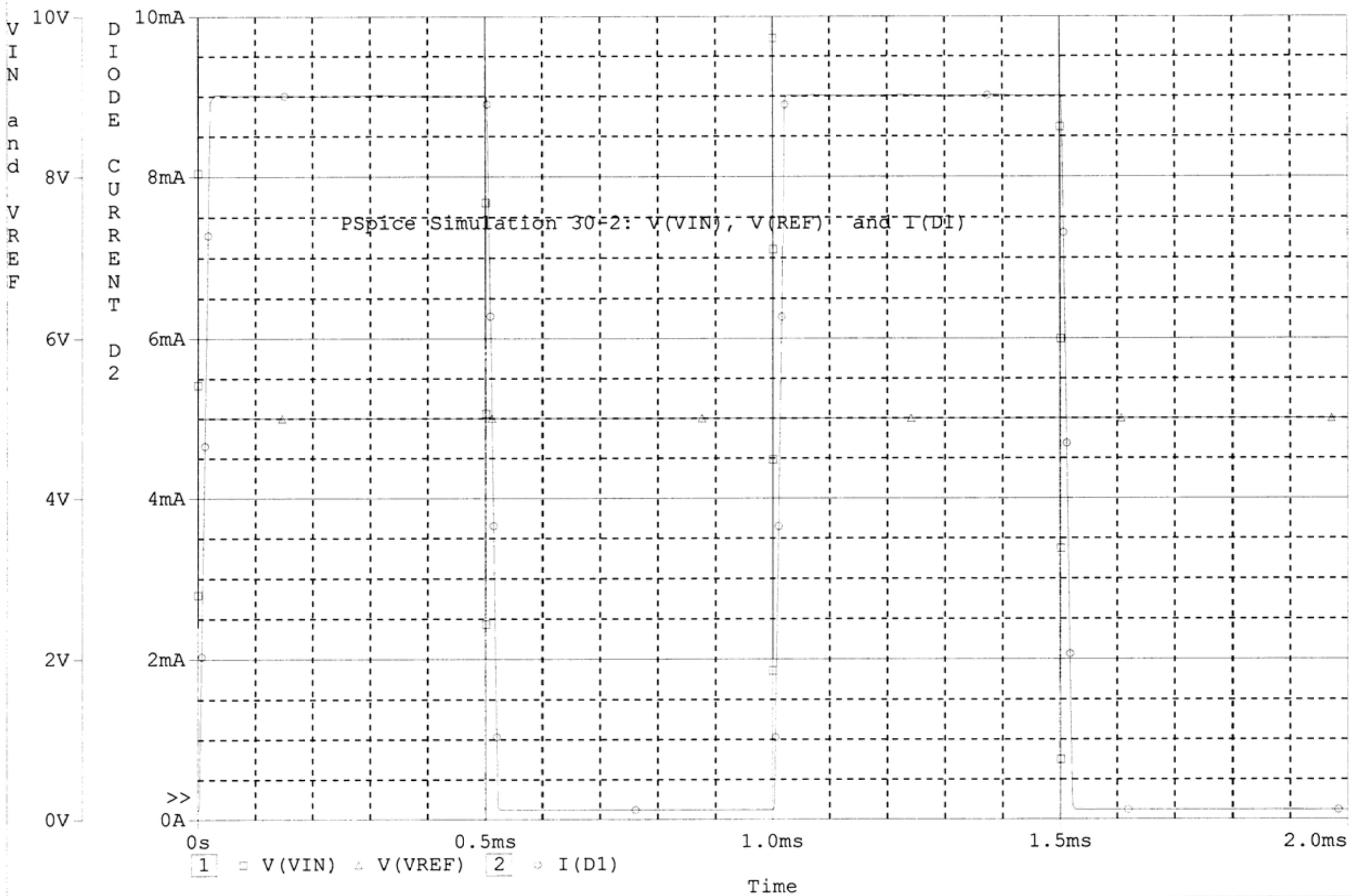
8. V_{in} = 4 V; V_{ref} = 5 V
9. No, I(D1) < 8 mA; I(D1) = 118.8 μA

PSpice Simulation 31-2

1-3. See Probe plot page 342.

** Profile: "SCHEMATIC1-1" [C:\Program Files\OrcadLite\My Documents\PSpice Revision II\Lab Revision...
Date/Time run: 02/01/05 11:33:57 Temperature: 27.0

(A) pspice simulation 31-1-SCHEMATIC1-1 (active)



Date: February 01, 2005 Page 1 Time: 11:43:43

EXPERIMENT 32: OSCILLATOR CIRCUITS 1: THE PHASE-SHIFT OSCILLATOR

Part 1: Determining Vout

d. f(theoretical) = 650 Hz

f. Estimated setting of RPot = 3 kohm

g. Vout (peak-peak) = 29 V

h. Period = 1.54 ms

i. f(experimental) = 649.4 Hz

j. Calculated % difference = 0.15

k. RPot + Rf = 29.5 kohm

l. Open-loop gain = 29.5

m. Calculated % difference = 7.8%

Part 2: PSpice Simulation

b. Vout(peak-peak) = 28.8 V

c. Vout(period) = 1.54 ms

d. Vout(frequency) = 649.4 Hz

e. Vout(peak-peak) = 19.1 V

f. Vout(frequency) = 646.5 Hz

j. P(V(feedback) = -89.9 degrees
P(V(VOUT) = 89.4 degrees
P(V(VOUT) – P(V(feedback) = 180 degrees

EXPERIMENT 33: OSCILLATOR CIRCUITS 2

Part 1: Wien Bridge Oscillator

c. T (measured) = 305 μs

d. $f = 1/T$ = 1/305 μs = 3.28 KHz

e. T (measured, C = 0.01 μF) = 3 ms
f (calculated, C = 0.01 μF) = 328 Hz

f. f (calculated, C = .001 μF) = 3.12 KHz
f (calculated, C = .01 μF) = 312 Hz

Again, the agreement between the two sets of values was well within 10 percent.

Part 2: 555 Timer Oscillator

c. T (measured) = 20.1 μs

d. $f = 1/T$ = 49.3 KHz

e. T (measured, C = 0.01 μF) = 203 μs
$f = 1/T$ = 4.93 KHz

f. $k = fRC$ = .48
f = 4.91 KHz

The agreement between the two values differed by only .4 percent.

Part 3: Schmitt-trigger Oscillator

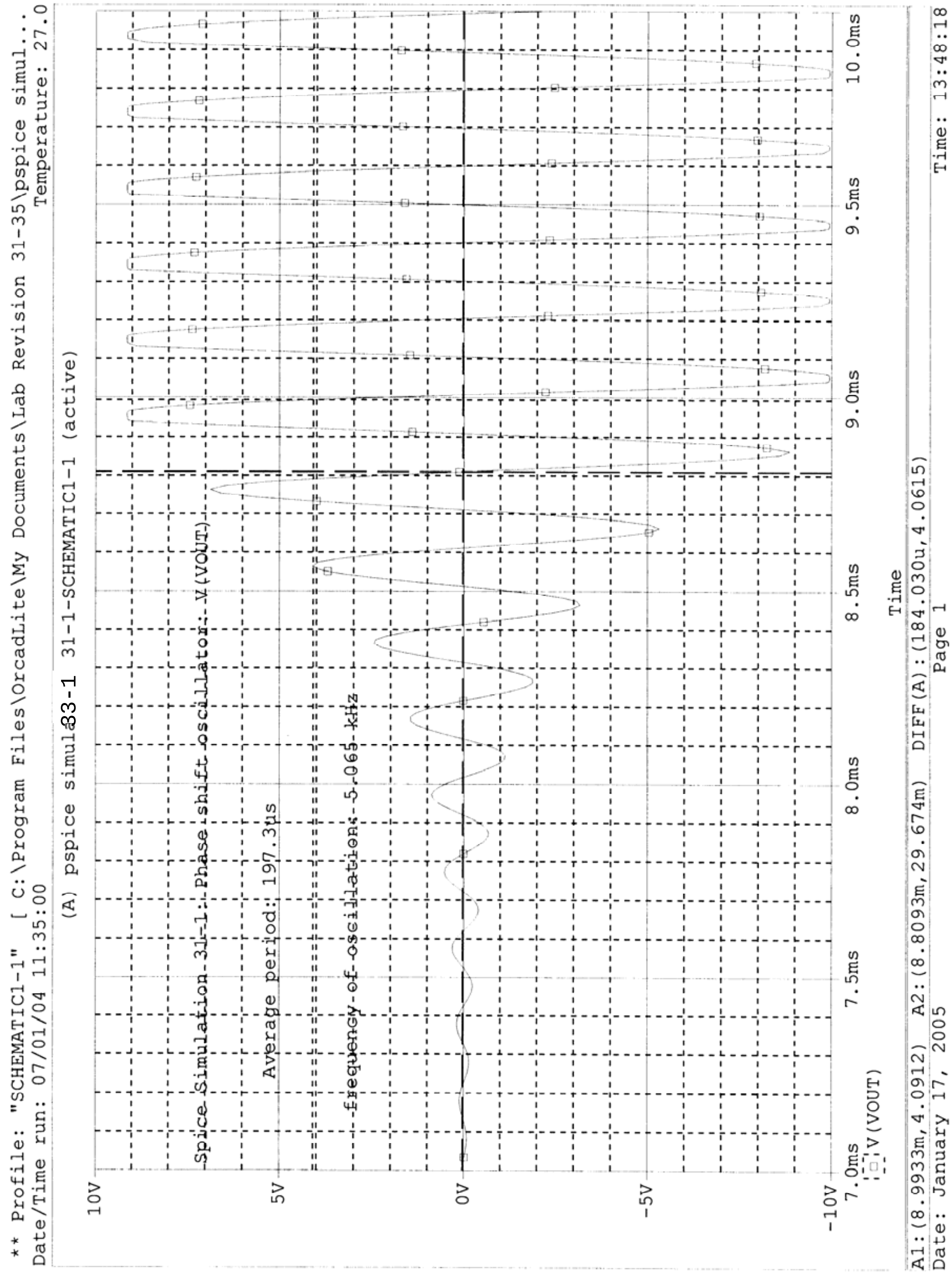
c. T (measured) = 21 μs

d. $f = 1/T$ = 46.9 KHz

e. T (measured, C = 0.01 μF) = 210 μs
$f = 1/T$ = 4.69 KHz

f. f (calculated, C = 0.001 μF) = 46 KHz
f (calculated, C = 0.01 μF) = 4.6 KHz

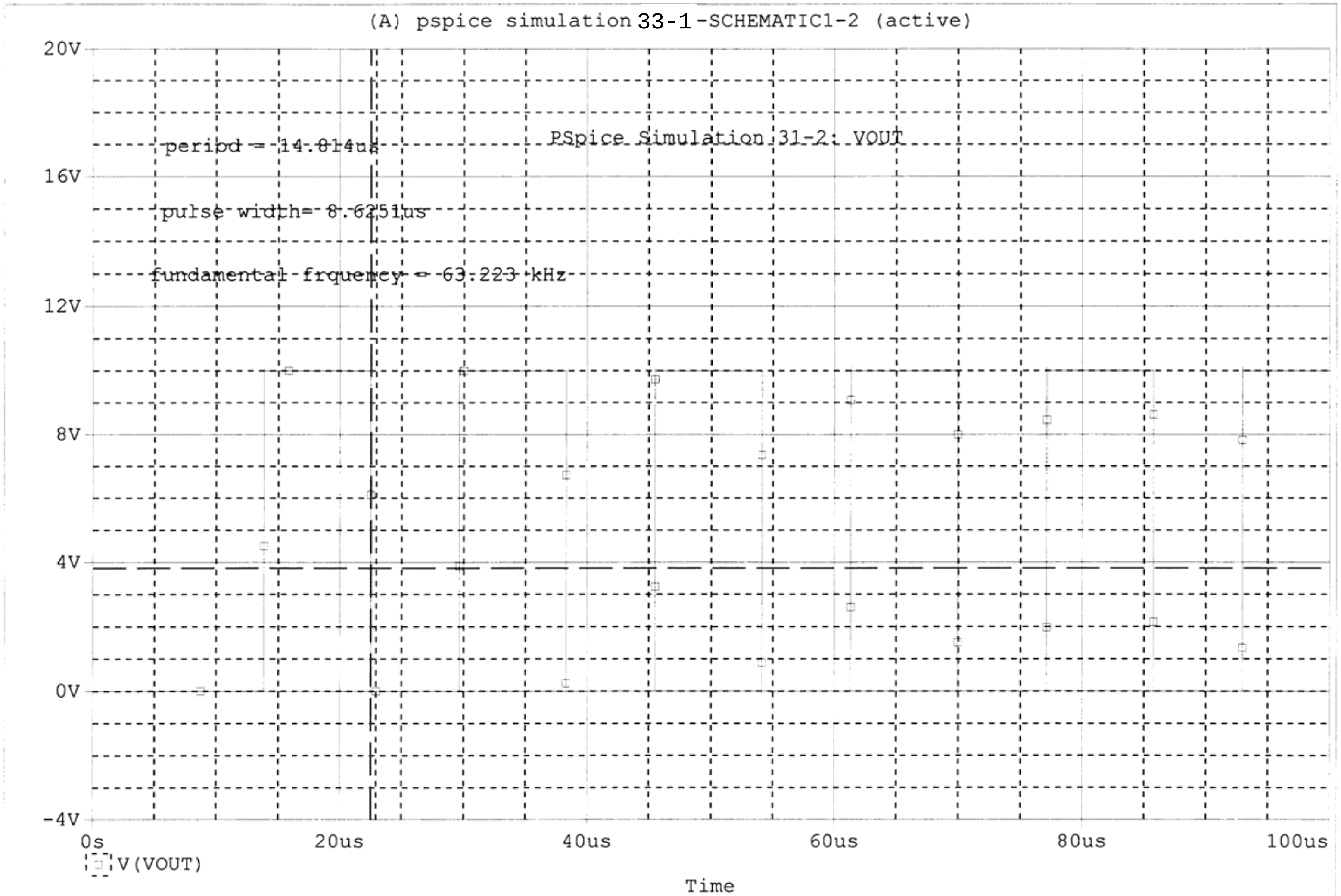
The measured and calculated values of the frequency for each capacitor were within 2 percent of each other.


** Profile: "SCHEMATIC1-1" [C:\Program Files\OrcadLite\My Documents\Lab Revision 31-35\pspice simul...
Date/Time run: 07/01/04 11:35:00
Temperature: 27.0
(A) pspice simul33-1 31-1-SCHEMATIC1-1 (active)
Spice Simulation 31-1: Phase shift oscillator: V(VOUT)
Average period: 197.3us
frequency of oscillation: 5.065 kHz
10V
5V
0V
-5V
-10V
7.0ms
7.5ms
8.0ms
8.5ms
9.0ms
9.5ms
10.0ms
V(VOUT)
Time
A1:(8.9933m,4.0912) A2:(8.8093m,29.674m) DIFF(A):(184.030u,4.0615)
Date: January 17, 2005
Page 1
Time: 13:48:18

PSpice Simulation 33-1

1. See Probe plot page 347.
   $(VOUT)_{min}$ = 0 V
   $(VOUT)_{max}$ = 10 V
2. Yes.
3. 15.87 μs
4. PW = 8.63 μs
5. f= 63.2 KHz
6. See Probe plot page 348.
7. Yes
8. No
9. P = 31.115 μs
10. PW = 23.993 μs
11. f = 41.67 KHz
12. Yes

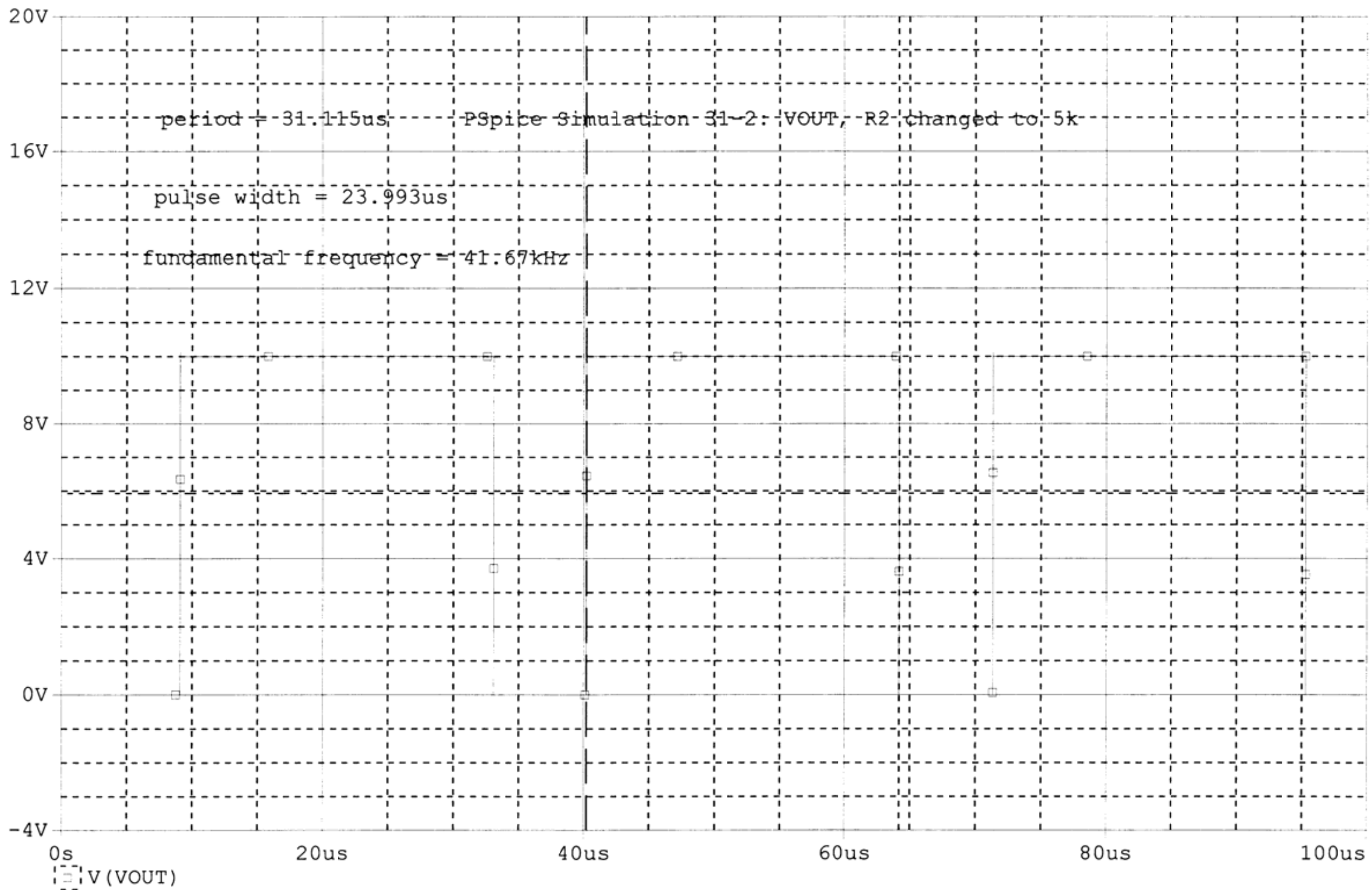
** Profile: "SCHEMATIC1-2" [C:\Program Files\Orcadlite\My Documents\Lab Revision 31-35\pspice simul...
Date/Time run: 11/29/04 11:21:14 Temperature: 27.0



A1:(22.921u,0.9999m) A2:(22.489u,3.8136) DIFF(A):(432.393n,-3.8126)
Date: November 29, 2004 Page 1 Time: 11:28:42

** Profile: "SCHEMATIC1-2" [C:\Program Files\Orcadlite\My Documents\Lab Revision 31-35\pspice simul...
Date/Time run: 11/29/04 11:35:09 Temperature: 27.0

(A) pspice simulation 33-1 -SCHEMATIC1-2 (active)



A1:(64.196u,5.9322) A2:(40.203u,5.9322) DIFF(A):(23.993u,0.000)
Date: November 29, 2004 Page 1 Time: 11:40:41

EXPERIMENT 34: 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. $V_L = V_Z - V_{BE} = 10\text{ V} - .7\text{ V} = 9.3\text{ V}$

b. V_O (measured) = 9.3 V

Table 34.1

V_i (V)	10	11	12	13	14	15	16
V_O (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. $A = 1 + R_1/R_2 = 1 + 1\text{ K}/2\text{ K} = 1.5$
$V_L = A_{VZ}$
V_L (calculated) = 15 V

b.

Table 34.2

V_i (V)	10	12	13	14	16	18	20	22	24
V_L (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. $V_L = (R_1 + R_2) * V_Z/R_1 = 3\text{ K}/2\text{ K} * 10\text{ V} = 15\text{ V}$

b. V_L (measured) = 14.7 V

Table 34.3

V_i (V)	24	26	28	30	32	34	36
V_O (V)	14.3	14.4	14.5	14.7	14.7	14.9	15.1

The regulation of this system was 2.7 percent.

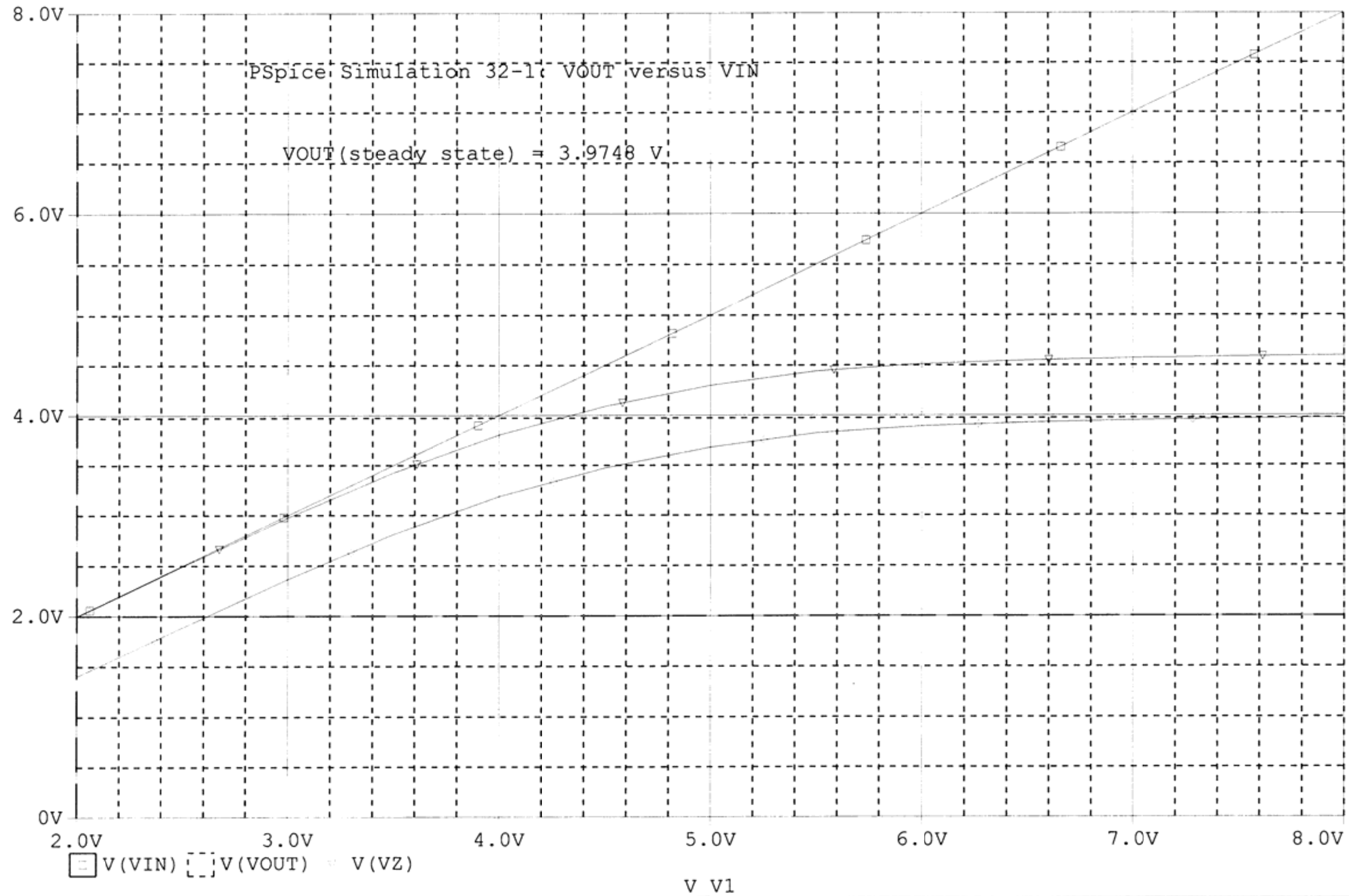
Part 4: Computer Exercises

PSpice Simulation 34-1

1. See Probe plot page 350.
2. V_{in} is swept linearly from 2 V to 8 V in 1 V increments.
3. $V(V2)$ = 4.68 V
   V(OUT) = 4 V
4. Approx. at V(VIN)) = 6.5 V
5. 0.68 V
6. Yes
7. $V_L = 4.68\text{ V} - 0.68\text{ V} = 4\text{ V}$

** Profile: "SCHEMATIC1-2" [C:\Program Files\Orcadlite\My Documents\Lab Revision 31-35\pspice simul...
Date/Time run: 07/09/04 19:27:54 Temperature: 27.0

(A) pspice simulation 34-1 -SCHEMATIC1-2 (active)



A1:(8.0000,3.9748) A2:(2.0000,2.0000) DIFF(A):(6.0000,1.9748)
Date: July 09, 2004 Page 1 Time: 19:31:24

PSpice Simulation 34-2

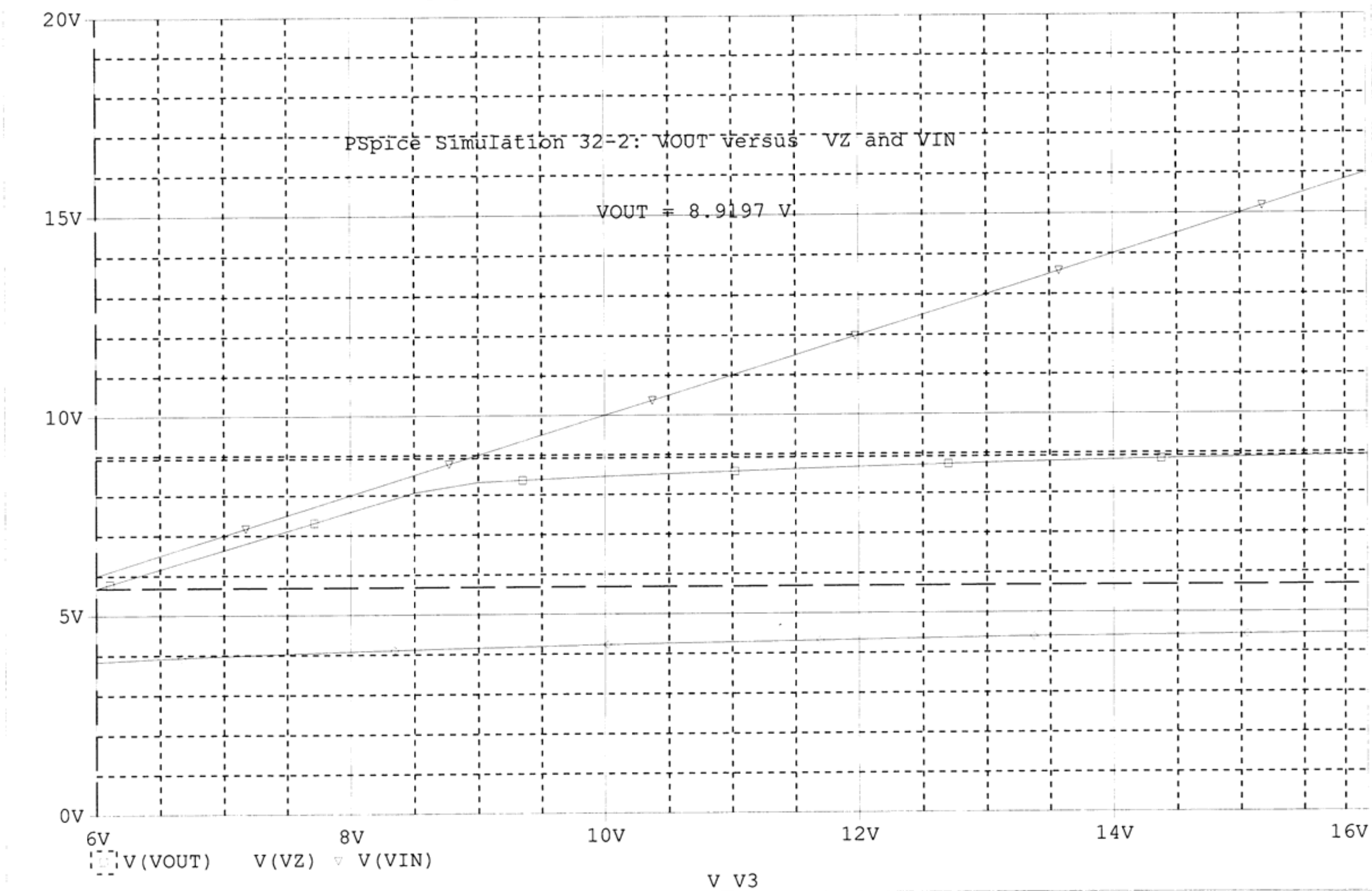
1. See Probe plot page 352.
2. V(IN) increases linearly from 6 V to 16 V in 0.5 V increments.
3. $V_L = V(\text{OUT}) = \dfrac{1\text{ k}\Omega + 1\text{ k}\Omega}{1\text{ k}\Omega}(4.68\text{ V}) = 9.36\text{ V}$
4. $V(\text{OUT})\big|_{\text{theor.}} = 9.36\text{ V}$

   $V(\text{OUT})\big|_{\text{PSpice}} = 8.9197\text{ V}$
5. $V(V2) = 4.68\text{ V}$

   $V(\text{VOUT}) = 8.9197\text{ V}$

** Profile: "SCHEMATIC1-2" [C:\Program Files\OrcadLite\My Documents\Lab Revision 31-35\pspice simul...
Date/Time run: 07/11/04 11:42:52 Temperature: 27.0

(A) pspice simulation 34-2 -SCHEMATIC1-2 (active)



A1:(15.822,8.9197) A2:(6.0000,5.6872) DIFF(A):(9.822,3.2325)
Date: July 11, 2004 Page 1 Time: 11:46:41

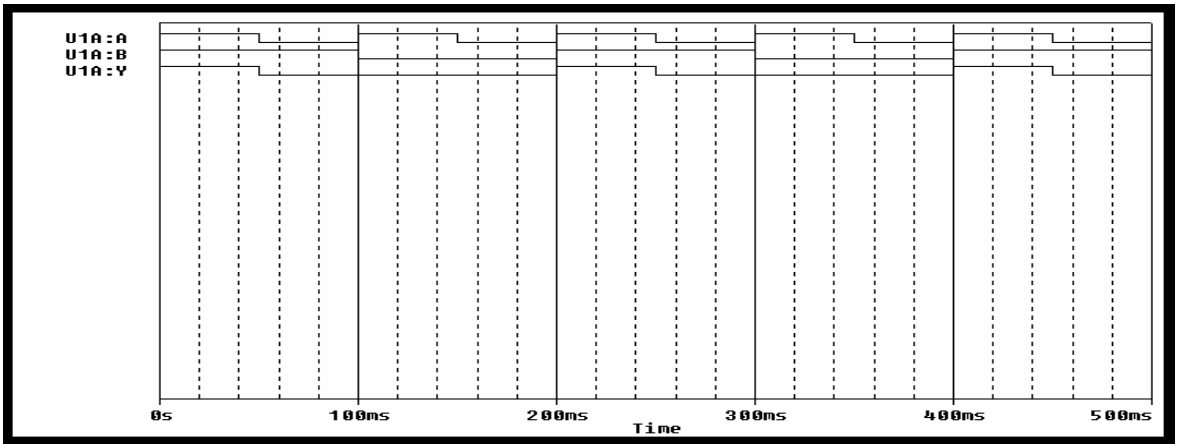
EXPERIMENT 35: ANALYSIS OF AND, NAND, AND INVERTER LOGIC GATES

Part 1: The **AND** Gate: Computer Simulation

a.

Table 35-1

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 inputs 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

b. Example of a calculation: assume: V(V1A:Y) = 3.5 volts, VY = 3.4 volts

$$\%\text{deviation} = \frac{3.5\text{V} - 3.4\text{V}}{3.5\text{V}} * 100 = 2.86 \text{ percent}$$

c. 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.

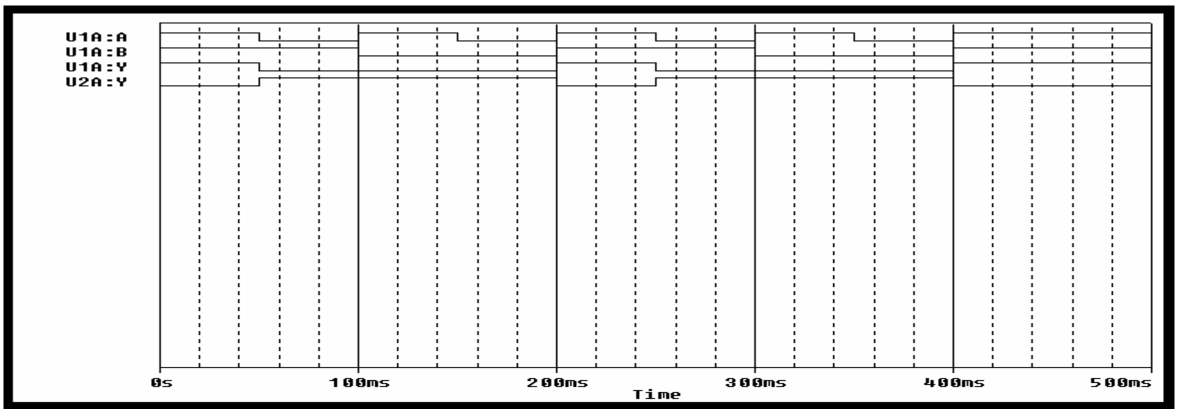
c. From Laboratory data, determine the percent deviation using the same procedure as before.

Part 5: **NOT-AND** Logic
A. Computer Simulation

a.

Table 35-2

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

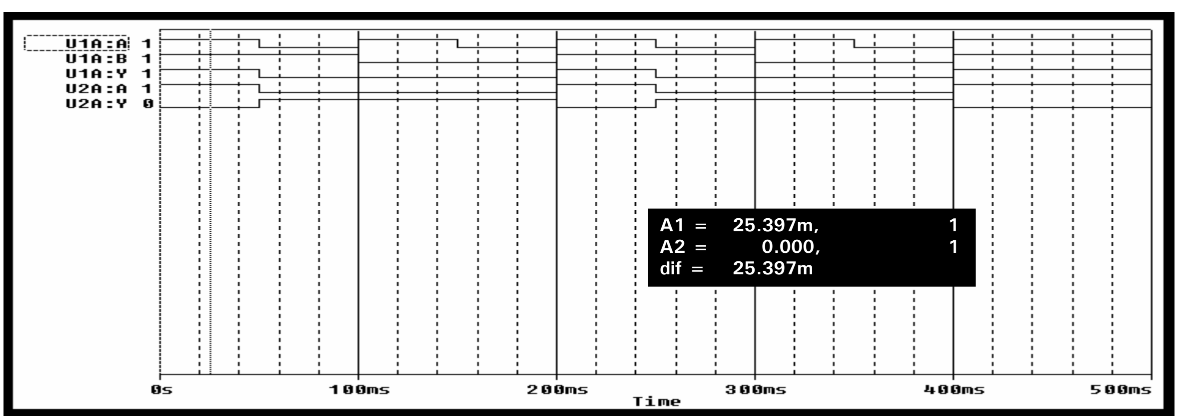


Traces **U1A: A** and **U1A:B** are the inputs to the 7408 gate, **U1A:Y** its output trace. Trace **U2A:Y** is the output of the 7404 gate.

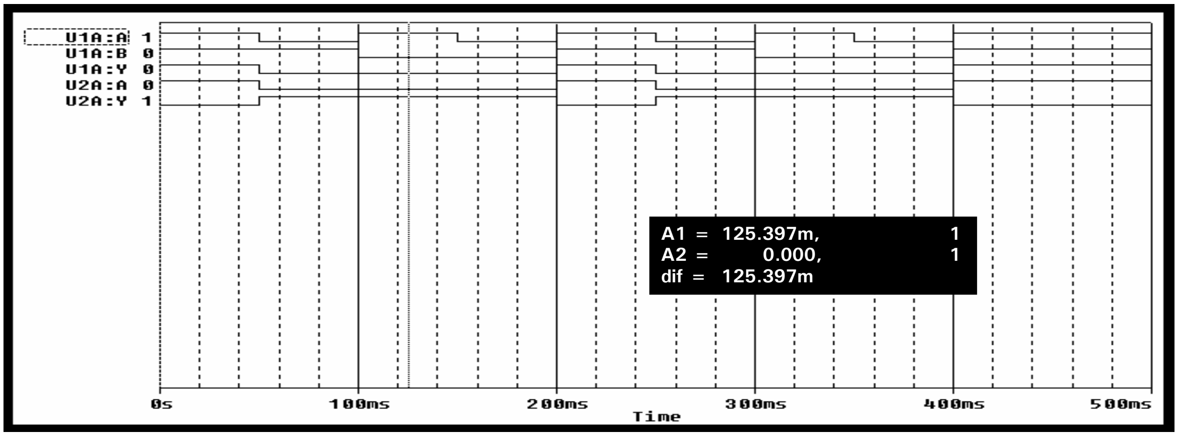
b. The Output of the 7404 gate will be **HIGH** if and only if the input to both terminals of the 7408 gate are **HIGH**, otherwise, the output of the 7404 gate will be **LOW**.

c. The most prevalent state of the Output terminal of the 7404 gate is **HIGH.**

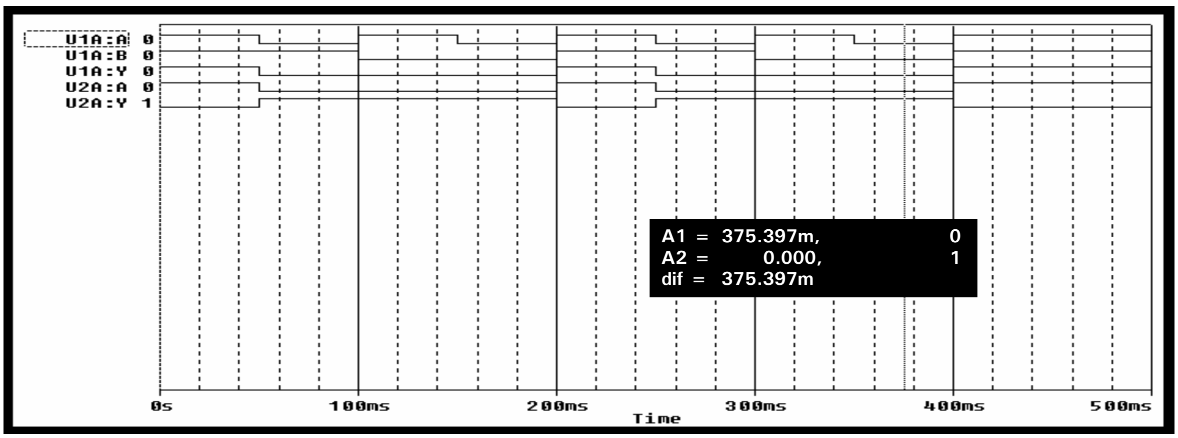
d. The **PSpice** cursor was used to determine the logic states at the requested times. The logic states are indicated at the left margin.
At t = 25 milliseconds:



At *t* = 125 milliseconds



At *t* = 375 milliseconds



B. Experimental Determination of Logic States

a. They should be relatively close to each other.

b. They are identical.

c. The output of the 7404 gate is the negation of the output of the 7408 gate.

Part 6: The 7400 **NAND** Gate

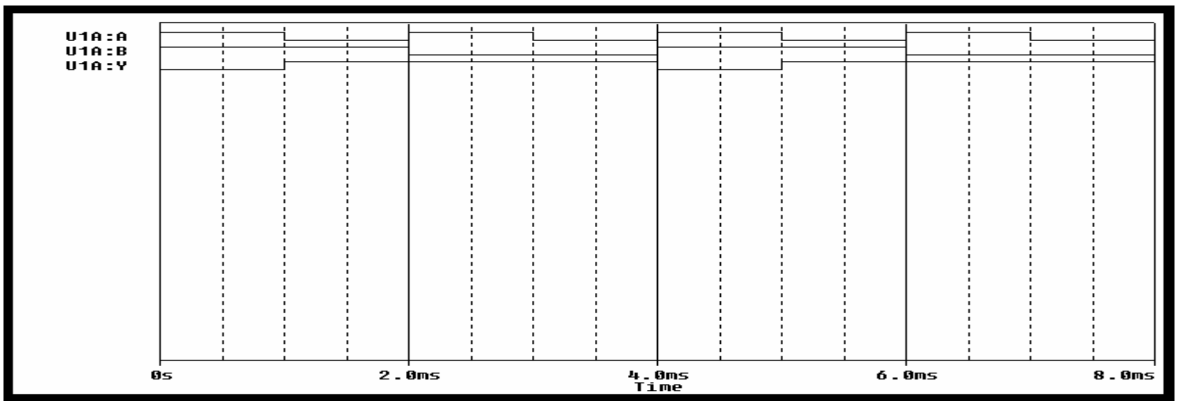
A. Computer Simulation

Table 35-3

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 35-4

Input terminal 1	Input terminal 2	Output terminal 3
1	1	0
0	1	1
1	0	1
0	0	1

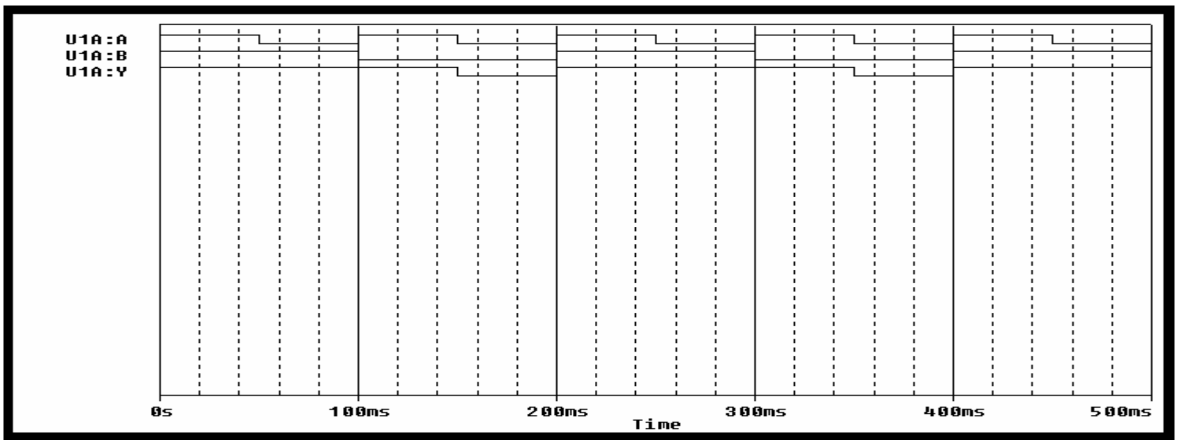
EXPERIMENT 36: ANALYSIS OF OR, NOR AND XOR LOGIC GATES

Part 1: The **OR** Gate: Computer Simulation

a.

Table 36-1

Input terminal 1	Input terminal 2	Output terminal 3
1	1	1
0	1	1
1	0	1
0	0	0

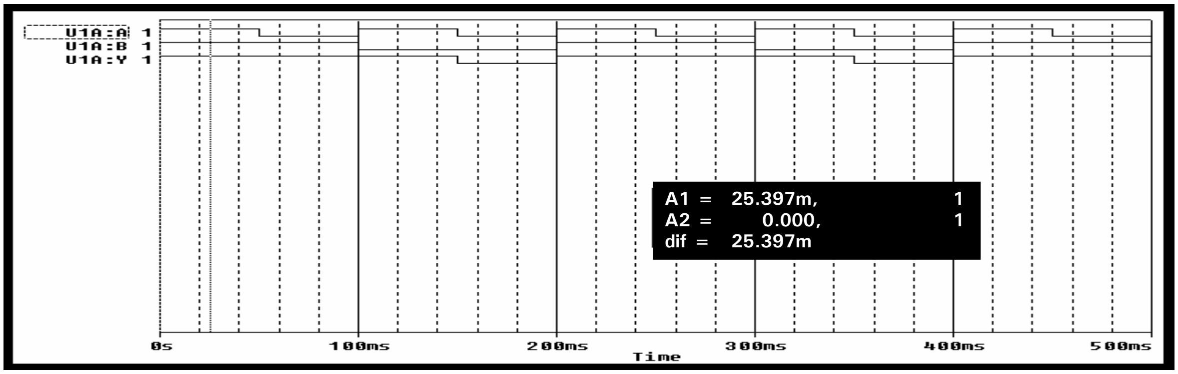


Traces U1A:A and U1A:b are the inputs to the gate.
Trace U1A:Y is the output of the gate.

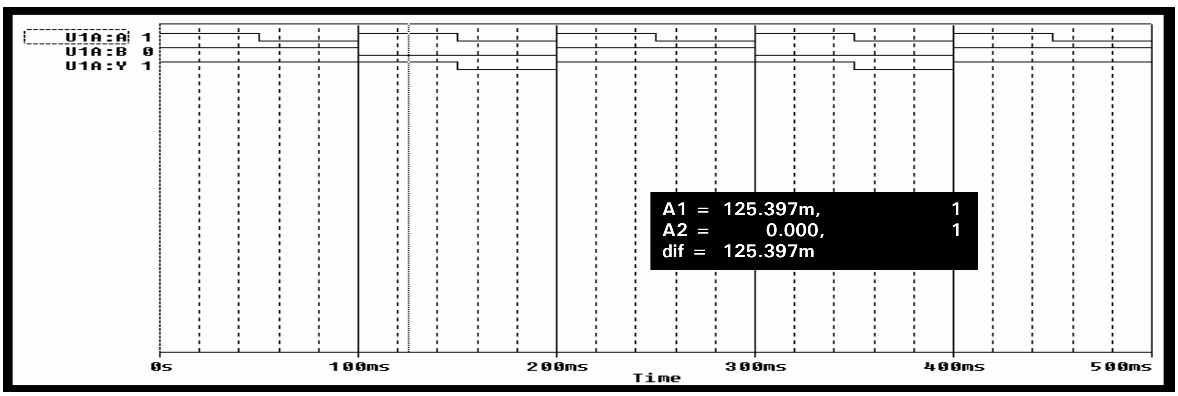
b. The output is a logical **LOW** if and only if both inputs are **LOW**, otherwise the output is **HIGH**.

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.

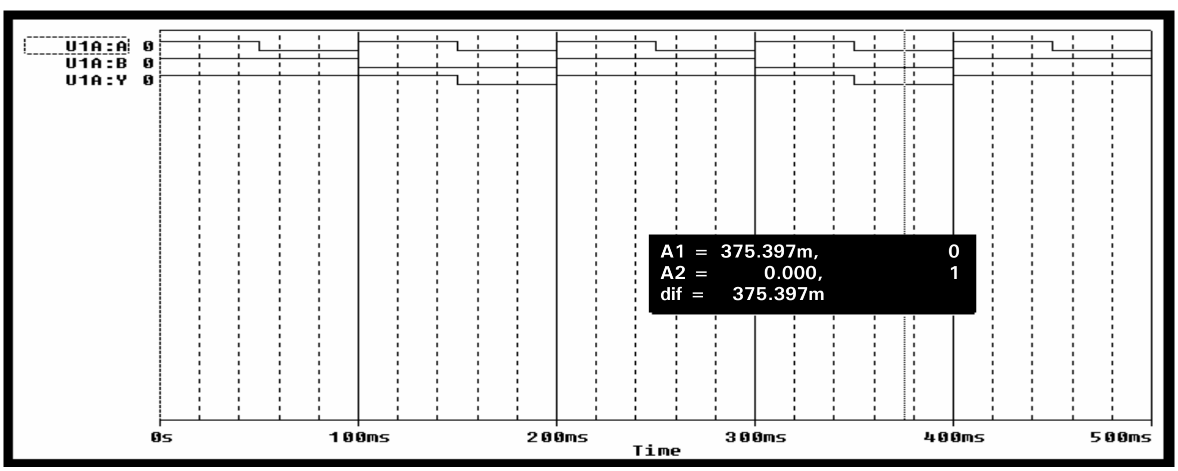
d. The **PSpice** cursor was used to determine the logic states at the requested times. The logic states are indicated at the left margin.
At t = 25 milliseconds:



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 shown on the PROBE plot for Figure 36-2.

b. Example of a calculation: assume V(V1A:Y) = 3.6 volts, VY = 3.4 volts

$$\%\text{deviation} = \frac{3.6\text{V} - 3.4\text{V}}{3.6\text{V}} * 100 = 5.56 \text{ percent}$$

a. It is larger by **(**5.56-2.86) = 2.7 percent.

Part 4: Combining **AND** with **OR** Logic

A. Computer Simulation

a.

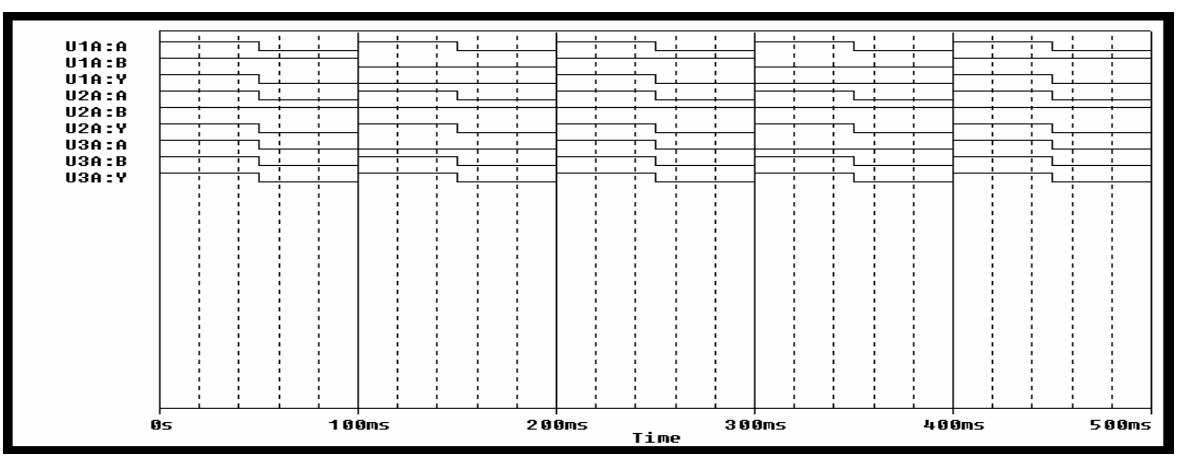
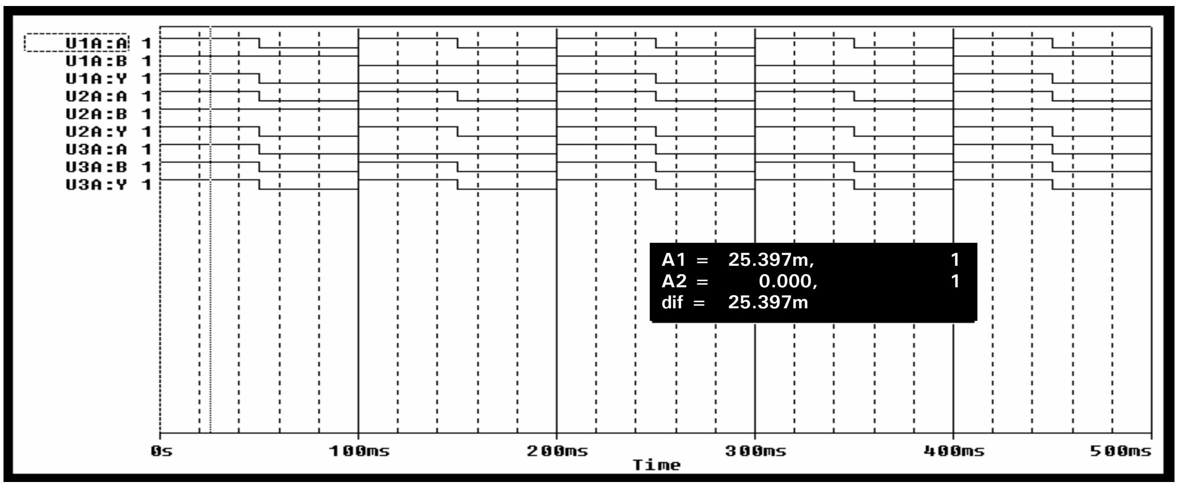


Table 36-2

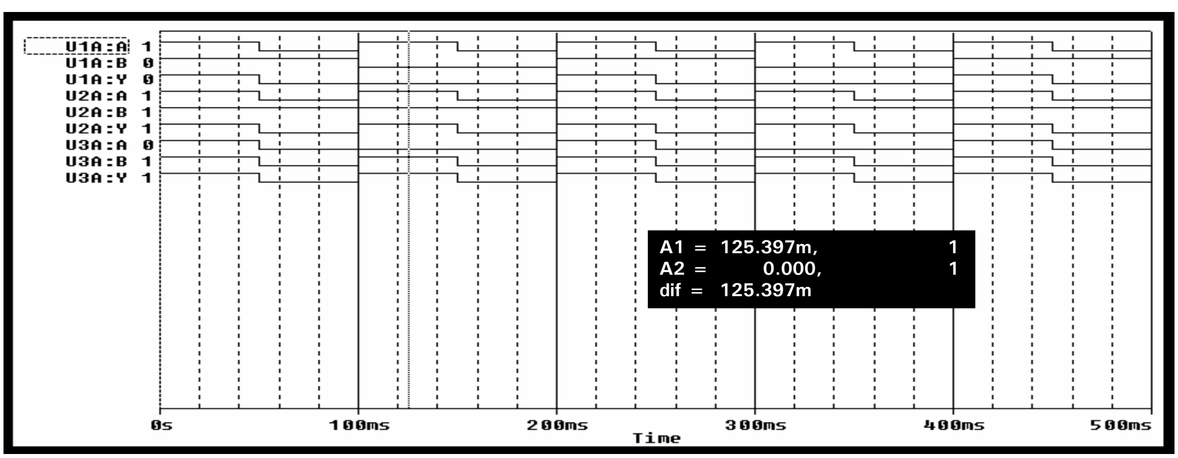
U1A:A	U1A:B	U1A:Y	U2A:A	U2A:B	U2A:Y	U3A:A	U3A:B	U3A:Y
1	1	1	1	1	1	1	1	1
0	1	0	0	1	0	0	0	0
1	0	0	1	1	1	0	1	1
0	0	0	0	1	0	0	0	0

c.

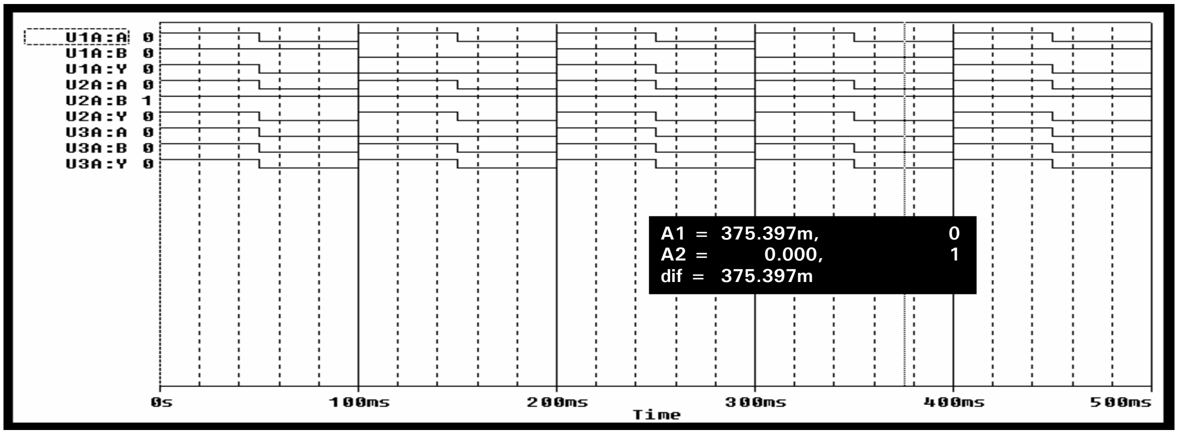
At *t* = 25 milliseconds



At *t* = 125 milliseconds



At *t* = 375 milliseconds



b. 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.

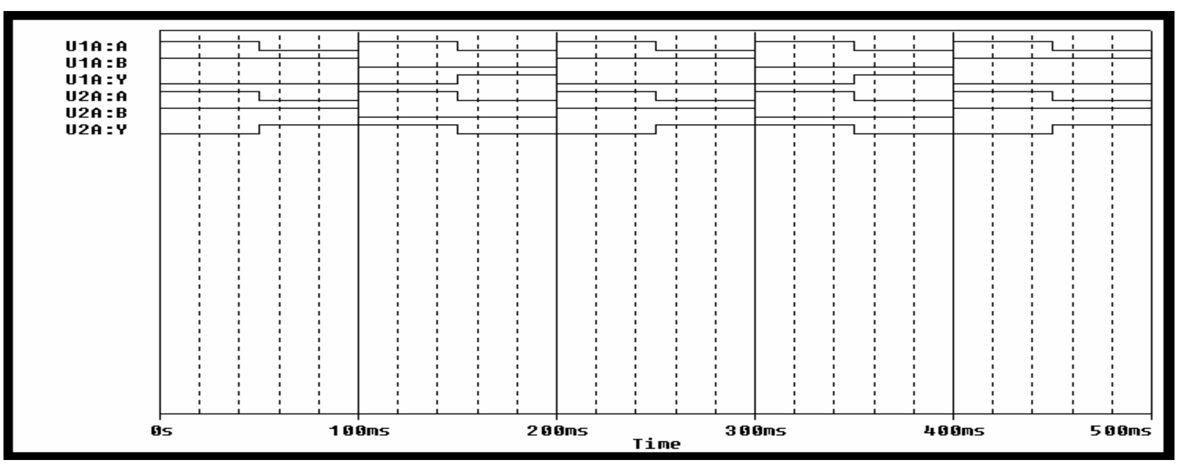
b. The logic state of the output terminal U3A:Y is identical to that of the **TTL** clock.

c. The logic state of the output terminal U3A:Y is identical to that of the output terminal U2A:Y of the U2A gate.

Part 5: **NOR** and **XOR** Logic combined

A. Computer Simulation

a.



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.

b.

Table 36-3

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

c. The output of the 7402 gate, U1A:Y is **HIGH** if and only if both inputs are **LOW**, otherwise the output is **LOW**.

d. This is a logical inversion of the **OR** gate.

c. 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.

f. 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 36-3.

c. Refer to the data in Table 36-3.

d. Refer to the data in Table 36-3.

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 37: ANALYSIS OF INTEGRATED CIRCUITS

Part 1: Positive Edge-Triggered D Flip-Flop

A. Computer Simulation

a. The PROBE data shows the flip flop 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.

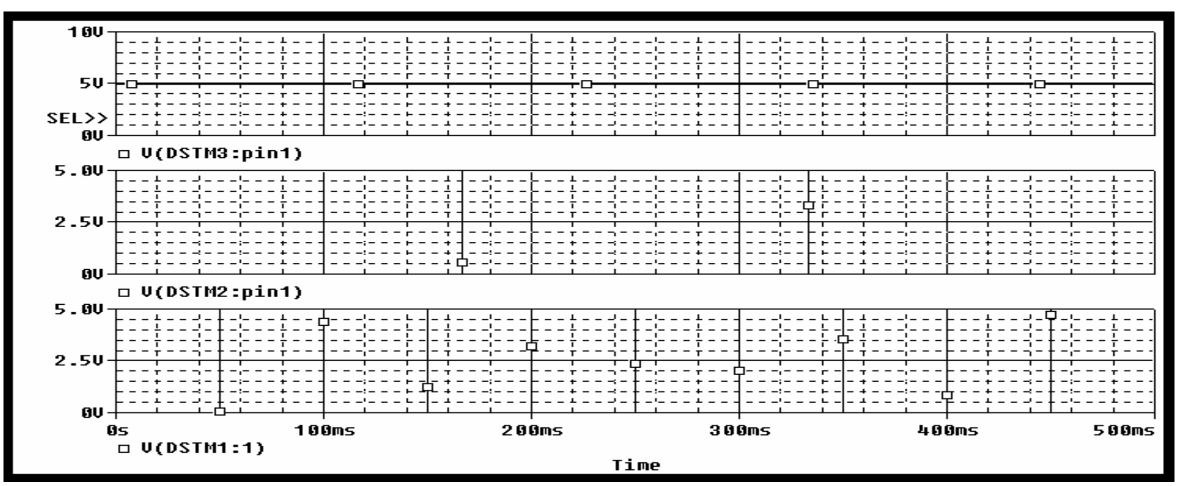
d. After the initial **SET** condition of the flip flop, and after a **RESET** state of 200 milliseconds, the flip flop returns to its **SET** condition because at 400 milliseconds, both the **CLOCK** and the **D** inputs are positive.

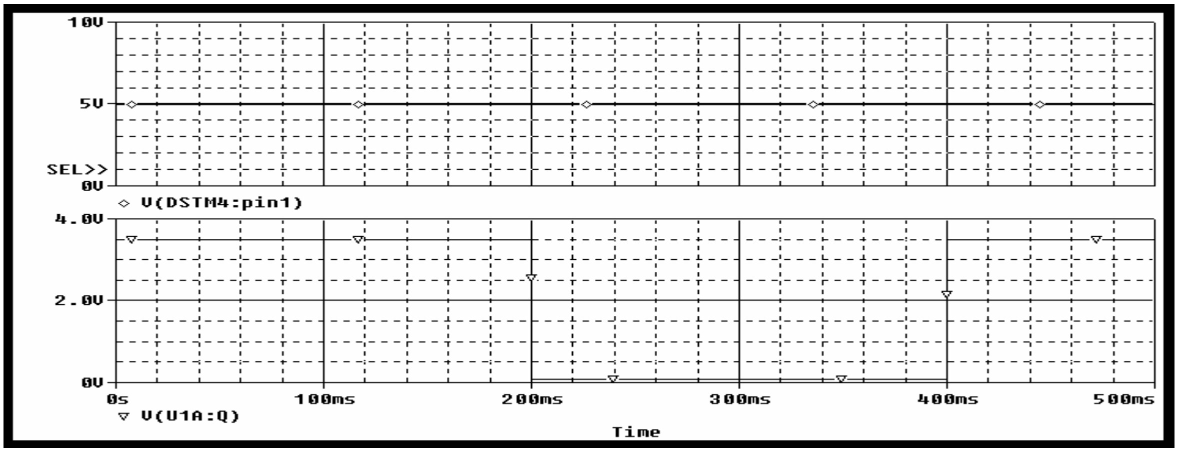
e. Starting from a **SET** condition, a transition to **RESET** will occur when the D input is negative and the **CLOCK** pulse goes positive. The flip flop will **SET** again when the **D** input is positive and the **CLOCK** goes positive.

f. The conditions stated in 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 **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.

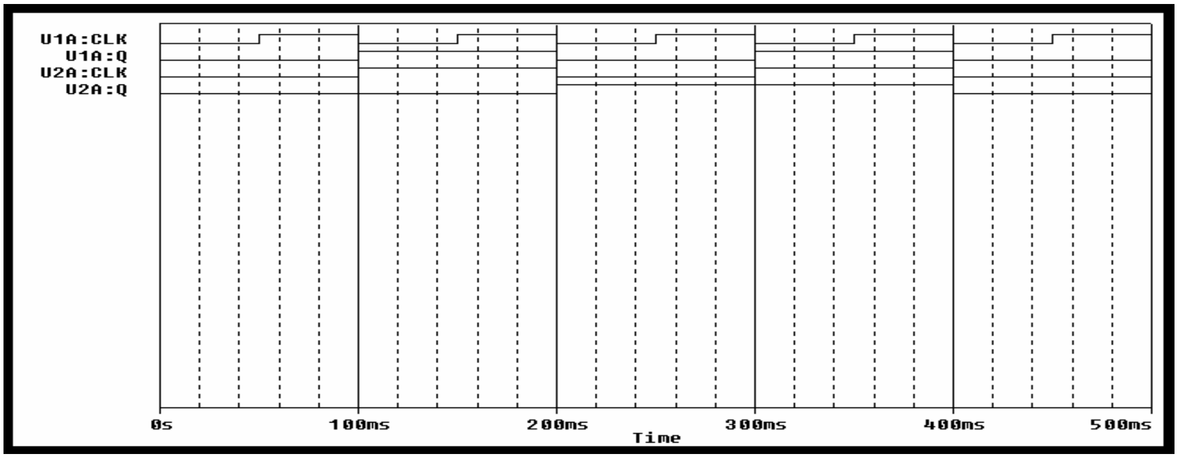
d. The difference between the input voltages and the output voltage is caused by the voltage drop through the flip flop.

e. The experimental and the simulation transition states occur at the same times.

Part 2: Frequency Division

A. Computer Simulation

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.

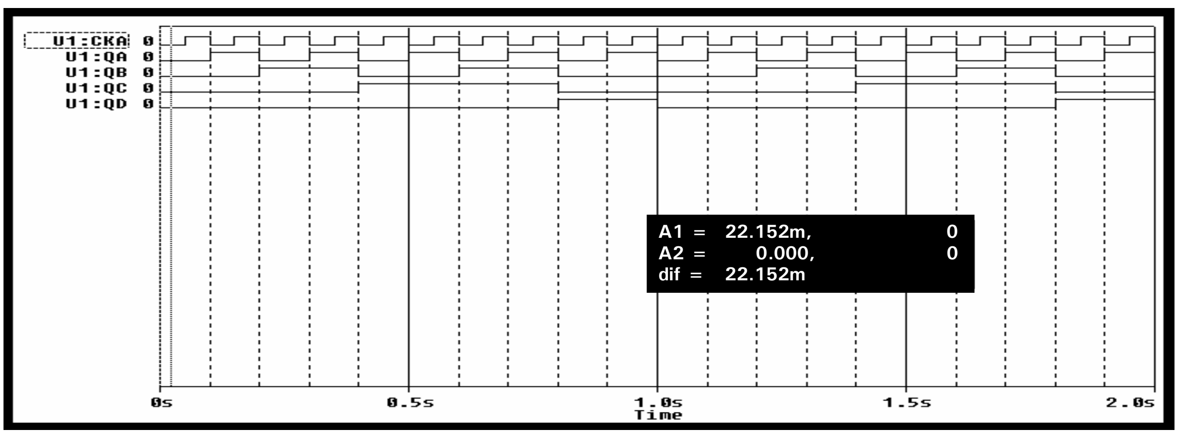
Pulse	Frequency
U1A:CLK	10.0 Hz
U1A:Q	5.0 Hz
U2A:CLK	5.0 Hz
U2A:Q	2.5 Hz

e. They are identical.

Part 3: An Asynchronous Counter: the 7493A Integrated Circuit

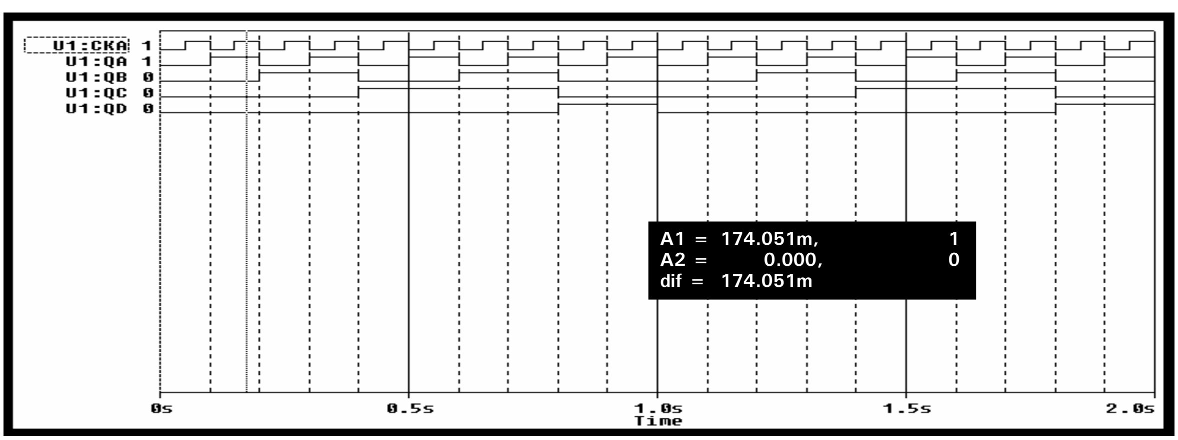
A. Computer Simulation

a.

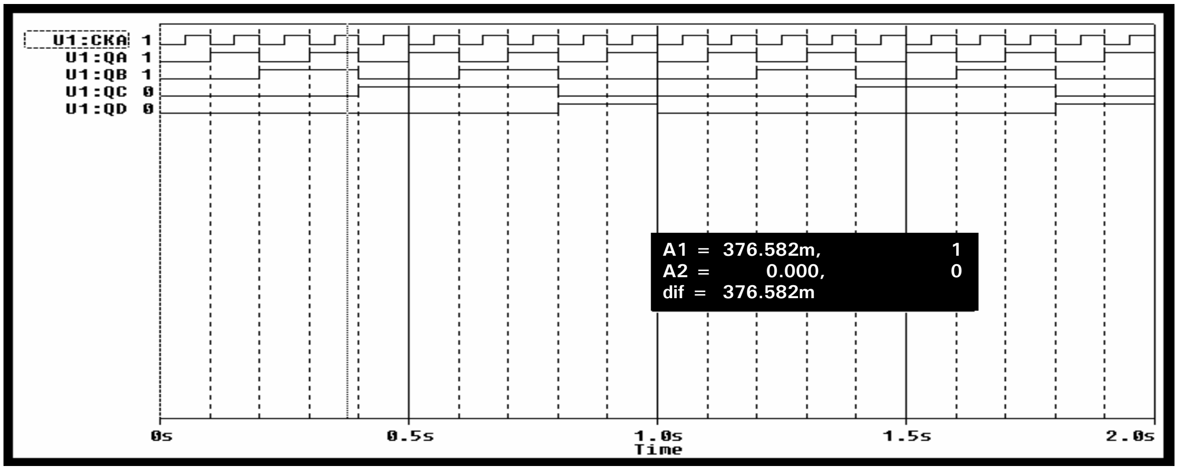


b. See **PROBE** plot above**.**

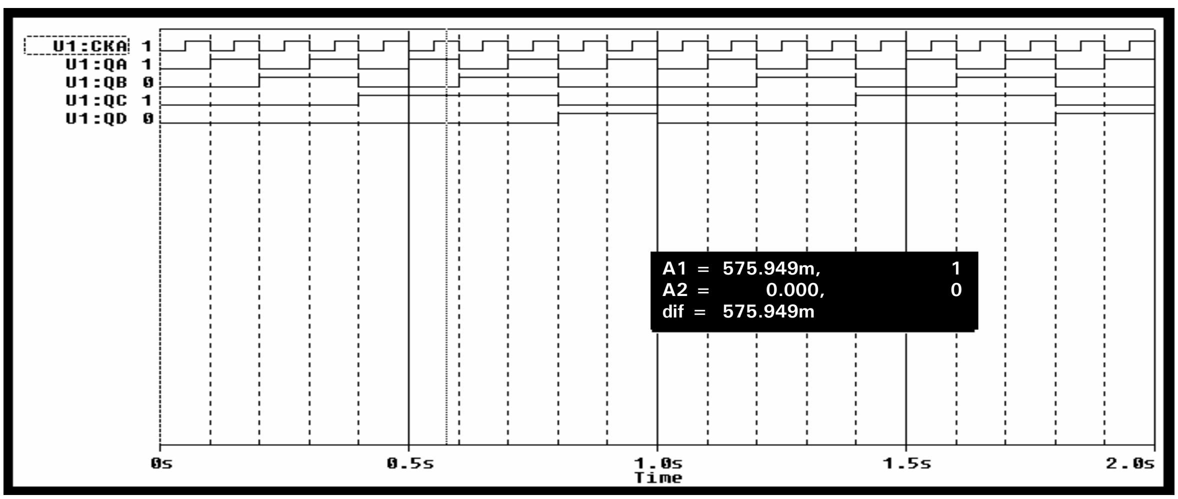
d. *t* = 175 milliseconds. There is one clock pulse to the left of the cursor.



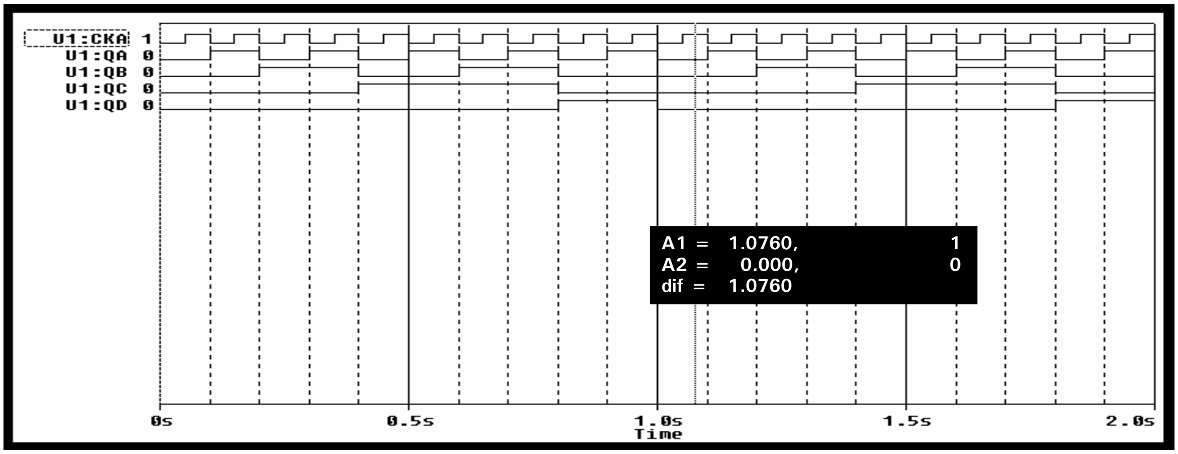
e. *t* = 375 milliseconds. There are three clock pulses to the left of the cursor.



f. *t* = 575 milliseconds. There are five clock pulses to the left of the cursor.



g. *t* = 1.075 seconds. There are ten clock pulses to the left of the cursor.

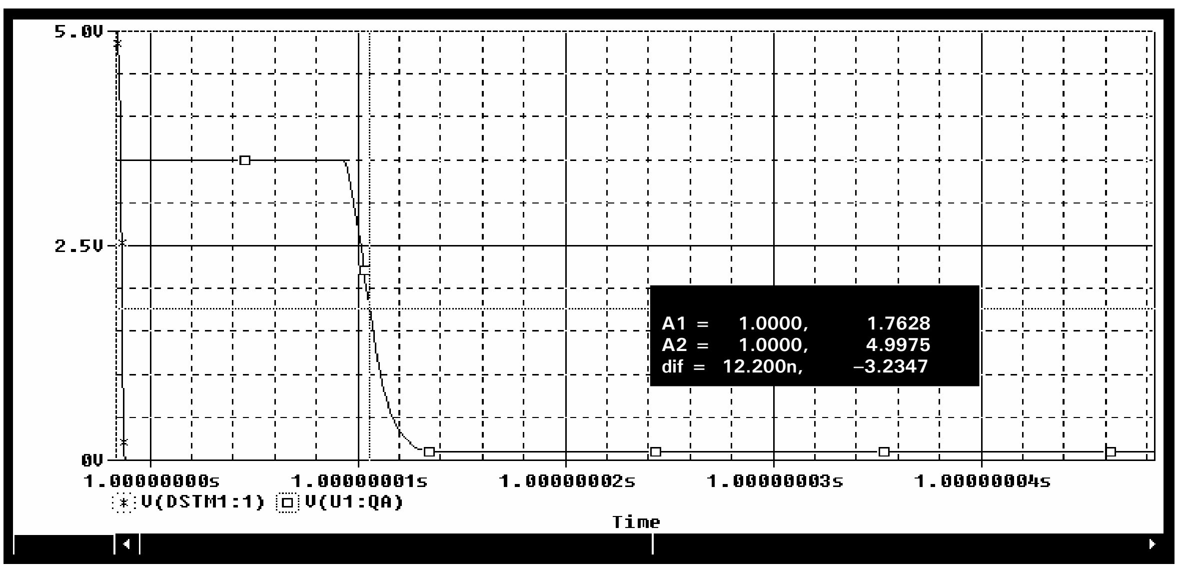


h. At t = 1.075 milliseconds, the output terminals, **QA**, **QB**, **QC** and **QD** have resumed their initial states.

i. **The MOD 10** counts to ten in binary code after which it recycles to its original condition.

j. The output terminal **QA** represents the most significant digit.

k. 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.