Chapter 8

Exercise Solutions

E8.1

For $V_{DS} = 0$, $I_D(\max) = \frac{24}{20} = 1.2\text{ A} = I_D(\max)$

For $I_D = 0 \Rightarrow V_{DS}(\max) = 24\text{ V}$

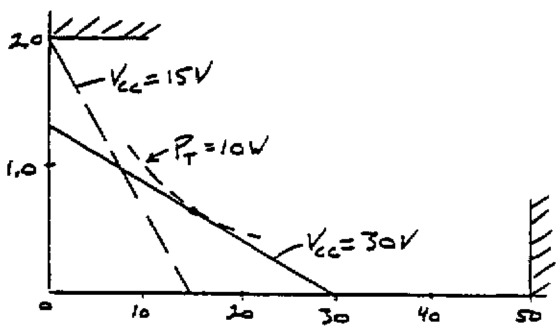
Maximum power when

$V_{DS} = \frac{V_{DS}(\max)}{2} = 12\text{ V}$ and

$I_D = \frac{I_D(\max)}{2} = 0.6\text{ A}$

$\Rightarrow P_D(\max) = (12)(0.6) = 7.2\text{ Watts}$

E8.2



a. $V_{CC} = 30\text{ V},\ V_{CE} = 30 - I_C R_C,\ I_C V_{CE} = 10$

Maximum power at $V_{CE} = \frac{1}{2}V_{CC} = 15$

$I_C = \frac{10}{V_{CE}} = \frac{10}{15} = \frac{2}{3}$

So $15 = 30 - \frac{2}{3}R_L \Rightarrow R_L = 22.5\ \Omega$

$\Rightarrow$ Maximum Power = 10 W

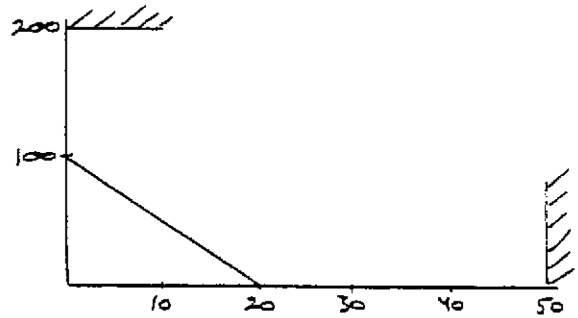
b. $V_{CC} = 15\text{ V},\ I_{C,\max} = 2\text{ A}$

$V_{CE} = 15 - I_C R_L$

$0 = 15 - 2R_L \Rightarrow R_L = 7.5\ \Omega$

$\Rightarrow$ Maximum Power $= (1)(7.5) = 7.5\text{ W}$

E8.3



Maximum power at center of load line

$P_{\max} = (0.05)(10) \Rightarrow P_{\max} = 0.5\text{ W}$

E8.4

Power $= i_D \cdot v_{DS} = (1)(12) = 12$ watts

c. $T_{sink} = T_{amb} + P \cdot \theta_{snk-amb}$

$T_{sink} = 25 + (12)(4) \Rightarrow T_{sink} = 73°\text{C}$

b. $T_{case} = T_{sink} + P \cdot \theta_{case-snk}$

$T_{case} = 73 + (12)(1) \Rightarrow T_{case} = 85°\text{C}$

a. $T_{dev} = T_{case} + P \cdot \theta_{dev-case}$

$T_{dev} = 85 + (12)(3) \Rightarrow T_{dev} = 121°\text{C}$

E8.5

$$\theta_{dev-case} = \frac{T_{j,\max} - T_{amb}}{P_{D,rated}} = \frac{200 - 25}{50} = 3.5°\text{C/W}$$

$$P_{D,\max} = \frac{T_{j,\max} - T_{amb}}{\theta_{dev-case} + \theta_{case-snk} + \theta_{snk-amb}} = \frac{200 - 25}{3.5 + 0.5 + 2}$$

$\Rightarrow P_{D,\max} = 29.2\text{ W}$

$$T_{case} = T_{amb} + P_{D,\max}(\theta_{case-snk} + \theta_{snk-amb}) = 25 + (29.2)(0.5 + 2)$$

$\Rightarrow T_{case} = 98°\text{C}$

E8.6

a. $P_Q = V_{CEQ} \cdot I_{CQ} = (7.5)(7.5)$

$\underline{P_Q = 56.3 \text{ mW}}$

b. $\overline{P_L} = \frac{1}{2} \cdot \frac{V_P^2}{R_L} = \frac{1}{2} \cdot \frac{(6.5)^2}{1} \Rightarrow \underline{\overline{P_L} = 21.1 \text{ mW}}$

$\overline{P_S} = (15)(7.5) \Rightarrow \overline{P_S} = 113 \text{ mW}$

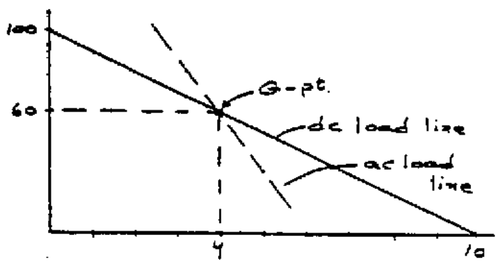
$\eta = \frac{\overline{P_L}}{\overline{P_S}} = \frac{21.1}{113} \Rightarrow \underline{\eta = 18.7\%}$

$\underline{\overline{P_Q} = 56.3 - 21.1 = 35.2 \text{ mW}}$

E8.7

a. $I_{DQ} = \frac{10-4}{0.1} \Rightarrow \underline{I_{DQ} = 60 \text{ mA}}$

b.



$v_{ds} = -\left(\frac{9}{10}\right)(60)(0.050) = -2.7 \text{ V}$

$\Rightarrow v_{DS}(\min) = 4 - 2.7 = 1.3 \text{ V}$

So maximum swing is determined by drain-to-source voltage.

$V_{PP} = 2 \times (2.5) = 5.0 \text{ V}$

c. $\overline{P_L} = \frac{1}{2} \cdot \frac{V_P^2}{R_L} = \frac{1}{2} \cdot \frac{(2.5)^2}{0.1} \Rightarrow \underline{\overline{P_L} = 31.25 \text{ mW}}$

$\overline{P_S} = V_{DD} \cdot I_{DQ} = (10)(60) = 600 \text{ mW}$

$\eta = \frac{\overline{P_L}}{\overline{P_S}} = \frac{31.25}{600} \Rightarrow \underline{\eta = 5.2\%}$

E8.8

a. $\overline{P_L} = \frac{1}{2} \cdot \frac{V_P^2}{R_L}$

$\Rightarrow V_P = \sqrt{2R_L\overline{P_L}} = \sqrt{2(8)(25)} \Rightarrow V_P = 20 \text{ V}$

$\Rightarrow V_{CC} = \frac{20}{0.8} \Rightarrow \underline{V_{CC} = 25 \text{ V}}$

b. $I_P = \frac{V_P}{R_L} = \frac{20}{8} \Rightarrow \underline{I_P = 2.5 \text{ A}}$

c. $\overline{P_Q} = \frac{V_{CC}V_P}{\pi R_L} - \frac{V_P^2}{4R_L}$

$\overline{P_Q} = \frac{(25)(20)}{\pi(8)} - \frac{(20)^2}{4(8)} = 19.9 - 12.5$

$\Rightarrow \underline{\overline{P_Q} = 7.4 \text{ W}}$

d. $\eta = \frac{\pi V_P}{4V_{CC}} = \frac{\pi}{4} \cdot \frac{20}{25} \Rightarrow \underline{\eta = 62.8\%}$

E8.9

a. $\overline{P_L} = \frac{1}{2} \cdot \frac{V_P^2}{R_L} = \frac{(4)^2}{2(0.1)} \Rightarrow \underline{\overline{P_L} = 80 \text{ mW}}$

b. $I_P = \frac{V_P}{R_L} = \frac{4}{0.1} \Rightarrow \underline{I_P = 40 \text{ mA}}$

c. $\overline{P_Q} = \frac{V_{CC}V_P}{\pi R_L} - \frac{V_P^2}{4R_L}$

$\overline{P_Q} = \frac{(5)(4)}{\pi(0.1)} - \frac{(4)^2}{4(0.1)} = 63.7 - 40$

$\Rightarrow \underline{\overline{P_Q} = 23.7 \text{ mW}}$

d. $\eta = \frac{\pi V_P}{4V_{CC}} = \frac{\pi}{4} \cdot \frac{4}{5} \Rightarrow \underline{\eta = 62.8\%}$

E8.10

a. $v_I = v_O + v_{GSn} - \frac{V_{BB}}{2}$

$\frac{dv_I}{dv_O} = 1 + \frac{dv_{GSn}}{dv_O}$

$i_{Dn} = K_n\left(v_{GSn} - V_{TN}\right)^2$

$v_{GSn} = \sqrt{\frac{i_{Dn}}{K_n}} + V_{TN}$

$\frac{dv_{GSn}}{dv_o} = \frac{dv_{GSn}}{di_{Dn}} \cdot \frac{di_{Dn}}{dv_o}$

So $\frac{dv_{GSn}}{di_{Dn}} = \frac{1}{\sqrt{K_n}} \cdot \frac{1}{2} \cdot \frac{1}{\sqrt{i_{Dn}}}$

At $v_O = 0$, $i_{Dn} = 0.050$ A

So $\frac{dv_{GSn}}{di_{Dn}} = \frac{1}{\sqrt{0.2}} \cdot \frac{1}{2} \cdot \frac{1}{\sqrt{0.050}} = 5$

$i_{Dn} = i_L + i_{Dp}$

For a small change in v_O — $\Delta i_L = \Delta i_{Dn} - (-\Delta i_{Dp})$

So $\Delta i_{Dn} = \frac{1}{2}\Delta i_L$

or

$\frac{di_{Dn}}{dv_O} = \frac{1}{2} \cdot \frac{di_L}{dv_O} = \frac{1}{2} \cdot \frac{1}{R_L} = \frac{1}{2} \cdot \frac{1}{20} = 0.025$

Then $\frac{dv_{GSn}}{dv_O} = (5)(0.025) = 0.125$

Then $\frac{dv_I}{dv_O} = 1 + 0.125 = 1.125$

and $A_v = \frac{dv_O}{dv_I} = \frac{1}{1.125} \Rightarrow \underline{A_v = 0.889}$

b. For $v_O = 5$ V, $i_L = 0.25 \text{ A} = i_{Dn}$, and $i_{Dp} = 0$

$$\frac{dv_{GSn}}{dv_O} = \frac{dv_{GSn}}{di_{Dn}} \cdot \frac{di_{Dn}}{dv_O}$$

$$\frac{dv_{GSn}}{di_{Dn}} = \frac{1}{\sqrt{K_n}} \cdot \frac{1}{2} \cdot \frac{1}{\sqrt{i_{Dn}}} = \frac{1}{\sqrt{0.2}} \cdot \frac{1}{2} \cdot \frac{1}{\sqrt{0.25}} = 2.24$$

$$\frac{di_{Dn}}{dv_O} = \frac{di_L}{dv_O} = \frac{1}{20} = 0.05$$

$$\frac{dv_{GSn}}{dv_O} = (2.24)(0.05) = 0.112$$

$$\frac{dv_I}{dv_O} = 1 + 0.112 = 1.112$$

$$A_v = \frac{dv_O}{dv_I} = \frac{1}{1.112} \Rightarrow \underline{A_v = 0.899}$$

E8.11

a. $$I_{CQ} \cong \frac{1}{2} \cdot \left(\frac{2V_{CC}}{R_L}\right) = \frac{V_{CC}}{R_L} = \frac{12}{1.5} = 8 \text{ mA}$$

$$R_{TH} = R_1 \| R_2$$

$$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right) V_{CC} = \frac{1}{R_1} \cdot R_{TH} \cdot V_{CC}$$

$$I_{BQ} = \frac{I_{CQ}}{\beta} = \frac{8}{75} = 0.107 \text{ mA} = \frac{V_{TH} - V_{BE}}{R_{TH} + (1+\beta)R_E}$$

Let $R_{TH} = (1+\beta)R_E = (76)(0.1) = 7.6 \text{ k}\Omega$

$$0.107 = \frac{\frac{1}{R_1} \cdot (7.6)(12) - 0.7}{7.6 + 7.6}$$

$$\frac{1}{R_1} \cdot (91.2) = 2.33 \Rightarrow \underline{R_1 = 39.1 \text{ k}\Omega}$$

$$\frac{39.1 R_2}{39.1 + R_2} = 7.6 \Rightarrow (39.1 - 7.6)R_2 = (7.6)(39.1)$$

$$\Rightarrow \underline{R_2 = 9.43 \text{ k}\Omega}$$

b. $$\overline{P_L} = \frac{1}{2} \cdot (0.9 I_{CQ})^2 R_L = \frac{1}{2}[(0.9)(8)]^2 (1.5)$$

$$\Rightarrow \underline{\overline{P_L} = 38.9 \text{ mW}}$$

$$\overline{P_S} = V_{CC} I_{CQ} = (12)(8) = 96 \text{ mW}$$

$$\overline{P_Q} = \overline{P_S} - \overline{P_L} = 96 - 38.9 \Rightarrow \underline{\overline{P_Q} = 57.1 \text{ mW}}$$

$$\eta = \frac{\overline{P_L}}{\overline{P_S}} = \frac{38.9}{96} \Rightarrow \underline{\eta = 40.5\%}$$

E8.12

a. $$R_b = r_\pi + (1+\beta)R'_E$$

and $R'_E = a^2 R_L = (10)^2(8) = 800\ \Omega$

$$R_i = 1.5 \text{ k}\Omega = R_{TH} \| R_b$$

$$I_Q = \frac{V_{CC}}{a^2 R_L} = \frac{18}{(10)^2(8)} = 22.5 \text{ mA}$$

$$r_\pi = \frac{(100)(0.026)}{22.5} = 0.116 \text{ k}\Omega$$

$$R_b = 0.116 + (101)(0.8) = 80.9 \text{ k}\Omega$$

$$1.5 = R_{TH} \| 80.9 = \frac{R_{TH}(80.9)}{R_{TH} + (80.9)}$$

$$\Rightarrow (80.9 - 1.5)R_{TH} = (1.5)(80.9)$$

$$\Rightarrow R_{TH} = 1.53 \text{ k}\Omega$$

$$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right) V_{CC} = \frac{1}{R_1} \cdot R_{TH} \cdot V_{CC}$$

$$I_{BQ} = \frac{I_Q}{\beta} = \frac{22.5}{100} = 0.225 \text{ mA}$$

$$I_{BQ} = \frac{V_{TH} - 0.7}{R_{TH}}$$

$$\Rightarrow \frac{1}{R_1}(1.53)(18) = (0.225)(1.53) + 0.7$$

$$\Rightarrow \underline{R_1 = 26.4 \text{ k}\Omega}$$

$$\frac{26.4 R_2}{26.4 + R_2} = 1.53$$

$$(26.4 - 1.53)R_2 = (1.53)(26.4)$$

$$\Rightarrow \underline{R_2 = 1.62 \text{ k}\Omega}$$

b. $$v_E = 0.9 V_{CC} = (0.9)(18) = 16.2 \text{ V}$$

$$i_E = 0.9 I_{CQ} = (0.9)(22.5) = 20.25 \text{ mA}$$

$$v_O = \frac{v_E}{a} = \frac{16.2}{10} \Rightarrow \underline{V_P = 1.62 \text{ V}}$$

$$i_O = a i_E = (10)(20.25) \Rightarrow \underline{I_P = 203 \text{ mA}}$$

$$\overline{P_L} = \frac{1}{2}(1.62)(0.203) \Rightarrow \underline{\overline{P_L} = 0.164 \text{ W}}$$

E8.13

a. $$I_C = I_{SQ} \exp\left(\frac{V_{BE}}{V_T}\right) \Rightarrow V_{BE} = V_T \ln\left(\frac{I_C}{I_{SQ}}\right)$$

$$V_{BE} = (0.026) \ln\left(\frac{5 \times 10^{-3}}{2 \times 10^{-13}}\right) = 0.6225 \text{ V}$$

$$\Rightarrow V_{D1} = V_{D2} = 0.6225$$

$$I_{\text{Bias}} = I_D = I_{SD} \exp\left(\frac{0.6225}{0.026}\right)$$

$$= 5 \times 10^{-13} \exp\left(\frac{0.6225}{0.026}\right)$$

$$\underline{I_{\text{Bias}} = 12.5 \text{ mA}}$$

b. $V_0 = 2\text{ V},\ i_L = \dfrac{2}{0.075} = 26.7\text{ mA}$

1st approximation:

$i_{Cn} \cong 26.7\text{ mA},\ i_{Bn} = 0.444\text{ mA}$

$V_{BE} = (0.026)\ln\left(\dfrac{26.7\times10^{-3}}{2\times10^{-13}}\right) = 0.6661$

$I_D = 12.5 - 0.444 = 12.056\text{ mA}$

$V_D = (0.026)\ln\left(\dfrac{12.056\times10^{-3}}{5\times10^{-13}}\right) = 0.6216$

$2V_D = 1.243\text{ V}$

$V_{EB} = 2V_D - V_{BE} = 0.5769$

$i_{Cp} = 2\times10^{-13}\exp\left(\dfrac{0.5769}{0.026}\right) = 0.866\text{ mA}$

2nd approximation:

$i_{En} = i_L + i_{Cp} = 26.7 + 0.866 \cong \underline{27.6\text{ mA} = i_{En}}$

$i_{Cn} = \left(\dfrac{60}{61}\right)(27.6) \Rightarrow \underline{i_{Cn} = 27.1\text{ mA}}$

$i_{Bn} = 0.452\text{ mA}$

$I_D = 12.5 - 0.452 \Rightarrow \underline{I_D = 12.05\text{ mA}}$

$V_{BEn} = (0.026)\ln\left(\dfrac{27.1\times10^{-3}}{2\times10^{-13}}\right)$

$\Rightarrow \underline{V_{BEn} = 0.6664\text{ V}}$

$V_D = (0.026)\ln\left(\dfrac{12.05\times10^{-3}}{5\times10^{-13}}\right) = 0.6215\text{ V}$

$2V_{DD} = 1.243\text{ V}$

$V_{EB} = 1.243 - 0.6664 \Rightarrow \underline{V_{EBp} = 0.5766\text{ V}}$

$i_{Cp} = 2\times10^{-13}\exp\left(\dfrac{0.5766}{0.026}\right) \Rightarrow \underline{i_{Cp} = 0.856\text{ mA}}$

c. $V_0 = 10\text{ V},\ i_L = \dfrac{10}{0.075} = 133\text{ mA}$

$i_{En} \cong i_L = 133\text{ mA} \Rightarrow \underline{i_{CN} = 131\text{ mA}}$

$i_{Bn} = 2.18\text{ mA} \Rightarrow I_D = 12.5 - 2.18$

$\Rightarrow \underline{I_D = 10.3\text{ mA}}$

$V_D = (0.026)\ln\left(\dfrac{10.3\times10^{-3}}{5\times10^{-13}}\right) = 0.6175$

$2V_{DD} = 1.235\text{ V}$

$V_{BEn} = (0.026)\ln\left(\dfrac{131\times10^{-3}}{2\times10^{-13}}\right)$

$\Rightarrow \underline{V_{BEn} = 0.7074\text{ V}}$

$V_{EBp} = 1.235 - 0.7074 \Rightarrow \underline{V_{EBp} = 0.5276\text{ V}}$

$i_{Cp} = 2\times10^{-13}\exp\left(\dfrac{0.5276}{0.026}\right)$

$\Rightarrow \underline{i_{Cp} = 0.130\text{ mA}}$

E8.14

a. $v_I = 0 = v_O,\ v_{B3} = 0.7\text{ V}$

$I_{R1} = \dfrac{12-0.7}{R_1} = \dfrac{11.3}{0.25} \Rightarrow I_{R1} = 45.2\text{ mA}$

If transistors are matched, then

$i_{E1} = i_{E3}$

$i_{R1} = i_{E1} + i_{B3} = i_{E1} + \dfrac{i_{E3}}{1+\beta}$

$i_{R1} = i_{E1}\left(1 + \dfrac{1}{1+\beta}\right) = i_{E1}\left(1 + \dfrac{1}{41}\right)$

$i_{E1} = \dfrac{45.2}{1.024} \Rightarrow \underline{i_{E1} = i_{E2} = 44.1\text{ mA}}$

$i_{B1} = i_{B2} = \dfrac{i_{E1}}{1+\beta} = \dfrac{44.1}{41}$

$\Rightarrow \underline{i_{B1} = i_{B2} = 1.08\text{ mA}}$

b. For $v_I = 5\text{ V} \Rightarrow v_O = 5\text{ V}$

$i_O = \dfrac{5}{8} \Rightarrow \underline{i_O = 0.625\text{ A}}$

$i_{E3} \cong 0.625\text{ A},\ i_{B3} = \dfrac{0.625}{41} \Rightarrow i_{B3} = 15.2\text{ mA}$

$v_{B3} = 5.7\text{ V} \Rightarrow i_{R1} = \dfrac{12-5.7}{0.25} = 25.2\text{ mA}$

$i_{E1} = 25.2 - 15.2 \Rightarrow \underline{i_{E1} = 10.0\text{ mA}}$

$\underline{\Rightarrow i_{B1} = \dfrac{10}{41} = 0.244\text{ mA}}$

$v_{B4} = 5 - 0.7 = 4.3\text{ V}$

$I_{R2} = \dfrac{4.3-(-12)}{0.25} = \underline{65.2\text{ mA} \cong i_{E2}}$

$\underline{i_{B2} = \dfrac{65.2}{41} = 1.59\text{ mA}}$

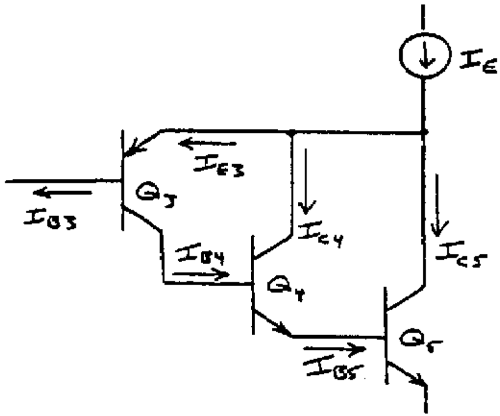
$i_I = i_{B2} - i_{B1} = 1.59 - 0.244 \Rightarrow \underline{i_I = 1.35\text{ mA}}$

c. $A_I = \dfrac{i_O}{i_I} = \dfrac{625}{1.35} \Rightarrow \underline{A_I = 463}$

From Equation (8.54)

$A_I = \dfrac{(1+\beta)R}{2R_L} = \dfrac{(41)(250)}{2(8)} = \underline{641}$

E8.15



$$I_E = I_{E3} + I_{C4} + I_{C5}$$
$$= I_{E3} + I_{C4} + \beta_5 I_{B5}$$
$$= I_{E3} + \beta_4 I_{B4} + \beta_5(1 + \beta_4) I_{B4}$$
$$I_E = (1 + \beta_3) I_{B3} + \beta_4 \beta_3 I_{B3} + \beta_5 (1 + \beta_4) \beta_3 I_{B3}$$

If β_4 and β_5 are large, then

$$I_E \cong \beta_3 \beta_4 \beta_5 I_{B3}$$

So that composite current gain is

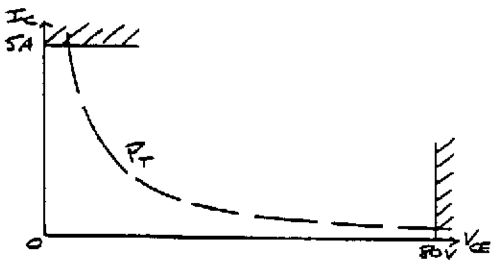
$$\underline{\beta \cong \beta_3 \beta_4 \beta_5}$$

Chapter 8

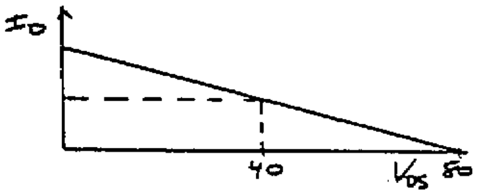
Problem Solutions

8.1

a.



b. i. $V_{DD} = 80$ V

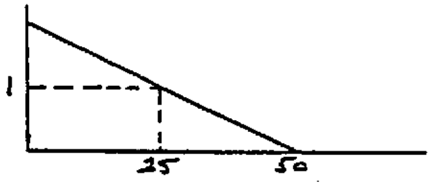


Maximum power at $V_{DS} = \dfrac{V_{DD}}{2} = 40$ V

$I_D = \dfrac{P_T}{V_{DS}} = \dfrac{25}{40} = 0.625$ A

$R_D = \dfrac{80 - 40}{0.625} \Rightarrow \underline{R_D = 64\ \Omega}$

ii. $V_{DD} = 50$ V



Maximum power at $V_{DS} = \dfrac{V_{DD}}{2} = 25$ V

$I_D = \dfrac{P_T}{V_{DS}} = \dfrac{25}{25} = 1$ A

$R_D = \dfrac{50 - 25}{1} \Rightarrow \underline{R_D = 25\ \Omega}$

8.2

a. $P_Q(\max) = I_{CQ} \cdot \dfrac{V_{CC}}{2}$

So $I_{CQ} = \dfrac{2P_Q(\max)}{V_{CC}} = \dfrac{2(20)}{24} = 1.67$ A

$R_L = \dfrac{V_{CC} - (V_{CC}/2)}{I_{CQ}} = \dfrac{24 - 12}{1.67} \Rightarrow \underline{R_L = 7.2\ \Omega}$

$I_B = \dfrac{I_{CQ}}{\beta} = \dfrac{1.67}{80} \Rightarrow 20.8$ mA

$R_B = \dfrac{24 - 0.7}{20.8} \Rightarrow \underline{R_B = 1.12\ \text{k}\Omega}$

b. $|A_v| = g_m R_L = \dfrac{I_{CQ} \cdot R_L}{V_T} = \dfrac{(1.67)(7.2)}{0.026} = 462$

$V_0(\max) = 12\ \text{V} \Rightarrow V_P = \dfrac{V_0(\max)}{A_v} = \dfrac{12}{462}$

$\Rightarrow \underline{V_P \cong 26\ \text{mV}}$

8.3

a. For maximum power delivered to the load, set

$V_{CEQ} = \dfrac{V_{CC}}{2}$

Set $V_{CC} = 25\ \text{V} = V_{CE(sus)}$

Then $I_{Cm} = \dfrac{V_{CC}}{R_L} = \dfrac{25}{0.1}$

$I_{Cm} = 250\ \text{mA} < I_{C,\max}$

$I_{CQ} = \dfrac{25 - 12.5}{0.1} = 125$ mA

$P_Q(\max) = I_{CQ} \cdot \dfrac{V_{CC}}{2} = (0.125)(12.5)$

$= 1.56\ \text{W} < P_{D,\max}$

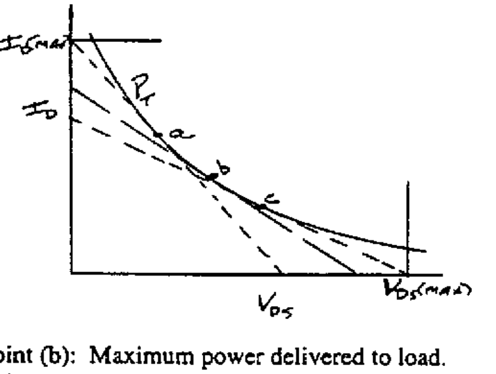
$I_{BQ} = \dfrac{125}{100} = 1.25$ mA

$R_B = \dfrac{25 - 0.7}{1.25} \Rightarrow \underline{R_B = 19.4\ \text{k}\Omega}$

b. $P_L(\max) = \dfrac{1}{2} \cdot I_{CQ}^2 \cdot R_L = \dfrac{1}{2}(0.125)^2(100)$

$\Rightarrow \underline{P_L(\max) = 0.781\ \text{W}}$

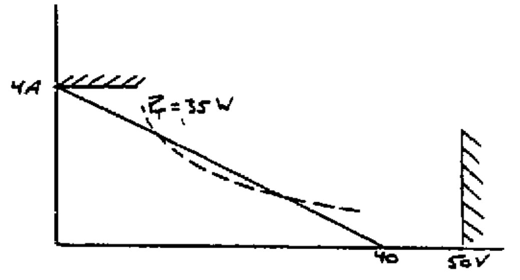
8.4



Point (b): Maximum power delivered to load.
Point (a): Will obtain maximum signal current output.
Point (c): Will obtain maximum signal voltage output.

8.5

a.



b. $V_{GG} = 5$ V, $I_D = 0.25(5-4)^2 = 0.25A$,

$V_{DS} = 37.5$ V, $P = 9.375$ W

$V_{GG} = 6$ V, $I_D = 0.25(6-4)^2 = 1.0$ A,

$V_{DS} = 30$ V, $P = 30$ W

$V_{GG} = 7$ V, $I_D = 0.25(7-4)^2 = 2.25$ A,

$V_{DS} = 17.5$ V, $P = 39.375$ W

$V_{GG} = 8$ V, $I_D = 0.25\left[2(8-4)V_{DS} - V_{DS}^2\right]$

$= \dfrac{40 - V_{DS}}{10} \Rightarrow V_{DS} = 2.92$

$I_D = 3.71$ A, $\underline{P = 10.8 \text{ W}}$

$V_{GG} = 9$ V, $I_D = 0.25\left[2(9-4)V_{DS} - V_{DS}^2\right]$

$= \dfrac{40 - V_{DS}}{10} \Rightarrow V_{DS} = 1.88$ V

$I_D = 3.81$ A, $\underline{P = 7.16 \text{ W}}$

c. Yes, at $V_{GG} = 7$ V, $P = 39.375$ W $> P_{D,\max} =$ 35 W

8.6

a. Set $V_{DSQ} = \dfrac{V_{DD}}{2} = 25$ V

$$I_{DQ} = \frac{50-25}{20} = 1.25 \text{ A}$$

$$I_{DQ} = K_n(V_{GS} - V_{TN})^2$$

$$\sqrt{\frac{1.25}{0.2}} + 4 = V_{GS} = 6.5 \text{ V}$$

$$V_{GS} = \left(\frac{R_2}{R_1 + R_2}\right)V_{DD}$$

Let $R_1 + R_2 = 100$ kΩ

$$6.5 = \left(\frac{R_2}{100}\right)(50) \Rightarrow \underline{R_2 = 13 \text{ k}\Omega}$$

$$\underline{R_1 = 87 \text{ k}\Omega}$$

b. $P_D = I_{DQ}V_{DSQ} = (1.25)(25) \Rightarrow \underline{P_D = 31.25 \text{ W}}$

c. $I_{D,\max} = 2I_{DQ} \Rightarrow \underline{I_{D,\max} = 2.5 \text{ A}}$

$V_{DS,\max} = V_{DD} \Rightarrow \underline{V_{DS,\max} = 50 \text{ V}}$

$\underline{P_{D,\max} = 31.25 \text{ W}}$

d. $\left|\dfrac{V_0}{V_i}\right| = g_m R_L$

$$g_m = 2\sqrt{K_n I_{DQ}} = 2\sqrt{(0.2)(1.25)} = 1 \text{ A/V}$$

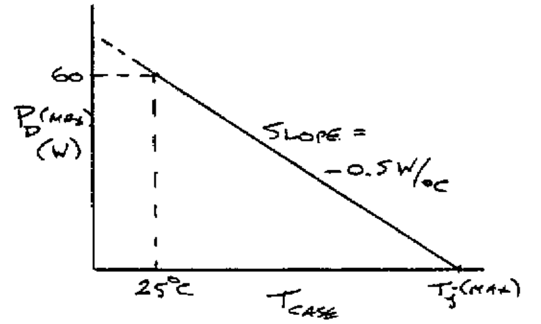
$$|V_0| = (1)(20)(0.5) = 10 \text{ V}$$

$$\overline{P_L} = \frac{1}{2}\cdot\frac{V_0^2}{R_L} = \frac{1}{2}\cdot\frac{(10)^2}{20} \Rightarrow \underline{\overline{P_L} = 2.5 \text{ W}}$$

$$\overline{P_Q} = 31.25 - 2.5 \Rightarrow \underline{\overline{P_Q} = 28.75 \text{ W}}$$

8.7

(a)



(b) $P_D = P_{D,\max} - (Slope)(T_j - 25)$

At $P_D = 0$, $T_{j,\max} = \dfrac{60}{0.5} + 25 \Rightarrow \underline{T_{j,\max} = 145°C}$

(c) $P_{D,\max} = \dfrac{T_{j,\max} - T_{case}}{\theta_{dev-amb}}$

or

$$\theta_{dev-amb} = \frac{145-25}{60} \Rightarrow \underline{\theta_{dev-amb} = 2\,°C/W}$$

8.8

$$P_{D,\text{rated}} = \frac{T_{j,\max} - T_{amb}}{\theta_{dev-case}}$$

or

$$\theta_{dev-case} = \frac{T_{j,\max} - T_{amb}}{P_{D,\text{rated}}} = \frac{150-25}{50} = 2.5°\text{C/W}$$

Then

$$T_{dev} - T_{amb} = P_D(\theta_{dev-case} + \theta_{case-amb})$$

$$150 - 25 = P_D(2.5 + \theta_{case-amb})$$

$$\Rightarrow \underline{125 = P_D(2.5 + \theta_{case-amb})}$$

8.9

$P_D = I_D \cdot V_{DS} = (4)(5) = 20$ W

$T_{dev} - T_{amb} = P_D(\theta_{dev-case} + \theta_{case-snk} + \theta_{snk-amb})$

$T_{dev} - 25 = 20(1.75 + 0.8 + 3) = 111$

$\Rightarrow \underline{T_{dev} = 136°C}$

$T_{dev} - T_{case} = P_D \cdot \theta_{dev-case} = (20)(1.75) = 35$

$T_{case} = T_{dev} - 35 = 136 - 35 \Rightarrow \underline{T_{case} = 101°C}$

$T_{case} - T_{sink} = P_D \cdot \theta_{case-snk} = (20)(0.8) = 16°C$

$T_{sink} = T_{case} - 16 = 101 - 16 \Rightarrow \underline{T_{sink} = 85°C}$

8.10

$T_{dev} - T_{amb} = P_D(\theta_{dev-case} + \theta_{case-amb})$

$200 - 25 = 25(3 + \theta_{case-amb})$

$\Rightarrow \underline{\theta_{case-amb} = 4°C/W}$

8.11

$$\theta_{dev-case} = \frac{T_{j,max} - T_{amb}}{P_{D,rated}} = \frac{175 - 25}{15} = 10°C/W$$

$$P_D = \frac{T_{j,max} - T_{amb}}{\theta_{dev-case} + \theta_{case-snk} + \theta_{snk-amb}}$$

$$= \frac{175 - 25}{10 + 1 + 4} \Rightarrow \underline{P_D = 10 \text{ W}}$$

8.12

$$\eta = \frac{\overline{P_L}}{\overline{P_S}}$$

$\overline{P_S} = V_{CC} \cdot I_Q$

$$\overline{P_L} = V_P \cdot I_P = \left(\frac{V_{CC}}{2}\right)(I_Q)$$

$$\eta = \frac{\frac{1}{2} \cdot V_{CC} \cdot I_Q}{V_{CC} \cdot I_Q} \Rightarrow \underline{\eta = 50\%}$$

8.13

a. Neglect base currents.

$v_O(\max) = V^+ - V_{CE}(\text{sat}) = 10 - 0.2 = 9.8$ V

$$i_L(\max) = I_Q = \frac{9.8}{R_L} = \frac{9.8}{1} \Rightarrow \underline{I_Q = 9.8 \text{ mA}}$$

$$R = \frac{0 - 0.7 - (-10)}{9.8} \Rightarrow \underline{R = 949\ \Omega}$$

$i_{E1}(\max) = 2I_Q \Rightarrow \underline{i_{E1}(\max) = 19.6 \text{ mA}}$

$\underline{i_{E1}(\min) = 0}$

$\underline{i_L(\max) = I_Q = 9.8 \text{ mA}}$

$\underline{i_L(\min) = -I_Q = -9.8 \text{ mA}}$

b. $$\overline{P_L} = \frac{1}{2}(i_L(\max))^2 R_L = \frac{1}{2}(9.8)^2(1)$$

$\Rightarrow \overline{P_L} = 48.02$ mW

$\overline{P_S} = I_Q(V^+ - V^-) + I_Q(0 - V^-)$

$= 9.8(20) + 9.8(10) \Rightarrow \overline{P_S} = 294$ mW

$$\eta = \frac{\overline{P_L}}{\overline{P_S}} = \frac{48.02}{294} \Rightarrow \underline{\eta = 16.3\%}$$

8.14

a. $$I_Q(\min) = \frac{v_O(\max)}{R_L} = \frac{10}{0.1} \Rightarrow \underline{I_Q(\min) = 100 \text{ mA}}$$

$$R = \frac{0 - 0.7 - (-12)}{100} \Rightarrow \underline{R = 113\ \Omega}$$

b. $P_{Q1} = I_Q \cdot V_{CE1} = (100)(12) \Rightarrow \underline{P_{Q1} = 1.2 \text{ W}}$

$P(\text{source}) = 2I_Q(12) = \underline{2.4 \text{ W}}$

c. $$\overline{P_L} = \frac{1}{2} \cdot \frac{V_P^2}{R_L} = \frac{(10)^2}{2(100)} = 0.5 \text{ W}$$

$\overline{P_S} = 1.2 + 2.4 = 3.6$ W

$$\eta = \frac{\overline{P_L}}{\overline{P_S}} = \frac{0.5}{3.6} \Rightarrow \underline{\eta = 13.9\%}$$

8.15

$$\overline{P_L} = \frac{V_P^2}{R_L} = \frac{(V^+)^2}{R_L}$$

$$\overline{P_S} = \frac{1}{2} \cdot \frac{(V^+)^2}{R_L} + \frac{1}{2} \cdot \frac{(V^-)^2}{R_L}, \quad V^- = -V^+$$

So $\overline{P_S} = \dfrac{(V^+)^2}{R_L}$

$$\eta = \frac{\overline{P_L}}{\overline{P_S}} \Rightarrow \underline{\eta = 100\%}$$

8.16

(a) $V_{DS} \geq V_{DS}(sat) = V_{GS} - V_{TN} = V_{GS}$

$V_{DS} = 10 - V_O(\max)$ and $I_D = I_L = K_n(V_{GS})^2$

$$\frac{V_O(\max)}{R_L} = K_n(V_{GS})^2$$

$$V_{GS} = \sqrt{\frac{V_O(\max)}{R_L \cdot K_n}}$$

So

$$10 - V_O(\max) = \sqrt{\frac{V_O(\max)}{R_L \cdot K_n}} = \sqrt{\frac{V_O(\max)}{(5)(0.4)}}$$

$$[10 - V_O(\max)]^2 = \frac{V_O(\max)}{2}$$

$$100 - 20V_O(\max) + V_O^2(\max) = \frac{V_O(\max)}{2}$$

$$V_0^2(\max) - 20.5V_0(\max) + 100 = 0$$

$$V_0(\max) = \frac{20.5 \pm \sqrt{(20.5)^2 - 4(100)}}{2}$$

$$\Rightarrow \underline{V_0(\max) = 8\text{ V}}$$

$$i_L = \frac{8}{5} \Rightarrow \underline{i_L = 1.6\text{ mA}}$$

$$V_{GS} = \sqrt{\frac{i_L}{K_n}} = \sqrt{\frac{1.6}{0.4}} = 2\,V$$

$$\Rightarrow \underline{v_I = 10\text{ V}}$$

b. $\overline{P_L} = \frac{1}{2} \cdot \frac{(8)^2}{5} = 6.4\text{ mW}$

$$\overline{P_S} = \frac{20(1.6)}{\pi} = 10.2\text{ mW}$$

$$\eta = \frac{\overline{P_L}}{\overline{P_S}} = \frac{6.4}{10.2} \Rightarrow \underline{\eta = 62.7\%}$$

8.17

$v_O = i_L R_L$ and $i_L = i_D = K_n(v_{GS} - V_{TN})^2$

or $i_L = K_n(v_{GS})^2$ and $v_{GS} = v_I - v_O$

Then

$v_O = K_n R_L (v_I - v_O)^2$ or $v_O = 2(v_I - v_O)^2$

$$\frac{dv_0}{dv_I} = 2.2(v_I - v_0)\left(1 - \frac{dv_0}{dv_I}\right)$$

$$\frac{dv_0}{dv_I}[1 + 4(v_I - v_0)] = 4(v_I - v_0)$$

or $\frac{dv_0}{dv_I} = \frac{4(v_I - v_0)}{1 + 4(v_I - v_0)}$

For $v_I = 10$ V, $v_0 = 8$ V $\Rightarrow \frac{dv_0}{dv_I} = \frac{4(10-8)}{1 + 4(10-8)}$

$$\Rightarrow \underline{\frac{dv_0}{dv_I} = 0.889}$$

At $v_I = 0$, $v_0 = 0 \Rightarrow \frac{dv_0}{dv_I} = 0$

At $v_I = 1$, $v_0 = 0.5 \Rightarrow \frac{dv_0}{dv_I} = 0.667$

8.18

a. $V_{BE} = V_T \ln\left(\frac{i_C}{I_S}\right) = (0.026)\ln\left(\frac{5 \times 10^{-3}}{5 \times 10^{-13}}\right)$

$$V_{BE} = \frac{V_{BB}}{2} = 0.5987\text{ V}$$

$$\Rightarrow \underline{V_{BB} = 1.1973\text{ V}}$$

$$P_Q = i_C \cdot v_{CE} = (5)(10) \Rightarrow \underline{P_Q = 50\text{ mW}}$$

b. $v_0 = -8$ V

$$i_L = \frac{-8}{0.1} \Rightarrow \underline{i_L = -80\text{ mA}}$$

$$\underline{i_{Cp} \approx 80\text{ mA}}$$

$$v_{EB} = V_T \ln\left(\frac{i_{Cp}}{I_S}\right) = (0.026)\ln\left(\frac{80 \times 10^{-3}}{5 \times 10^{-13}}\right)$$

$$v_{EB} = 0.6708\text{ V}$$

$$v_I = \frac{V_{BB}}{2} - v_{EB} + v_0 = 0.5987 - 0.6708 - 8$$

$$\Rightarrow \underline{v_I = -8.072\text{ V}}$$

$$v_{BE} = V_{BB} - v_{EB} = 1.1973 - 0.6708 = 0.5265\text{ V}$$

$$i_{Cn} = I_S \exp\left(\frac{v_{BE}}{V_T}\right) = 5 \times 10^{-13} \exp\left(\frac{0.5265}{0.026}\right)$$

$$\Rightarrow \underline{i_{Cn} = 0.311\text{ mA}}$$

$$P_L = i_L^2 R_L = (80)^2(0.1) \Rightarrow \underline{P_L = 640\text{ mW}}$$

$$P_{Qn} = i_{Cn} \cdot v_{CE} = (0.311)(10 - (-8))$$

$$\Rightarrow \underline{P_{Qn} = 5.60\text{ mW}}$$

$$P_{Qp} = i_{Cp} \cdot v_{EC} = (80)(2) \Rightarrow \underline{P_{Qp} = 160\text{ mW}}$$

8.19

(a) $i_{Dn} = K_n(v_{GSn} - V_{TN})^2$

$$\sqrt{\frac{0.5}{2}} + 2 = v_{GSn} = 2.5\text{ V} = \frac{V_{BB}}{2}$$

$$\Rightarrow \underline{V_{BB} = 5.0\text{ V}}$$

$$P_n = (0.5)(10) \Rightarrow \underline{P_n = P_p = 5\text{ mW}}$$

(b) $V_{DS} = V_{GS} - V_{TN} \Rightarrow V_{DS} = V_{GS} - 2$

$V_{DS} = 10 - v_O(\max)$

and

$$V_{GS} = \sqrt{\frac{i_L}{K_n}} + V_{TN} = \sqrt{\frac{v_O(\max)}{R_L K_n}} + 2$$

$$= \sqrt{\frac{v_O(\max)}{(2)(1)}} + 2$$

so

$$10 - v_0(\max) = \sqrt{\frac{v_0(\max)}{2}} + 2 - 2 = \sqrt{\frac{v_0(\max)}{2}}$$

so $\underline{v_0(\max) = 8\text{ V}}$

$$i_{Dn} = i_L = \frac{8}{1} \Rightarrow \underline{i_{Dn} = i_L = 8\text{ mA}}$$

$$V_{GS} = \sqrt{\frac{8}{2}} + 2 \Rightarrow V_{GS} = 4\text{ V}$$

Then $v_I = v_0 + V_{GS} - \frac{V_{BB}}{2} = 8 + 4 - 2.5$

$$\Rightarrow \underline{v_I = 9.5\text{ V}}$$

$$v_{SGp} = v_0 - \left(v_I - \frac{V_{BB}}{2}\right) = 8 - (9.5 - 2.5)$$

$v_{SGp} = 1$ V $\Rightarrow M_p$ cutoff $\Rightarrow \underline{i_{Dp} = 0}$

$P_L = i_L^2 R_L = (8)^2(1) \Rightarrow \underline{P_L = 64 \text{ mW}}$

$P_{Mn} = i_{Dn} \cdot v_{DS} = (8)(10-8) \Rightarrow \underline{P_{Mn} = 16 \text{ mW}}$

$P_{Mp} = i_{Dp} \cdot v_{SD} \Rightarrow \underline{P_{Mp} = 0}$

8.20

a. $v_O = 24 \text{ V} \Rightarrow i_L = \dfrac{24}{8} \Rightarrow \underline{i_L \approx i_N = 3 \text{ A}}$

$i_{Bn} = \dfrac{3}{41} \Rightarrow i_{Bn} = 73.2 \text{ mA}$

For $i_D = 25$ mA $\Rightarrow i_{R1} = 25 + 73.2 = 98.2$ mA

$$V_{BE} = V_T \ln\left(\frac{i_N}{I_S}\right) = (0.026)\ln\left(\frac{3}{6\times 10^{-12}}\right) = 0.7004 \text{ V}$$

$$\text{Then } 98.2 = \frac{30-(24+0.7)}{R_1} \Rightarrow R_1 = \frac{5.3}{98.2} \Rightarrow \underline{R_1 = 53.97\ \Omega}$$

$$V_D = (0.026)\ln\left(\frac{25\times 10^{-3}}{6\times 10^{-12}}\right) = 0.5759 \text{ V}$$

$$V_{EB} = 2V_D - V_{BE} = 2(0.5759) - 0.7004 = 0.4514 \text{ V}$$

$$i_P = I_S \exp\left(\frac{V_{EB}}{V_T}\right) = (6\times 10^{-12})\exp\left(\frac{0.4514}{0.026}\right) \Rightarrow \underline{i_P = 0.208 \text{ mA}}$$

b. Neglecting base current

$$i_D \approx \frac{30-0.6}{R_1} = \frac{30-0.6}{53.97} \Rightarrow \underline{i_D \approx 545 \text{ mA}}$$

$$V_D = (0.026)\ln\left(\frac{0.545}{6\times 10^{-12}}\right) = 0.656 \text{ V}$$

Approximation for i_D is okay.

Diodes and transistors matched $\Rightarrow \underline{i_N = i_P = 545 \text{ mA}}$

8.21

(a) $I_{D1} = K_1(V_{GS1} - V_{TN})^2$

$V_{GS1} = \sqrt{\dfrac{5}{5}} + 1 = 2\ V$

$I_{D3} = K_3(V_{GS3} - V_{TN})^2$

$200 = K_3(2-1)^2 \Rightarrow \underline{K_{n3} = K_{p4} = 200\ \mu A/V^2}$

(b) $v_I + V_{SG4} + V_{GS3} - V_{GS1} = v_O$

For v_O large, $i_L = i_1 = K_{n1}(V_{GS1} - V_{TN})^2$

$$V_{GS1} = \sqrt{\frac{i_L}{K_{n1}}} + V_{TN} = \sqrt{\frac{v_O}{R_L K_{n1}}} + V_{TN}$$

$$\text{So } v_I + 2 + 2 - \left(\sqrt{\frac{v_O}{(0.5)(5)}} + 1\right) = v_O$$

$$v_I = v_O + \sqrt{\frac{v_O}{2.5}} - 3$$

$$\frac{dv_I}{dv_I} = 1 = \frac{dv_O}{dv_I} + \frac{1}{2}\cdot\frac{1}{\sqrt{2.5 v_O}}\cdot\frac{dv_O}{dv_I}$$

$$1 = \frac{dv_O}{dv_I}\left[1 + \frac{1}{2\sqrt{2.5 v_O}}\right]$$

For $v_O = 5$ V:

$$1 = \frac{dv_O}{dv_I}\left[1 + \frac{1}{2\sqrt{2.5(5)}}\right] = \frac{dv_O}{dv_I}(1.1414) \Rightarrow \underline{\frac{dv_O}{dv_I} = 0.876}$$

8.22

$$v_O = v_I + \frac{V_{BB}}{2} - V_{GS} \quad \text{and} \quad V_{GS} = \sqrt{\frac{I_{Dn}}{K_n}} + V_{TN}$$

For $v_O = 0$, $I_{Dn} = I_{DQ} + i_L = I_{DQ} + \dfrac{v_O}{R_L}$

Then

$$v_O = v_I + \frac{V_{BB}}{2} - V_{TN} - \sqrt{\frac{I_{DQ} + (v_O/R_L)}{K_n}}$$

or

$$v_O = v_I + \frac{V_{BB}}{2} - V_{TN} - \sqrt{\frac{I_{DQ}}{K_n}}\cdot\sqrt{1 + \frac{v_O}{I_{DQ}R_L}}$$

For v_O small,

$$v_O \cong v_I + \frac{V_{BB}}{2} - V_{TN} - \sqrt{\frac{I_{DQ}}{K_n}}\left(1 + \frac{1}{2}\cdot\frac{v_O}{I_{DQ}R_L}\right)$$

$$v_O\left[1 + \frac{1}{2}\cdot\sqrt{\frac{I_{DQ}}{K_n}}\cdot\frac{1}{I_{DQ}R_L}\right] = v_I + \frac{V_{BB}}{2} - V_{TN} - \sqrt{\frac{I_{DQ}}{K_n}}$$

Now

$$\frac{dv_O}{dv_I} = \frac{1}{\left[1 + \frac{1}{2}\cdot\sqrt{\frac{I_{DQ}}{K_n}}\cdot\frac{1}{I_{DQ}R_L}\right]} = 0.95$$

$$\text{So } \frac{1}{2}\cdot\sqrt{\frac{I_{DQ}}{K_n}}\cdot\frac{1}{I_{DQ}R_L} = \frac{1}{0.95} - 1 = 0.0526$$

For $R_L = 0.1\ k\Omega$, then $\dfrac{1}{\sqrt{K_n I_{DQ}}} = 0.01052$

Or $\sqrt{K_n I_{DQ}} = 95.1$

We can write

$g_m = 2\sqrt{K_n I_{DQ}} = 190\ mA/V$

This is the required transconductance for the output transistor. This implies a very large transistor.

8.23

$A_v = -g_m R_L$

So $-12 = -g_m(2) \Rightarrow g_m = 6 \text{ mA/V} = \dfrac{I_{CQ}}{V_T}$

$I_{CQ} = (6)(0.026) \Rightarrow I_{CQ} = 0.156 \text{ mA}$

But for maximum symmetrical swing, set

$$I_{CQ} = \frac{V_{CC}}{R_L} = \frac{10}{2} = 5 \text{ mA} \Rightarrow |A_v| > 12$$

Maximum power to the load:

$$\overline{P_L}(\max) = \frac{1}{2}\cdot\frac{V_{CC}^2}{R_L} = \frac{(10)^2}{2(2)} \Rightarrow \underline{\overline{P_L}(\max) = 25 \text{ mW}}$$

$\overline{P_S} = V_{CC}\cdot I_{CQ} = (10)(5) = 50 \text{ mW}$

So $\underline{\eta = 50\%}$

$$I_{BQ} = \frac{I_{CQ}}{\beta} = \frac{5}{180} = 0.0278 \text{ mA}$$

$R_i = R_{TH} = 6 \text{ k}\Omega$

$V_{TH} = I_{BQ}R_{TH} + V_{BE}(\text{on}) + (1+\beta)I_{BQ}R_E$

Set $R_E = 20\ \Omega$

$V_{TH} = (0.0278)(6) + 0.7 + (181)(0.0278)(0.020)$

$V_{TH} = 0.967 \text{ V}$

$$V_{TH} = \frac{1}{R_1}\cdot R_{TH}\cdot V_{CC}$$

$$0.967 = \frac{1}{R_1}(6)(10) \Rightarrow \underline{R_1 = 62.0 \text{ k}\Omega}$$

$$\underline{R_2 = 6.64 \text{ k}\Omega}$$

8.24

$$I_{CQ} = \frac{V_{CC}}{R_L} = \frac{15}{1} = 15 \text{ mA}$$

$$I_{BQ} = \frac{15}{100} = 0.15 \text{ mA}$$

$$\overline{P_L}(\max) = \frac{1}{2}\cdot\frac{V_{CC}^2}{R_L} = \frac{(15)^2}{2(1)} \Rightarrow \underline{\overline{P_L}(\max) = 112.5 \text{ mW}}$$

Let $R_{TH} = 10 \text{ k}\Omega$

$V_{TH} = I_{BQ}R_{TH} + V_{BE} + (1+\beta)I_{BQ}R_E$

$\quad = (0.15)(10) + 0.7 + (101)(0.15)(0.1)$

$$V_{TH} = 3.715 = \frac{1}{R_1}\cdot R_{TH}\cdot V_{CC} = \frac{1}{R_1}\cdot(10)(15)$$

$\underline{R_1 = 40.4 \text{ k}\Omega}$

$\underline{R_2 = 13.3 \text{ k}\Omega}$

8.25

$$V_{TH} = \left(\frac{R_2}{R_1+R_2}\right)V_{CC} = \left(\frac{1.55}{1.55+0.73}\right)(10)$$

$$= 6.80 \text{ V}$$

$R_{TH} = R_1\|R_2 = 0.73\|1.55 = 0.496 \text{ k}\Omega$

$$I_{BQ} = \frac{V_{TH} - V_{BE}}{R_{TH} + (1+\beta)R_E} = \frac{6.80 - 0.70}{0.496 + (26)(0.02)}$$

$I_{BQ} = 6.0 \text{ mA},\ I_{CQ} = 150 \text{ mA}$

$A_v = -g_m R_L'$ and $R_L' = a^2 R_L = (3)^2(8) = 72\ \Omega$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{150}{0.026} \Rightarrow 5.77 \text{ A/V}$$

$A_v = -(5.77)(72) = -415$

$|V_0|' = |A_v|\cdot V_i = (415)(0.017) = 7.06 \text{ V}$

$$V_0 = \frac{7.06}{3} = 2.35 \text{ V}$$

$$\overline{P_L} = \frac{1}{2}\cdot\frac{V_0^2}{R_L} = \frac{(2.35)^2}{2(8)} \Rightarrow \underline{\overline{P_L} = 345 \text{ mW}}$$

$\overline{P_S} = I_{CQ}\cdot V_{CC} = (0.15)(10) = 1.5 \text{ W}$

$$\eta = \frac{\overline{P_L}}{\overline{P_S}} = \frac{0.345}{1.5} \Rightarrow \underline{\eta = 23\%}$$

8.26

a. Assuming the maximum power is being delivered, then

$$V_0'(\text{peak}) = 36 \text{ V} \Rightarrow V_0 = \frac{36}{4} = 9 \text{ V}$$

$$\Rightarrow V_{rms} = \frac{9}{\sqrt{2}} \Rightarrow \underline{V_{rms} = 6.36 \text{ V}}$$

b. $V_0 = \dfrac{36}{\sqrt{2}} \Rightarrow \underline{V_0 = 25.5 \text{ V}}$

c. Secondary $I_{rms} = \dfrac{R_L}{V_{rms}} = \dfrac{2}{6.36} \Rightarrow \underline{I_{rms} = 0.314 \text{ A}}$

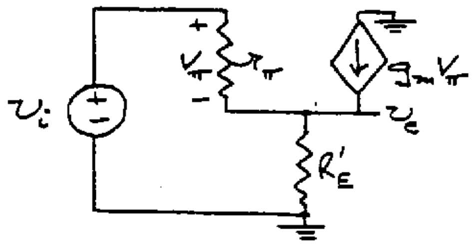
Primary $I_P = \dfrac{0.314}{4} \Rightarrow \underline{I_P = 78.6 \text{ mA}}$

d. $\overline{P_S} = I_{CQ}\cdot V_{CC} = (0.15)(36) = 5.4 \text{ W}$

$$\eta = \frac{2}{5.4} \Rightarrow \underline{\eta = 37\%}$$

8.27

a.



$$v_e = \left(\frac{V_\pi}{r_\pi} + g_m V_\pi\right) R'_E = V_\pi \left(\frac{1}{r_\pi} + g_m\right) R'_E$$

$$= V_\pi \left(\frac{1+\beta}{r_\pi}\right) R'_E$$

$$v_i = V_\pi + v_e \Rightarrow V_\pi = v_i - v_e$$

$$v_e = (v_i - v_e)\left(\frac{1+\beta}{r_\pi}\right) R'_E$$

$$\frac{v_e}{v_i} = \frac{\frac{1+\beta}{r_\pi} \cdot R'_E}{1 + \frac{1+\beta}{r_\pi} \cdot R'_E} = \underline{\frac{(1+\beta)R'_E}{r_\pi + (1+\beta)R'_E} = \frac{v_e}{v_i}}$$

where $\underline{R'_E = \left(\frac{n_1}{n_2}\right)^2 R_L}$

$$v_0 = \frac{v_e}{\left(\frac{n_1}{n_2}\right)} \text{ so } v_e = v_0 \left(\frac{n_1}{n_2}\right)$$

$$\text{so } \underline{\frac{v_0}{v_i} = \frac{1}{\left(\frac{n_1}{n_2}\right)} \cdot \frac{(1+\beta)R'_E}{r_\pi + (1+\beta)R'_E}}$$

b. $\overline{P_L} = \frac{1}{2} \cdot I_P^2 R_L$, $a = \frac{n_1}{n_2}$, $I_{CQ} = \frac{I_P}{a}$

so $\overline{P_L} = \frac{1}{2} \cdot a^2 I_{CQ}^2 R_L$

$\overline{P_S} = I_{CQ} \cdot V_{CC}$

For $\eta = 50\%$:

$$\frac{\overline{P_L}}{\overline{P_S}} = 0.5 = \frac{\frac{1}{2} \cdot a^2 I_{CQ}^2 R_L}{I_{CQ} \cdot V_{CC}} = \frac{a^2 I_{CQ} R_L}{2V_{CC}}$$

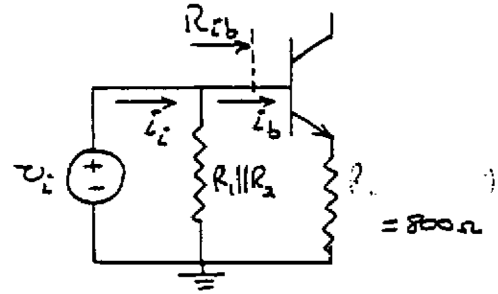
$$\text{so } a^2 = \frac{V_{CC}}{I_{CQ} \cdot R_L} = \frac{V_{CC}}{(0.1)(50)} \Rightarrow \underline{a^2 = \frac{V_{CC}}{5}}$$

c. $$R_0 = \frac{r_\pi}{1+\beta} = \frac{\beta V_T}{(1+\beta) I_{CQ}} = \frac{49(0.026)}{(50)(0.1)}$$

$$\Rightarrow \underline{R_0 = 0.255\ \Omega}$$

8.28

a. With a 10:1 transformer ratio, we need a current gain of 8 through the transistor.



$$i_e = (1+\beta) i_b \text{ and } i_b = \left(\frac{R_1 \| R_2}{R_1 \| R_2 + R_{ib}}\right) i_i$$

so we need

$$\frac{i_e}{i_i} = 8 = (1+\beta)\left(\frac{R_1 \| R_2}{R_1 \| R_2 + R_{ib}}\right)$$

where

$$R_{ib} = r_\pi + (1+\beta) R'_L \approx (1+\beta) R'_L$$

$$= (101)(0.8) = 80.8$$

$$\text{Then } 8 = (101)\left(\frac{R_1 \| R_2}{R_1 \| R_2 + 80.8}\right)$$

$$\frac{R_1 \| R_2}{R_1 \| R_2 + 80.8} = 0.0792 \text{ or } R_1 \| R_2 = 6.95\ \text{k}\Omega$$

Set

$$\frac{2V_{CC}}{2I_{CQ}} = R'_L \Rightarrow I_{CQ} = \frac{V_{CC}}{R'_L} = \frac{12}{0.8} = 15\ \text{mA}$$

$$I_{BQ} = \frac{15}{100} = 0.15\ \text{mA}$$

$$V_{TH} = I_{BQ} R_{TH} + V_{BE}$$

$$\frac{1}{R_1} \cdot R_{TH} \cdot V_{CC} = I_{BQ} R_{TH} + V_{BE}$$

$$\frac{1}{R_1}(6.95)(12) = (0.15)(6.95) + 0.7$$

$$\Rightarrow \underline{R_1 = 47.9\ \text{k}\Omega} \text{ then } \underline{R_2 = 8.13\ \text{k}\Omega}$$

b. $I_e = 0.9 I_{CQ} = 13.5\ \text{mA} = \frac{I_L}{a} \Rightarrow I_L = 135\ \text{mA}$

$$\overline{P_L} = \frac{1}{2}(0.135)^2(8) \Rightarrow \underline{\overline{P_L} = 72.9\ \text{mW}}$$

$$\overline{P_S} = V_{CC} I_{CQ} = (12)(15) \Rightarrow \underline{\overline{P_S} = 180\ \text{mW}}$$

$$\eta = \frac{\overline{P_L}}{\overline{P_S}} \Rightarrow \underline{\eta = 40.5\%}$$

8.29

a. $V_P = \sqrt{2R_L P_L}$

$V_P = \sqrt{2(8)(1)} = 5.66$ V = peak output voltage

$I_P = \dfrac{V_P}{R_L} = \dfrac{5.66}{8} = 0.708$ A = peak output current

Set $V_e = 0.9V_{CC} = aV_P$ to minimize distortion

Then $a = \dfrac{(0.9)(18)}{5.66} \Rightarrow \underline{a = 2.86}$

b. Now

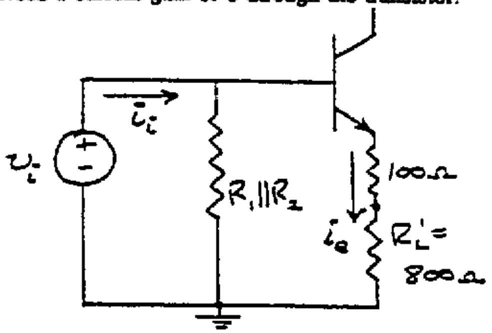
$I_{CQ} = \dfrac{1}{0.9}\left(\dfrac{I_P}{a}\right) = \dfrac{1}{0.9}\left(\dfrac{0.708}{2.86}\right) \Rightarrow I_{CQ} = 0.275$ A

Then $P_Q = V_{CC}I_Q = (18)(0.275)$

$\Rightarrow \underline{P_Q = 4.95 \text{ W}}$ Power rating of transistor

8.30

a. Need a current gain of 8 through the transistor.



$\dfrac{i_b}{i_i} = 8 = (1+\beta)\left(\dfrac{R_1\|R_2}{R_1\|R_2 + R_{ib}}\right)$

where $R_{ib} \approx (1+\beta)(0.9) = 90.9$ kΩ

$\dfrac{8}{101} = \left(\dfrac{R_1\|R_2}{R_1\|R_2 + 90.9}\right) = 0.0792$

or $R_1\|R_2 = 7.82$ kΩ

Set

$\dfrac{2V_{CC}}{2I_{CQ}} = 0.9 \text{ k}\Omega \Rightarrow I_{CQ} = \dfrac{12}{0.9} = 13.3$ mA

$I_{BQ} = \dfrac{13.3}{100} = 0.133$ mA

Then

$\dfrac{1}{R_1}(7.82)(12) = (0.133)(7.82) + 0.7$

$\Rightarrow \underline{R_1 = 53.9 \text{ k}\Omega}$ and $\underline{R_2 = 9.15 \text{ k}\Omega}$

b. $I_e = (0.9)I_{CQ} = 12 \text{ mA} = \dfrac{I_L}{a} \Rightarrow I_L = 120$ mA

$\overline{P_L} = \dfrac{1}{2}(0.12)^2(8) \Rightarrow \underline{\overline{P_L} = 57.6 \text{ mW}}$

$\overline{P_S} = V_{CC}I_{CQ} = (12)(13.3) \Rightarrow \underline{\overline{P_S} = 159.6 \text{ mW}}$

$\eta = \dfrac{\overline{P_L}}{\overline{P_S}} = \dfrac{57.6}{159.6} \Rightarrow \underline{\eta = 36.1\%}$

8.31

a. All transistors are matched.

$3 \text{ mA} = i_{E1} + i_{B3} = \left(\dfrac{1+\beta}{\beta}\right)i_C + \dfrac{i_C}{\beta}$

$3 = \left(\dfrac{61}{60} + \dfrac{1}{60}\right)i_C \Rightarrow \underline{i_C = 2.90 \text{ mA}}$

b. For $v_0 = 6$ V, let $\underline{R_L = 200\ \Omega}$.

$i_0 = \dfrac{6}{200} = 0.03 \text{ A} = 30 \text{ mA} \cong i_{E3}$

$i_{B3} = \dfrac{30}{61} = 0.492$ mA

$i_{E1} = 3 - 0.492 = 2.508$ mA

$i_{B1} = \dfrac{2.508}{61} \Rightarrow \underline{i_{B1} = 41.11\ \mu\text{A}}$

$i_{E2} \cong 3 \text{ mA} \Rightarrow i_{B2} = \dfrac{3}{61} \Rightarrow 49.18\ \mu$A

$i_I = i_{B2} - i_{B1} = 49.18 - 41.11 \Rightarrow i_I = 8.07\ \mu$A

Current gain

$A_i = \dfrac{30\times10^{-3}}{8.07\times10^{-6}} \Rightarrow \underline{A_i = 3.72\times10^3}$

$V_{BE3} = V_T \ln\left(\dfrac{i_{E3}}{I_S}\right) = (0.026)\ln\left(\dfrac{30\times10^{-3}}{5\times10^{-13}}\right)$

$V_{BE3} = 0.6453$ V

$V_{EB1} = V_T \ln\left(\dfrac{i_{E1}}{I_S}\right) = (0.026)\ln\left(\dfrac{2.508\times10^{-3}}{5\times10^{-13}}\right)$

$V_{EB1} = 0.5807$ V

$v_I = v_0 + V_{BE3} - V_{EB1} = 6 + 0.6453 - 0.5807$

$v_I = 6.0646$ V

Voltage gain

$A_v = \dfrac{v_0}{v_I} = \dfrac{6}{6.0646} \Rightarrow \underline{A_v = 0.989}$

8.32

a. For $i_0 = 1$ A, $I_{B3} \cong \frac{1}{50} \Rightarrow 20$ mA

We can then write

$$\frac{10 - V_{EB1}}{R_1} = 2\left[\frac{10 - (v_{0,\max} + V_{BE3})}{R_1} - 20\right]$$

If, for simplicity, we assume $V_{EB1} = V_{BE3} = 0.7$ V, then

$$\frac{10 - V_{BE}}{R_1} = \frac{2v_{0,\max}}{R_1} + 40$$

If we assume $v_{0,\max} = 4$ V, then

$$\frac{9.3}{R_1} = \frac{2(4)}{R_1} + 40$$

which yields $\underline{R_1 = R_2 = 32.5\ \Omega}$

b. For $v_I = 0$,

$$I_{E1} = \frac{9.3}{32.5} \Rightarrow \underline{I_{E1} = 0.286\text{ A} = I_{E2}}$$

Since $I_{S3,4} = 10 I_{S1,2}$, then

$$\underline{I_{E3} = I_{E4} = 2.86\text{ A}}$$

c. We can write

$$R_0 = \frac{1}{2}\left\{\frac{r_{\pi3} + R_1 \left\| \frac{r_{\pi1}}{1+\beta_1}\right.}{1+\beta_3}\right\}$$

Now $r_{\pi3} = \frac{\beta_3 V_T}{I_{C3}} = \frac{(50)(0.026)}{2.86} = 0.4545\ \Omega$

$$r_{\pi1} = \frac{\beta_1 V_T}{I_{C1}} = \frac{(120)(0.026)}{0.286} = 10.91\ \Omega$$

So

$$R_0 = \frac{1}{2}\left\{\frac{0.4545 + 32.5 \left\| \frac{10.91}{121}\right.}{51}\right\}$$

$$32.5 \left\| \frac{10.91}{121}\right. = 32.5\|0.0902 = 0.0900$$

Then

$$R_0 = \frac{1}{2}\left\{\frac{0.4545 + 0.0900}{51}\right\} \text{ or } \underline{R_0 = 0.00534\ \Omega}$$

8.33

$$R_i = \frac{1}{2}\{r_{\pi1} + (1+\beta)[R_1\|(r_{\pi3} + (1+\beta)R_L)]\}$$

$i_{C1} \approx 7.2$ mA and $i_{C3} \approx 7.2$ mA

Then $r_\pi = \frac{(60)(0.026)}{7.2} = 0.217$ kΩ

So

$$R_i = \frac{1}{2}\{0.217 + (61)[2\|(0.217 + (61)(0.1))]\}$$

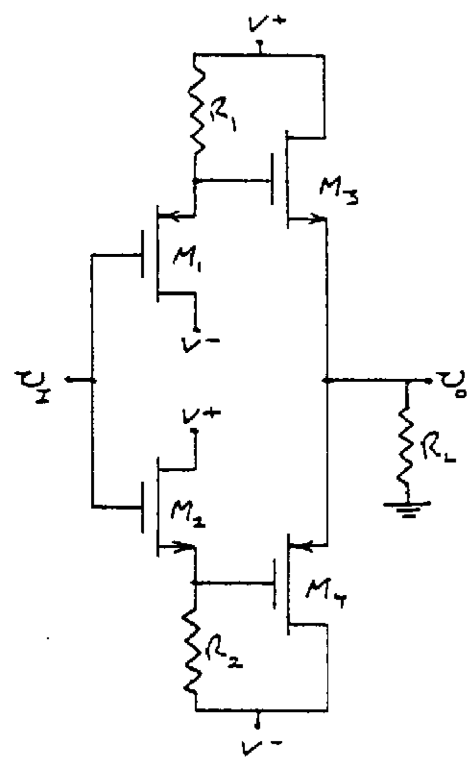
$$= \frac{1}{2}\{0.217 + 61[2\|6.32]\}$$

or

$$R_i = 46.4\text{ k}\Omega$$

8.34

a.



b. $I_1 = K_1(V_{SG} + V_{TP})^2 = \frac{V^+ - V_{SG}}{R_1}$

$5 = 10(V_{SG} - 2)^2 \Rightarrow V_{SG} = 2.707$ V

$5 = \frac{10 - 2.707}{R_1} \Rightarrow \underline{R_1 = R_2 = 1.46\text{ k}\Omega}$

c. $R_L = 100\ \Omega$ For a sinusoidal output signal:

$$\overline{P_L} = \frac{1}{2}\cdot\frac{(v_0)^2}{R_L} = \frac{1}{2}\cdot\frac{(5)^2}{0.1} \Rightarrow \underline{\overline{P_L} = 125\text{ mW}}$$

$$i_{D3} \approx \frac{(v_0)}{R_L} = \frac{(5)}{0.1} \Rightarrow i_{D3} = 50\text{ mA}$$

$$V_{GS3} = \sqrt{\frac{50}{10}} + 2 = 4.236\text{ V}$$

$$I_1 = \frac{10 - (4.236 + 5)}{1.46} \Rightarrow \underline{I_{D1} = 0.523\text{ mA}}$$

$$V_{SG1} = \sqrt{\frac{0.523}{10}} + 2 = 2.229\text{ V}$$

$$v_I = 5 + 4.236 - 2.229 \Rightarrow v_I = 7.007\text{ V}$$

$$I_{D2} = \frac{(v_I - V_{SG}) - (-10)}{1.46} = 10(V_{SG} - 2)^2$$

$$\frac{17.007 - V_{SG}}{1.46} = 10(V_{SG}^2 - 4V_{SG} + 4)$$

$$14.6V_{SG}^2 - 57.4V_{SG} + 41.4 = 0$$

$$V_{SG} = \frac{57.4 \pm \sqrt{(57.4)^2 - 4(14.6)(41.4)}}{2(14.6)}$$

$$V_{SG2} = 2.98\text{ V}$$

$$I_{D2} = 10(2.98 - 2)^2 \Rightarrow \underline{I_{D2} = 9.60\text{ mA}}$$

$$V_{G4} = v_I - V_{GS2} = 7 - 2.98 = 4.02\text{ V}$$

$$V_{SG4} = 5 - 4.02 = 0.98\text{ V} \Rightarrow \underline{I_{D4} = 0}$$

8.35

For $v_0 = 0$

$$I_Q = I_{C3} + I_{C2} + I_{E1}$$

$$I_{B3} = I_{E2} = \left(\frac{1+\beta_n}{\beta_n}\right)I_{C2} = \frac{I_{C3}}{\beta_n}$$

$$I_{C3} = (1+\beta_n)I_{C2}$$

$$I_{B2} = I_{C1} = \left(\frac{\beta_p}{1+\beta_p}\right)I_{E1} = \frac{I_{C2}}{\beta_n}$$

$$I_{C2} = \beta_n\left(\frac{\beta_p}{1+\beta_p}\right)I_{E1}$$

$$I_{C3} = (1+\beta_n)\beta_n\left(\frac{\beta_p}{1+\beta_p}\right)I_{E1}$$

$$I_Q = (1+\beta_n)\beta_n\left(\frac{\beta_p}{1+\beta_p}\right)I_{E1} + \beta_n\left(\frac{\beta_p}{1+\beta_p}\right)I_{E1} + I_{E1}$$

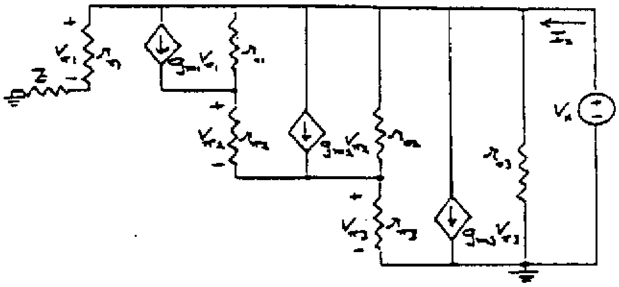
$$= (51)(50)\left(\frac{10}{11}\right)I_{E1} + (50)\left(\frac{10}{11}\right)I_{E1} + I_{E1}$$

$$I_Q = 2318.18I_{E1} + 45.45I_{E1} + I_{E1}$$

$$I_{E1} = 1.692\ \mu\text{A} \Rightarrow \underline{I_{C1} = 1.534\ \mu\text{A}}$$

$$I_{C2} = (50)\left(\frac{10}{11}\right)(1.692) \Rightarrow I_{C2} = 76.9\ \mu\text{A}$$

$$I_{C3} = (51)(50)\left(\frac{10}{11}\right)(1.692) \Rightarrow \underline{I_{C3} = 3.92\text{ mA}}$$



Because of $r_{\pi1}$ and Z, neglect effect of r_0. Then neglecting r_{01}, r_{02}, and r_{03}, we find

$$I_X = g_{m3}V_{\pi3} + g_{m2}V_{\pi2} + g_{m1}V_{\pi1} + \frac{V_X}{r_{\pi1} + Z}$$

Now

$$V_{\pi1} = \left(\frac{r_{\pi1}}{r_{\pi1} + Z}\right)V_X, \quad V_{\pi2} \cong g_{m1}V_{\pi1}r_{\pi2}$$

and

$$V_{\pi3} = (g_{m1}V_{\pi1} + g_{m2}V_{\pi2})r_{\pi3}$$
$$= [g_{m1}V_{\pi1} + g_{m2}(g_{m1}V_{\pi1}r_{\pi2})]r_{\pi3}$$

$$V_{\pi3} = \left(\frac{r_{\pi1}}{r_{\pi1} + Z}\right)[g_{m1} + g_{m1}g_{m2}r_{\pi2}]r_{\pi3}\cdot V_X$$

$$V_{\pi3} = \frac{(\beta_1 + \beta_1\beta_2)r_{\pi3}}{r_{\pi1} + Z}\cdot V_X$$

and

$$V_{\pi2} = g_{m1}\left(\frac{r_{\pi1}}{r_{\pi1} + Z}\right)r_{\pi2}V_X = \left(\frac{\beta_1 r_{\pi2}}{r_{\pi1} + Z}\right)V_X$$

Then

$$I_X = \frac{(\beta_1 + \beta_1\beta_2)\beta_3}{r_{\pi1} + Z}\cdot V_X + \frac{\beta_1\beta_2}{r_{\pi1} + Z}\cdot V_X + \frac{\beta_1}{r_{\pi1} + Z}\cdot V_X + \frac{V_X}{r_{\pi1} + Z}$$

Then

$$R_0 = \frac{V_X}{I_X} = \frac{r_{\pi1} + Z}{1 + \beta_1 + \beta_1\beta_2 + (\beta_1 + \beta_1\beta_2)\beta_3}$$

$$r_{\pi1} = \frac{(10)(0.026)}{1.534} = 0.169\text{ M}\Omega$$

$$Z = 25\text{ k}\Omega$$

Then

$$R_o = \frac{169 + 25}{1 + (10) + (10)(50) + [10 + (10)(50)](50)}$$

$$R_o = \frac{194}{26,011} = 0.00746 \text{ k}\Omega$$

or $\underline{R_o = 7.46\ \Omega}$

8.36

a. Neglect base currents.

$$V_{BB} = 2V_D = 2V_T \ln\left(\frac{I_{\text{Bias}}}{I_S}\right)$$

$$= 2(0.026)\ln\left(\frac{5 \times 10^{-3}}{10^{-13}}\right)$$

$$\Rightarrow \underline{V_{BB} = 1.281 \text{ V}}$$

$$V_{BE1} + V_{EB3} = V_{BB}$$

$$I_{E1} = I_{E3} + I_{C2}$$

$$I_{B2} = I_{C3} = \left(\frac{\beta_p}{1+\beta_p}\right) I_{E3}$$

$$I_{C2} = \beta_n I_{B2} = \beta_n \left(\frac{\beta_p}{1+\beta_p}\right) I_{E3}$$

$$I_{E1} = I_{E3} + \beta_n \left(\frac{\beta_p}{1+\beta_p}\right) I_{E3}$$

$$I_{E1} = I_{E3}\left[1 + \beta_n\left(\frac{\beta_p}{1+\beta_p}\right)\right]$$

$$\left(\frac{1+\beta_n}{\beta_n}\right) I_{C1} = \left(\frac{1+\beta_p}{\beta_p}\right) I_{C3}\left[1 + \beta_n\left(\frac{\beta_p}{1+\beta_p}\right)\right]$$

$$V_{BE1} = V_T \ln\left[\frac{I_{C1}}{I_S}\right],\ V_{EB3} = V_T \ln\left[\frac{I_{C3}}{I_S}\right]$$

$$(1.01) I_{C1} = \left(\frac{21}{20}\right) I_{C3}\left[1 + (100)\left(\frac{20}{21}\right)\right]$$

$$= I_{C3}\left[\frac{21}{20} + 100\right] = 101.05 I_{C3}$$

$$I_{C1} = 100.05 I_{C3}$$

$$V_T \ln\left(\frac{100.05 I_{C3}}{I_S}\right) + V_T \ln\left(\frac{I_{C3}}{I_S}\right) = V_{BB}$$

$$V_T \ln\left(\frac{100.05 I_{C3}^2}{I_S^2}\right) = V_{BB}$$

$$\frac{100.05 I_{C3}^2}{I_S^2} = \exp\left(\frac{V_{BB}}{V_T}\right)$$

$$I_{C3} = \frac{I_S}{\sqrt{100.05}}\sqrt{\exp\left(\frac{V_{BB}}{V_T}\right)} = \underline{0.4997 \text{ mA} = I_{C3}}$$

Then $I_{E3} = 0.5247$ mA

Now

$$I_{C1} = 100.05 I_{C3} = \underline{50 \text{ mA} = I_{C1}}$$

$$I_{C2} = (100)\left(\frac{20}{21}\right)(0.5247) = \underline{49.97 \text{ mA} = I_{C2}}$$

b. $v_O = 10 \text{ V} \Rightarrow i_{E1} \approx \frac{10}{100} = 0.10 \text{ A} = i_{C1}$

$$i_{B1} = \frac{100}{100} = 1 \text{ mA}$$

$$V_{BB} = 2(0.026)\ln\left(\frac{4 \times 10^{-3}}{10^{-13}}\right) = 1.269 \text{ V}$$

$$V_{BE1} = (0.026)\ln\left(\frac{0.1}{10^{-13}}\right) = 0.7184$$

$$V_{EB3} = 1.269 - 0.7184 = 0.5506 \text{ V}$$

$$I_{C3} = 10^{-13}\exp\left(\frac{0.5506}{0.026}\right) = 0.157 \text{ mA}$$

$$\overline{P_L} = \frac{v_0^2}{R_L} = \frac{(10)^2}{100} \Rightarrow \underline{\overline{P_L} = 1 \text{ W}}$$

$$P_{Q1} = i_{C1}\cdot v_{CE1} = (0.1)(12-10) \Rightarrow \underline{P_{Q1} = 0.2 \text{ W}}$$

$$P_{Q3} = i_{C3}\cdot v_{EC3} = (0.157)(10 - [0.7 - 12])$$

$$\Rightarrow \underline{P_{Q3} = 3.34 \text{ mW}}$$

$$i_{C2} = (100)(i_{C3}) = (100)(0.157) = 15.7 \text{ mA}$$

$$P_{Q2} = i_{C2}\cdot v_{CE2} = (15.7)(10 - [-12])$$

$$\Rightarrow \underline{P_{Q2} = 0.345 \text{ W}}$$

8.37

a. $V_{BB} = 3(0.026)\ln\left(\frac{10 \times 10^{-3}}{2 \times 10^{-12}}\right)$

$$\Rightarrow \underline{V_{BB} = 1.74195 \text{ V}}$$

$$V_{BE1} + V_{BE2} + V_{EB3} = V_{BB}$$

$$I_{C1} \approx \frac{I_{C2}}{\beta_n},\quad I_{C3} \approx \frac{I_{C2}}{\beta_n^2}$$

$$V_T \ln\left(\frac{I_{C1}}{I_S}\right) + V_T \ln\left(\frac{I_{C2}}{I_S}\right) + V_T \ln\left(\frac{I_{C3}}{I_S}\right) = V_{BB}$$

$$V_T \ln\left[\frac{I_{C2}^3}{\beta_n^3 I_S^3}\right] = V_{BB}$$

$$I_{C2} = \beta_n I_S \sqrt[3]{\exp\left(\frac{V_{BB}}{V_T}\right)}$$

$$= (20)(2 \times 10^{-12})\sqrt[3]{\exp\left(\frac{1.74195}{0.026}\right)}$$

$$I_{C2} = 0.20 \text{ A},\ I_{C1} \approx 10 \text{ mA},\ I_{C3} \approx 0.5 \text{ mA}$$

$$V_{BE1} = (0.026)\ln\left(\frac{10 \times 10^{-3}}{2 \times 10^{-12}}\right)$$

$$\Rightarrow \underline{V_{BE1} = 0.58065 \text{ V}}$$

$$V_{BE2} = (0.026)\ln\left(\frac{0.2}{2\times 10^{-12}}\right)$$

$$\Rightarrow \underline{V_{BE2} = 0.6585 \text{ V}}$$

$$V_{EB3} = (0.026)\ln\left(\frac{0.5\times 10^{-3}}{2\times 10^{-12}}\right)$$

$$\Rightarrow \underline{V_{EB3} = 0.50276 \text{ V}}$$

b. $\overline{P_L} = 10 \text{ W} = \frac{1}{2}\cdot\frac{V_0^2}{R_L} = \frac{1}{2}\cdot\frac{V_0^2}{20}$

$$\Rightarrow V_0(\text{max}) = 20 \text{ V}$$

For $v_0(\text{max})$:

$$P_L = \frac{v_0^2}{R_L} = \frac{(20)^2}{20} \Rightarrow \underline{P_L = 20 \text{ W}}$$

$$i_0(\text{max}) = -\frac{20}{20} = -1 \text{ A}$$

$$i_{C5} + i_{C4} + i_{E3} = -i_0(\text{max}) = 1 \text{ A}$$

$$i_{C5} + \frac{i_{C5}}{\beta_n}\cdot\left(\frac{1+\beta_p}{\beta_p}\right) + \frac{i_{C4}}{\beta_n}\cdot\left(\frac{1+\beta_p}{\beta_p}\right) = 1$$

$$i_{C5}\left[1 + \frac{1}{\beta_n}\cdot\left(\frac{1+\beta_p}{\beta_p}\right) + \left\{\frac{1}{\beta_n}\cdot\left(\frac{1+\beta_p}{\beta_p}\right)\right\}^2\right] = 1$$

$$i_{C5}\left[1 + \frac{1}{20}\cdot\left(\frac{6}{5}\right) + \left(\frac{1}{20}\cdot\frac{6}{5}\right)^2\right]$$

$$i_{C5}[1 + 0.06 + 0.0036] = 1 \Rightarrow \underline{i_{C5} = 0.940 \text{ A}}$$

$$\underline{i_{C4} = 0.0564 \text{ A}}$$

$$\underline{i_{E3} = 3.38 \text{ mA}}$$

$$i_{C2} = 2.82 \text{ mA}$$

$$V_{EB3} = (0.026)\ln\left(\frac{2.82\times 10^{-3}}{2\times 10^{-12}}\right) = 0.5477 \text{ V}$$

$$V_{BE1} + V_{BE2} = 1.74195 - 0.5477 = 1.1942$$

$$V_T\ln\left(\frac{I_{C2}}{\beta_n I_S}\right) + V_T\ln\left(\frac{I_{C2}}{I_S}\right) = 1.1942$$

$$I_{C2} = \sqrt{\beta_n}\cdot I_S\sqrt{\exp\left(\frac{1.1942}{0.026}\right)}$$

$$= \sqrt{20}(18.83) \text{ mA}$$

$$I_{C2} = 84.2 \text{ mA}$$