Chapter 4

Exercise Solutions

E4.1

$$g_m = \frac{I_{CQ}}{V_T} = \frac{0.25}{0.026} \Rightarrow \underline{g_m = 9.62 \text{ mA/V}}$$
$$r_\pi = \frac{V_T \beta}{I_{CQ}} = \frac{(0.026)(120)}{0.25} \Rightarrow \underline{r_\pi = 12.5 \text{ k}\Omega}$$
$$r_0 = \frac{V_A}{I_{CQ}} = \frac{150}{0.25} \Rightarrow \underline{r_0 = 600 \text{ k}\Omega}$$

E4.2

$$r_0 = \frac{V_A}{I_{CQ}} \Rightarrow I_{CQ} = \frac{V_A}{r_0} = \frac{75}{200 \text{ k}\Omega}$$
$$\Rightarrow \underline{I_{CQ} = 0.375 \text{ mA}}$$

E4.3

$$I_{BQ} = \frac{V_{BB} - V_{BE}(\text{on})}{R_B} = \frac{0.92 - 0.7}{100}$$
$$\Rightarrow I_{BQ} = 0.0022 \text{ mA}$$
$$I_{CQ} = (150)(0.0022) = 0.33 \text{ mA}$$

a. $$g_m = \frac{I_{CQ}}{V_T} = \frac{0.33}{0.026} \Rightarrow \underline{g_m = 12.7 \text{ mA/V}}$$

$$r_\pi = \frac{V_T \beta}{I_{CQ}} = \frac{(0.0026)(150)}{0.33} \Rightarrow \underline{r_\pi = 11.8 \text{ k}\Omega}$$
$$r_0 = \frac{V_A}{I_{CQ}} = \frac{200}{0.33} \Rightarrow \underline{r_0 = 606 \text{ k}\Omega}$$

b. $$v_0 = -g_m v_\pi (r_0 \| R_C), \quad v_\pi = \left(\frac{r_\pi}{r_\pi + R_B}\right) v_S$$

$$A_v = \frac{v_0}{v_S} = -g_m \left(\frac{r_\pi}{r_\pi + R_B}\right)(r_0 \| R_C)$$
$$= -(12.7)\left(\frac{11.8}{11.8 + 100}\right)(606\|15)$$
$$= -(12.7)(0.1055)(14.64)$$
$$\Rightarrow \underline{A_v = -19.6}$$

E4.4

$$g_m = \frac{I_{CQ}}{V_T}$$

a. $$I_{BQ} = \frac{V_{BB} - V_{EB}(\text{on})}{R_B} = \frac{1.145 - 0.70}{50}$$
$$\Rightarrow I_{BQ} = 0.0089 \text{ mA}$$
$$I_{CQ} = (90)(0.0089) \Rightarrow I_{CQ} = 0.801 \text{ mA}$$
$$g_m = \frac{0.801}{0.026} \Rightarrow \underline{g_m = 30.8 \text{ mA/V}}$$

$$r_\pi = \frac{V_T \beta}{I_{CQ}} = \frac{(0.0026)(90)}{0.801} \Rightarrow \underline{r_\pi = 2.92 \text{ k}\Omega}$$
$$r_0 = \frac{V_A}{I_{CQ}} = \frac{120}{0.801} \Rightarrow \underline{r_0 = 150 \text{ k}\Omega}$$

b. $$v_0 = g_m v_\pi (r_0 \| R_C), \quad v_\pi = -\left(\frac{r_\pi}{r_\pi + R_B}\right) v_S$$

$$A_v = \frac{v_0}{v_S} = -g_m \left(\frac{r_\pi}{r_\pi + R_B}\right)(r_0 \| R_C)$$
$$= -(30.8)\left(\frac{2.92}{2.92 + 50}\right)(150\|2.5)$$
$$= -(30.8)(0.055)(2.46)$$
$$\Rightarrow \underline{A_v = -4.17}$$

E4.5

$$R_{TH} = 250\|75 = 57.7 \text{ k}\Omega$$
$$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right)(5) = \left(\frac{75}{75 + 250}\right)(5) = 1.154$$
$$I_{BQ} = \frac{1.154 - 0.7}{57.7 + (121)(0.6)} = 3.48 \ \mu\text{A}$$
$$I_{CQ} = 0.418 \text{ mA}$$

a. $$r_\pi = \frac{(120)(0.026)}{0.418} = 7.46 \text{ k}\Omega$$

$$g_m = \frac{0.418}{0.026} = 16.08 \text{ mA/V}$$
$$V_0 = -g_m V_\pi R_C$$
$$R_{ib} = r_\pi + (1+\beta)R_E = 7.46 + (121)(0.6) = 80.1 \ k\Omega$$
$$R_1 \| R_2 = 250\|75 = 57.7 \ k\Omega$$
$$R_1 \| R_2 \| R_{ib} = 57.7\|80.1 = 33.54 \ k\Omega$$
$$V_S' = \left(\frac{R_1\|R_2\|R_{ib}}{R_1\|R_2\|R_{ib} + R_S}\right)\cdot V_S = \left(\frac{33.54}{33.54 + 0.5}\right)\cdot V_S$$
$$V_S' = (0.985)V_S$$
$$V_S' = V_\pi\left[1 + \left(\frac{1+\beta}{r_\pi}\right)R_E\right]$$

Then

$$A_v = (0.985)(-8.39) = -8.27$$

b. $$R_{ib} = r_\pi + (1+\beta)(R_E) = 7.46 + (121)(0.6)$$
$$\Rightarrow \underline{R_{ib} = 80.1 \text{ k}\Omega}$$

E4.6

As a first approximation,

$$A_v \cong -\frac{R_C}{R_E}$$

Resulting gain is always smaller than this value. The effect of R_S is very small.

Set $\frac{R_C}{R_E} = 10$

$5 \cong I_C(R_C + R_E) + V_{CEQ}$

$5 = 0.5(R_C + R_E) + 2.5$

So that $\underline{R_E = 0.454\ k\Omega}$ and $\underline{R_C = 4.54\ k\Omega}$

$I_{BQ} = \dfrac{0.5}{100} = 0.005\ mA$

$R_{TH} = (0.1)(1+\beta)R_E = (0.1)(101)(0.454) = 4.59\ k\Omega$

$V_{TH} = \left(\dfrac{R_2}{R_1 + R_2}\right)\cdot V_{CC} = \dfrac{1}{R_1}\cdot R_{TH}\cdot V_{CC} = \dfrac{1}{R_1}(4.59)(5)$

or $V_{TH} = \dfrac{23}{R_1}$

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

$\dfrac{23}{R_1} = (0.005)(4.59) + 0.7 + (101)(0.005)(0.454)$

which yields, $\underline{R_1 = 24.1\ k\Omega}$ and $\underline{R_2 = 5.67\ k\Omega}$

E4.7

dc analysis

$R_{TH} = R_1 \| R_2 = 15\|85 = 12.75$

$V_{TH} = \left(\dfrac{R_2}{R_1 + R_2}\right)V_{CC} = \left(\dfrac{85}{85 + 15}\right)(12)$

$V_{TH} = 10.2$ V

$I_{BQ} = \dfrac{12 - 0.7 - V_{TH}}{R_{TH} + (1+\beta)R_E}$

$= \dfrac{12 - 0.7 - 10.2}{12.75 + (101)(0.5)} = \dfrac{1.1}{63.25} = 0.0174$

$I_{CQ} = 1.74$ mA

ac analysis

$V_0 = h_{fe}I_b(R_C\|R_L)$

$I_b = \dfrac{-V_S}{h_{ie} + (1 + h_{fe})R_E}$

$A_v = \dfrac{-h_{fe}(R_C\|R_L)}{h_{ie} + (1 + h_{fe})R_E}$

For $I_{CQ} = 1.7$ mA

$h_{fe}(\max) = 110 \qquad h_{fe}(\min) = 70$

$h_{ie}(\max) = 2\ k\Omega \qquad h_{ie}(\min) = 1.1\ k\Omega$

$A_v(\max) = \dfrac{-110(4\|2)}{2 + (111)(0.5)} = -2.54$

$A_v(\min) = \dfrac{-70(4\|2)}{1.1 + (71)(0.5)} = -2.54$

E4.8

First approximation, $A_v = -\dfrac{R_C}{R_E}$ which predicts a low value. Set $\dfrac{R_C}{R_E} = 9$. Now

$V_{CC} \cong I_{CQ}(R_C + R_E) + V_{ECQ}$

$7.5 = (0.6)(9R_E + R_E) + 3.75$

So $\underline{R_E = 0.625\ k\Omega}$ and $\underline{R_C = 5.62\ k\Omega}$

$R_{TH} = (0.1)(1+\beta)R_E = (0.1)(101)(0.625) = 6.31\ k\Omega$

$V_{TH} = \dfrac{1}{R_1}\cdot R_{TH}\cdot V_{CC} = \dfrac{1}{R_1}(6.31)(7.5)$

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

$I_{BQ} = \dfrac{0.6}{100} = 0.006\ mA$

$$7.5 = (101)(0.006)(0.625) + 0.7 + (0.006)(6.31) + \frac{1}{R_1}(6.31)(7.5)$$

Then $\underline{R_1 = 7.40\ k\Omega}$ and $\underline{R_2 = 42.8\ k\Omega}$

E4.9

dc analysis

$I_{BQ} = \dfrac{10 - 0.7}{100 + (101)(20)} = 0.00439$ mA

$I_{CQ} = 0.439$ mA. $I_{EQ} = 0.443$ mA

$r_\pi = \dfrac{V_T\beta}{I_{CQ}} = \dfrac{(0.026)(100)}{0.439} = 5.92\ k\Omega$

$g_m = \dfrac{I_{CQ}}{V_T} = \dfrac{0.439}{0.026} = 16.88$ mA/V

$r_0 = \dfrac{V_A}{I_{CQ}} = \dfrac{100}{0.439} = 228\ k\Omega$

(a) $V_o = -g_m V_\pi (r_o \| R_C)$

$V_\pi = V_s' = \left(\dfrac{R_B\|r_\pi}{R_B\|r_\pi + R_S}\right)\cdot V_s$

$R_B\|r_\pi = 100\|5.92 = 5.59\ k\Omega$

Then

$V_\pi = \left(\dfrac{5.59}{5.59 + 0.5}\right)\cdot V_s = 0.918V_s$

Then

$A_v = -(161.7)(0.918) = -148$

b. $R_{in} = R_B\|r_\pi = (100)\|(5.92)$

$\Rightarrow \underline{R_{in} = 5.59\ k\Omega}$

$R_0 = R_C\|r_0 = 10\|228 \Rightarrow \underline{R_0 = 9.58\ k\Omega}$

E4.10

$A_v = \dfrac{-\beta R_C}{r_\pi + (1+\beta)R_E} = -(0.95)\left(\dfrac{R_C}{R_E}\right) = -(0.95)\left(\dfrac{2}{0.4}\right)$

or $A_v = -4.75$

Assume $r_\pi = 1.2\ k\Omega$ from Example 4.5. Then

$\dfrac{-\beta(2)}{1.2 + (1+\beta)(0.4)} = -4.75$

which yields $\underline{\beta = 76}$

E4.11

dc analysis: $V_{TH} = 0, R_{TH} = R_1 \| R_2 = 10\ k\Omega$

$$I_{BQ} = \frac{5 - 0.7}{10 + (126)(5)} = 0.00672$$

$I_{CQ} = 0.84$ mA

$$r_\pi = \frac{V_T \beta}{I_{CQ}} = \frac{(0.026)(125)}{0.84} = 3.87\ \text{k}\Omega$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{0.84}{0.026} = 32.3\ \text{mA/V}$$

$$r_0 = \frac{V_A}{I_{CQ}} = \frac{200}{0.84} = 238\ \text{k}\Omega$$

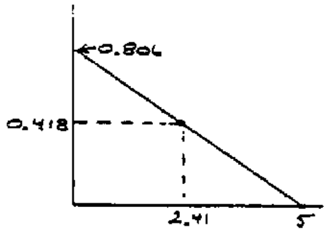
a. $v_0 = -g_m v_\pi (r_0 \| R_C \| R_L)$. $v_\pi = v_S$

$A_v = -g_m(r_0 \| R_C \| R_L) = -(32.3)(238 \| 2.3 \| 5)$

$A_v = -(32.3)(1.56) \Rightarrow \underline{A_v = -50.4}$

b. $R_0 = r_0 \| R_C \Rightarrow \underline{R_0 = 2.28\ \text{k}\Omega}$

E4.12



$$V_{CEQ} = 5 - (0.418)(5.6) - \left(\frac{121}{120}\right)(0.418)(0.6)$$

$= 5 - 2.34 - 0.253$

$V_{CEQ} = 2.41$

ΔV_{CE} variation $(2.41 - 0.5)2 = 3.82$ V peak-to-peak

E4.13

a. dc load line:

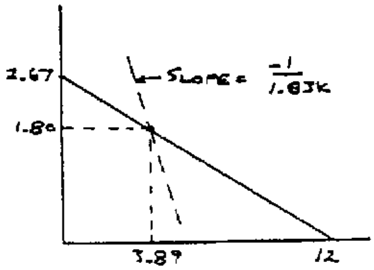
$V_{EC} = V_{CC} - I_E R_E - I_C R_C$

$V_{EC} \cong 12 - I_C(R_E + R_C) = 12 - I_C(4.5)$

ac load line:

$v_{ec} \approx -i_C(R_E + R_C \| R_L)$

$v_{ec} = -i_C(0.5 + 4 \| 2) = -i_C(1.83)$



$$I_{BQ} = \frac{12 - 0.7 - 10.2}{12.75 + (121)(0.5)} = \frac{1.1}{73.25}$$

$I_{BQ} = 0.0150$

$I_{CQ} = 1.80,\ I_{EQ} = 1.82$

$\Rightarrow V_{ECQ} = 3.89$

b. For $\Delta i_C = 1.8 \Rightarrow \Delta v_{EC} = (1.8)(1.83) = 3.29$

For $\Delta v_{EC} = -3.29 \Rightarrow \Delta v_{CE} = 3.89 - 3.29 = 0.6$

$\Rightarrow$ Max. symmetrical swing

$= 2 \times (3.29) = \underline{6.58\ \text{V}}$ peak-to-peak

E4.14

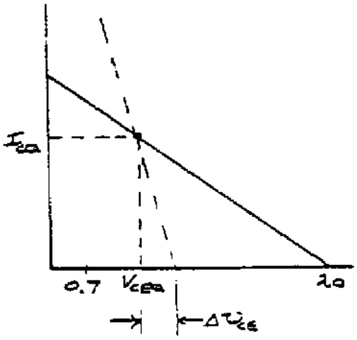
dc load line:

$V_{CE} \approx (10 + 10) - I_C(R_C + R_E)$

$V_{CE} = 20 - I_C(10 + R_E)$

$v_{ce} = -i_C R_C = -i_C(10)$

ac load line:



$\Delta v_{ce} = V_{CEQ} - 0.7 = \Delta i_C(10) = I_{CQ}(10)$

So $V_{CEQ} - 0.7 = I_{CQ}(10)$

We have

$V_{CEQ} = 20 - I_{CQ}(10 + R_E)$

$I_{CQ}(10) + 0.7 = 20 - I_{CQ}(10 + R_E)$ (1)

$$I_{BQ} = \frac{10 - 0.7}{100 + (101)R_E} \Rightarrow I_{CQ} = \frac{(100)(9.3)}{100 + (101)R_E} \qquad (2)$$

From (1)

$I_{CQ}[10 + 10 + R_E] = 20 - 0.7$

Substitute (2)

$\left[\dfrac{(100)(9.3)}{100 + (101)R_E}\right](20 + R_E) = 19.3$

$930(20 + R_E) = 19.3[100 + (101)R_E]$

$18,600 + 930R_E = 1930 + 1949.3R_E$

$16,670 = 1019.3R_E \Rightarrow \underline{R_E = 16.35\ \text{k}\Omega}$

So

$I_{CQ} = \dfrac{(100)(9.3)}{100 + (101)(16.35)} \Rightarrow I_{CQ} = 0.531\ \text{mA}$

$V_{CEQ} = 20 - (0.531)(10 + 16.35) \Rightarrow V_{CEQ} = 6.0\ \text{V}$

$\Delta v_{CE} = V_{CEQ} - 0.7 = 6 - 0.7 = 5.3$

Max symmetrical swing

$2 \times (5.3) = \underline{10.6\ \text{V}}$ peak-to-peak

E4.15

a. $I_{BQ} = \dfrac{5 - 0.7}{10 + (126)(5)} = 0.00672$

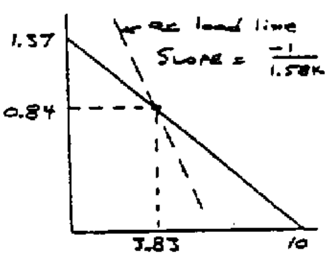
$I_{CQ} = 0.84\ \text{mA},\ I_{EQ} = 0.847\ \text{mA}$

$r_0 = \dfrac{V_A}{I_{CQ}} = \dfrac{200}{0.84} = 238\ \text{k}\Omega$

$V_{CEQ} = 10 - (0.84)(2.3) - (0.847)(5)$

$= 10 - 1.932 - 4.235$

$V_{CEQ} = 3.83\ \text{V}$



dc load line

$V_{CE} \approx 10 - I_C(7.3)$

ac load line

$v_{ce} = -i_c(R_C \| R_L) = -i_c(2.3\|5) = -i_c(1.58)$

(neglecting r_0)

b. $\Delta i_C = 0.84$

$\Rightarrow \Delta v_{CE} = (0.84)(1.58) = 1.33\ \text{V}$

$V_{CE}(\min) = 3.83 - 1.33 = 2.5\ \text{V}$

$V_{CE}(\max) = 3.83 + 1.33 = 5.16\ \text{V}$

So max symmetrical swing

$= 2 \times (1.33) = \underline{2.66\ \text{V}}$ peak-to-peak

E4.16

a. $V_{TH} = \left(\dfrac{R_2}{R_1 + R_2}\right)(12).\quad V_{TH} = \dfrac{1}{R_1}(R_{TH})(12)$

$R_{TH} = (0.1)(1 + \beta)R_E = (0.1)(121)R_E$

$= 12.1R_E = 12.1\ \text{k}\Omega$

$I_{BQ} = \dfrac{12 - 0.7 - V_{TH}}{R_{TH} + (1 + \beta)R_E} = \dfrac{11.3 - \frac{1}{R_1}(12.1)(12)}{12.1 + (121)(1)}$

$I_{CQ} = 1.6 \Rightarrow I_{BQ} = \dfrac{1.6}{120} = 0.01333\ \text{mA}$

$0.01333 = \dfrac{11.3 - \frac{1}{R_1}(145.2)}{133.1}$

$\dfrac{1}{R_1}(145.2) = 11.3 - (0.01333)(133.1)$

$\Rightarrow \underline{R_1 = 15.24\ \text{k}\Omega}$

$\dfrac{R_1 R_2}{R_1 + R_2} = 12.1 = \dfrac{15.24R_2}{15.24 + R_2}$

$(12.1)(15.24) = (15.24 - 12.1)R_2$

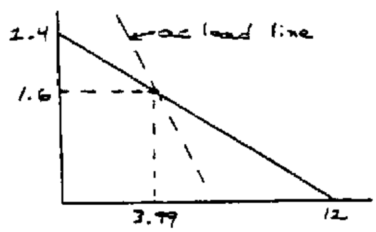
$\Rightarrow \underline{R_2 = 58.7\ \text{k}\Omega}$

$V_{ECQ} = 12 - (1.6)(4) - (1.61)(1) \Rightarrow \underline{V_{ECQ} = 3.99\ \text{V}}$

b. $v_0 = g_m v_\pi (R_C \| R_L) = -g_m(R_C \| R_L) = -v_{ec}$

$i_C = g_m v_\pi = -g_m v_S$

or $-v_{ec} = i_C(R_C \| R_L)$



Want $\Delta i_C = 1.6 - 0.1 = 1.5$

$\Delta v_{ec} = 3.99 - 0.5 = 3.49$

$\dfrac{\Delta v_{ec}}{\Delta i_C} = \dfrac{3.49}{1.5} = 2.327\ \text{k}\Omega = R_C \| R_L$

$\dfrac{R_C R_L}{R_C + R_L} = \dfrac{4R_L}{4 + R_L} = 2.327$

$(4 - 2.327)R_L = (4)(2.327) \Rightarrow \underline{R_L = 5.56\ \text{k}\Omega}$

E4.17

$R_{TH} = R_1 \| R_2 = 25\|50 = 16.7\ \text{k}\Omega$

$V_{TH} = \left(\dfrac{R_2}{R_1 + R_2}\right)V_{CC} = \left(\dfrac{50}{50 + 25}\right)(5)$

$V_{TH} = 3.33\ \text{V}$

$I_{BQ} = \dfrac{V_{BB} - V_{BE}(\text{on})}{R_{TH} + (1 + \beta)R_E} = \dfrac{3.33 - 0.70}{16.7 + (121)(1)}$

$= \dfrac{2.63}{137.7}$

$\Rightarrow I_{BQ} = 0.0191$

$I_{CQ} = 2.29\ \text{mA}$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{2.29}{0.026} = 88.1 \text{ mA/V}$$
$$r_\pi = \frac{V_T\beta}{I_{CQ}} = \frac{(0.026)(120)}{2.29} = 1.36 \text{ k}\Omega$$
$$r_0 = \frac{V_A}{I_{CQ}} = \frac{100}{2.29} = 43.7 \text{ k}\Omega$$

a.

$$V_s' = \left(\frac{R_1\|R_2\|R_{ib}}{R_1\|R_2\|R_{ib} + R_S}\right)\cdot V_s$$
$$R_{ib} = r_\pi + (1+\beta)(R_E\|r_o) = (1.36) + (121)(1\|43.7) \Rightarrow$$
$R_{ib} = 120\ k\Omega$ and $R_1\|R_2 = 16.7\ k\Omega$

Then $R_1\|R_2\|R_{ib} = 16.7\|120 = 14.7\ k\Omega$

Then
$$V_s' = \left(\frac{14.7}{14.7+0.5}\right)\cdot V_s = (0.967)V_s$$
Now
$$V_o = \left(\frac{V_\pi}{r_\pi} + g_m V_\pi\right)(R_E\|r_o) = V_\pi\left(\frac{1+\beta}{r_\pi}\right)R_E\|r_o$$
$$V_\pi = \frac{V_s'}{1+\left(\frac{1+\beta}{r_\pi}\right)R_E\|r_o} = \frac{(0.967)V_s}{1+\left(\frac{1+\beta}{r_\pi}\right)R_E\|r_o}$$
So
$$\frac{V_o}{V_s} = \frac{(0.967)\left(\frac{1+\beta}{r_\pi}\right)R_E\|r_o}{1+\left(\frac{1+\beta}{r_\pi}\right)R_E\|r_o} = \frac{(0.967)(1+\beta)R_E\|r_o}{r_\pi+(1+\beta)R_E\|r_o}$$
$$R_E\|r_o = 1\|43.7 = 0.978\ k\Omega$$
Then
$$A_v = \frac{(0.967)(121)(0.978)}{1.36+(121)(0.978)} \Rightarrow \underline{A_v = 0.956}$$

b. $R_{ib} = r_\pi + (1+\beta)R_E\|r_0 = 1.36 + (121)(0.978)$

$\Rightarrow \underline{R_{ib} = 120 \text{ k}\Omega}$

(c)
$$R_o = R_E\|r_o\left\|\frac{r_\pi + R_1\|R_2\|R_S}{1+\beta}\right. = 1\|43.7\left\|\frac{1.36+16.7\|0.5}{121}\right.$$
which yields

$\underline{R_o = 15.1\ \Omega}$

E4.18

$$V_{CEQ} = 5 \text{ V} \Rightarrow I_{EQ} = \frac{5}{2} = 2.5 \text{ mA}$$
$$I_{BQ} = \frac{2.5}{101} = 0.0248 \text{ mA}$$
$$V_{TH} = I_{BQ}R_{TH} + V_{BE}(\text{on}) + (1+\beta)I_{BQ}R_E$$
$$R_{in} = R_{TH}\|[r_\pi + (1+\beta)R_E]$$
$$r_\pi = 1.05 \text{ k}\Omega$$

$$65 = R_{TH}\|203 = \frac{R_{TH}\cdot 203}{R_{TH}+203}$$
$$\Rightarrow R_{TH} = 95.6 \text{ k}\Omega$$
$$\frac{1}{R_1}(95.6)(10) = (0.0248)(95.6) + 0.7 + 2.5(2)$$
$$= 8.07$$
$\underline{R_1 = 118 \text{ k}\Omega}$. $\frac{118R_2}{118+R_2} = 95.6$

$\underline{R_2 = 504 \text{ k}\Omega}$

$R_{in} = 65\ k\Omega$
$$V_s' = \left(\frac{R_{in}}{R_{in}+R_S}\right)\cdot V_s = \left(\frac{65}{65+0.5}\right)\cdot V_s = 0.992V_s$$
Then
$$A_v = \frac{(0.992)(1+\beta)R_E}{r_\pi+(1+\beta)R_E} = \frac{(0.992)(101)(2)}{1.05+(101)(2)} \Rightarrow$$
$\underline{A_v = 0.987}$

Neglecting R_S, $\underline{A_v = 0.995}$
$$R_o = R_E\left\|\frac{r_\pi + R_1\|R_2\|R_S}{1+\beta}\right. = 2\left\|\frac{1.05+95.6\|0.5}{101}\right.$$
or

$R_o = 15.2\ \Omega$

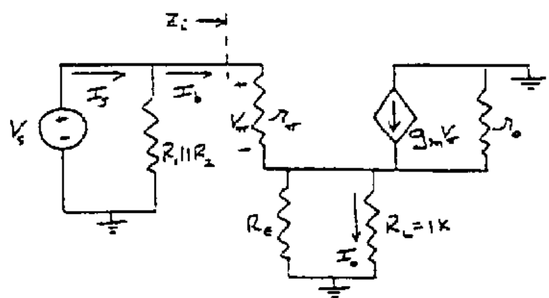
Neglecting R_S, $R_o = 2\left\|\frac{1.05}{102}\right. \Rightarrow \underline{R_o = 10.3\ \Omega}$

E4.19

$$V_{TH} = \left(\frac{R_2}{R_1+R_2}\right)(10) - 5$$
$\beta = 100$, $V_A = 125$ V, $V_{BE}(\text{on}) = 0.7$ V

$I_{CQ} = 0.75$ mA

Then $r_0 = \frac{125}{0.75} = 167 \text{ k}\Omega$
$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{(100)(0.026)}{0.75} \Rightarrow r_\pi = 3.47 \text{ k}\Omega$$
$$I_{BQ} = \frac{V_{TH} - V_{BE}(\text{on}) - (-5)}{R_{TH} + (1+\beta)R_E}$$
$$I_{CQ} = \beta I_{BQ}$$



$$Z_i = r_\pi + (1+\beta)[R_E \| R_L \| r_o]$$
$$I_o = \left(\frac{R_E\|r_o}{R_E\|r_o + R_L}\right)(1+\beta)I_b$$
$$I_b = \left(\frac{R_1\|R_2}{R_1\|R_2 + Z_i}\right)I_S$$
$$A_I = \frac{I_o}{I_S}$$
$$= \left(\frac{R_E\|r_o}{R_E\|r_o + R_L}\right)(1+\beta)\left(\frac{R_1\|R_2}{R_1\|R_2 + Z_i}\right)$$

Assume that $R_E \| r_o \approx R_E$

$$R_1\|R_2 = (0.1)(1+\beta)R_E$$
$$= (0.1)(101)R_E = 10.1R_E$$

Assume $R_L = 1\text{ k}\Omega$

Then

$$A_I = 15 = \left(\frac{R_E}{R_E+1}\right)(101)\times \left(\frac{10.1R_E}{10.1R_E + 3.47 + (101)[R_E\|1\text{ k}\Omega]}\right)$$

where $R_E\|R_L\|r_o \approx R_E\|R_L = R_E\|1\text{ k}\Omega$

$$15 = \frac{(101)(10.1)R_E^2}{R_E+1}\times \frac{1}{\left[10.1R_E + 3.47 + \dfrac{101R_E}{1+R_E}\right]}$$
$$15 = \frac{(101)(10.1)R_E^2}{R_E+1}\times \frac{1}{\dfrac{(1+R_E)[10.1R_E+3.47]+101R_E}{1+R_E}}$$
$$15 = \frac{(101)(10.1)R_E^2}{10.1R_E + 3.47 + 10.1R_E^2 + 3.47R_E + 101R_E}$$
$$15 = \frac{(101)(10.1)R_E^2}{10.1R_E^2 + 114.57R_E + 3.47}$$

$$(101)(10.1)R_E^2 = 15[10.1R_E^2 + 114.57R_E + 3.47]$$
$$1020.1R_E^2 = 151.5R_E^2 + 1718.55R_E + 52.05$$
$$868.6R_E^2 - 1718.55R_E - 52.05 = 0$$
$$16.7R_E^2 - 33.0R_E - 1 = 0$$
$$R_E = \frac{33 \pm \sqrt{(33)^2 + 4(16.7)}}{2(16.7)}$$

Must use + sign $\Rightarrow$ $\underline{R_E = 2.0\text{ k}\Omega}$

Then $R_1\|R_2 = 10.1R_E = 20.2\text{ k}\Omega$

$$V_{TH} = \left(\frac{R_2}{R_1+R_2}\right)(10) - 5$$
$$= \frac{1}{R_1}\left(\frac{R_1R_2}{R_1+R_2}\right)(10) - 5$$
$$= \frac{1}{R_1}(20.2)(10) - 5$$
$$I_{CQ} = 0.75$$
$$= (100)\left\{\frac{\frac{1}{R_1}(20.2)(10) - 5 - 0.7 + 5}{20.2 + (101)(2)}\right\}$$
$$1.67 = \frac{1}{R_1}(202) - 0.7 \Rightarrow \underline{R_1 = 85.2\text{ k}\Omega}$$
$$\frac{R_1R_2}{R_1+R_2} = 20.2 = \frac{85.2R_2}{85.2+R_2} \Rightarrow \underline{R_2 = 26.5\text{ k}\Omega}$$

E4.20

a. $\beta = 100$, $V_{BE}(\text{on}) = 0.7$, $I_{CQ} = 1.25$ mA

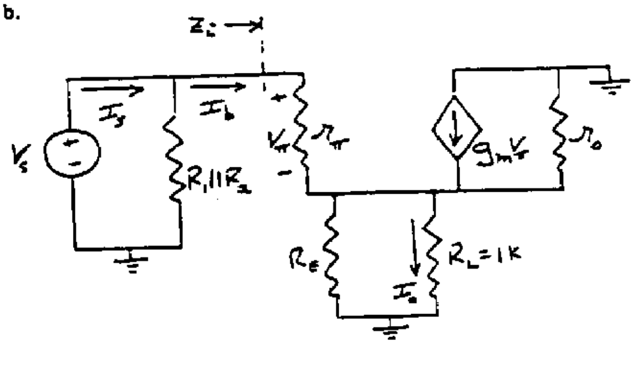
$I_{EQ} = 1.26$ mA, $I_{BQ} = 0.0125$ mA

$$V_{TH} = \left(\frac{R_2}{R_1+R_2}\right)(10) - 5$$
$$V_{TH} = \frac{1}{R_1}(R_1\|R_2)(10) - 5$$
$$I_{BQ} = \frac{V_{TH} - 0.7 - (-5)}{R_{TH} + (1+\beta)R_E}$$
$$V_{CEQ} = 10 - I_{EQ}R_E = 4$$
$$I_{EQ}R_E = 6 \Rightarrow I_{EQ} = \frac{6}{R_E} \Rightarrow R_E = \frac{6}{1.26} = 4.76\text{ k}\Omega$$
$$\Rightarrow \underline{R_E = 4.76\text{ k}\Omega}$$
$$R_{TH} = (0.1)(1+\beta)R_E = 10.1R_E$$

Then

$$I_{BQ} = \frac{I_{EQ}}{101} = \frac{\frac{1}{R_1}(101)R_E(10) - 5 - 0.7 + 5}{10.1R_E + (101)R_E}$$
$$0.0125 = \frac{\frac{1}{R_1}(101)(4.76) - 0.7}{(111.1)(4.76)} \Rightarrow \underline{R_1 = 65.8\text{ k}\Omega}$$
$$\frac{R_1R_2}{R_1+R_2} = (10.1)R_E = (10.1)(4.76) = 48.1\text{ k}\Omega$$
$$(65.8)R_2 = (48.1)(65.8) + (48.1)R_2$$
$$(65.8 - 48.1)R_2 = (48.1)(65.8)$$
$$\Rightarrow \underline{R_2 = 178.8\text{ k}\Omega}$$

b.



$$r_0 = \frac{V_A}{I_{CQ}} = \frac{125}{1.25} = 100\text{ k}\Omega$$
$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{(100)(0.026)}{1.25} = 2.08\text{ k}\Omega$$
$$g_m V_\pi = g_m(i_b r_\pi) = \beta I_b$$
$$Z_i = r_\pi + (1+\beta)[R_E \| R_L \| r_0]$$
$$= 2.08 + (101)[4.76\|1\|100]$$
$$= 2.08 + (101)[0.826\|100]$$
$$= 2.08 + (101)(0.819)$$
$$Z_i = 84.8\text{ k}\Omega$$

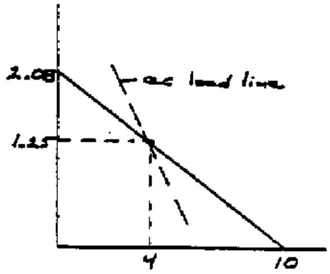
Assume $R_L = 1\text{ k}\Omega$

$$I_0 = \left(\frac{R_E\|r_0}{R_E\|r_0 + R_L}\right)(1+\beta)I_b$$
$$I_b = \left(\frac{R_1\|R_2}{R_1\|R_2 + Z_i}\right)I_S$$
$$A_I = \frac{I_0}{I_S} = \left(\frac{R_E\|r_0}{R_E\|r_0 + R_L}\right)(1+\beta)\left(\frac{R_1\|R_2}{R_1\|R_2 + Z_i}\right)$$
$$R_E\|r_0 = 4.76\|100 = 4.54$$
$$A_I = \left(\frac{4.54}{4.54+1}\right)(101)\left(\frac{48.1}{48.1+84.8}\right)$$
$$= \left(\frac{4.54}{5.54}\right)(101)\left(\frac{48.1}{132.9}\right)$$
$$\Rightarrow \underline{A_I = 30.0}$$

c. $R_0 = \dfrac{r_\pi}{1+\beta}\,\Big\|\, R_E \,\Big\|\, r_0 = \dfrac{2.08}{101}\,\Big\|\, 4.76 \,\Big\|\, 100$

$\Rightarrow R_0 = 20.4\ \Omega$

d.



$$v_0 = v_{ce} = (1+\beta)i_b(R_E\|R_L\|r_0)$$
$$i_b = \frac{i_C}{\beta}$$
$$v_{ce} = i_C\left(\frac{1+\beta}{\beta}\right)(R_E\|R_L\|r_0)$$
$$= i_C\left(\frac{101}{100}\right)(4.76\|1\|100)$$
$$= i_C(0.828)$$

If $\Delta i_C = 1.25$ mA, $\rightarrow \Delta v_{ce} = 1.035$ V

Maximum symmetrical swing in output voltage is $= 2\Delta v_{ce} = \underline{2.07\text{ V peak-to-peak}}$

E4.21

For $\beta = 130$

$$I_{BQ} = \frac{10-0.7}{100+(131)(10)} \Rightarrow 6.596\ \mu\text{A}$$
$$I_{CQ} = 0.857\text{ mA}$$

From Figure 4.21

$$3 < h_{ie} < 5\text{ k}\Omega \qquad \text{Let } h_{re} = 0$$
$$98 < h_{fe} < 170$$
$$8 < h_{oe} < 16\ \mu\text{S}$$
$$h_{ie} = 4\text{ k}\Omega$$
$$h_{fe} = 134$$
$$h_{oe} = 12\ \mu\text{S} \Rightarrow \frac{1}{h_{oe}} = 83.3\text{ k}\Omega$$

a. $R_S = R_L = 10\text{ k}\Omega$

$$R_{ib} = h_{ie} + (1+h_{fe})\left(R_E \,\Big\|\, R_L \,\Big\|\, \frac{1}{h_{oe}}\right)$$
$$= 4 + (135)(10\|10\|83.3)$$
$$\Rightarrow \underline{R_{ib} = 641\text{ k}\Omega}$$
$$A_v = \left(\frac{R_B\|R_{ib}}{R_S + R_B\|R_{ib}}\right) \times \left(\frac{(1+h_{fe})\left(R_E \,\|\, R_L \,\|\, \frac{1}{h_{oe}}\right)}{h_{ie} + (1+h_{fe})\left(R_E \,\|\, R_L \,\|\, \frac{1}{h_{oe}}\right)}\right)$$
$$A_v = \left(\frac{100\|641}{10+100\|641}\right)\left[\frac{(135)(10\|10\|83.3)}{4+(135)(10\|10\|83.3)}\right]$$
$$= \left(\frac{86.5}{10+86.5}\right)\left[\frac{637}{641}\right]$$
$$\Rightarrow \underline{A_v = 0.891}$$
$$A_i = \left(\frac{R_E \,\|\, \frac{1}{h_{oe}}}{R_E \,\|\, \frac{1}{h_{oe}} + R_L}\right)(1+h_{fe})\left(\frac{R_B}{R_B + R_{ib}}\right)$$
$$= \left(\frac{10\|83.3}{10\|83.3+10}\right)(135)\left(\frac{100}{100+641}\right)$$
$$\Rightarrow \underline{A_i = 8.59}$$
$$R_0 = R_E \,\Big\|\, \frac{1}{h_{oe}} \,\Big\|\, \frac{h_{ie} + R_S\|R_B}{1+h_{fe}}$$
$$= 10 \,\Big\|\, 83.3 \,\Big\|\, \frac{4+10\|100}{135} = 8.93\|0.0970$$
$$\Rightarrow \underline{R_0 = 96.0\ \Omega}$$

b. $R_S = 1\text{ k}\Omega$, $\underline{R_{ib} = 641\text{ k}\Omega}$, $\underline{A_i = 8.59}$

$$A_v = \left(\frac{86.5}{1+86.5}\right)\left(\frac{637}{641}\right) \Rightarrow \underline{A_v = 0.982}$$
$$R_0 = 10 \,\Big\|\, 8.33 \,\Big\|\, \left[\frac{4+1\|100}{135}\right]$$
$$= 8.93\|0.03696 \Rightarrow \underline{R_0 = 36.8\ \Omega}$$

E4.22

$V_{TH} = 2.5V,\ R_{TH} = 25\ k\Omega$

$I_{BQ} = \dfrac{5 - 0.7 - 2.5}{25 + (101)(2)} = \dfrac{1.8}{227} = 0.00793\ \text{mA}$

$I_{CQ} = 0.793\ \text{mA}$

$g_m = \dfrac{I_{CQ}}{V_T} = \dfrac{0.793}{0.026} = 30.5\ \text{mA/V}$

$r_\pi = \dfrac{V_T\beta}{I_{CQ}} = \dfrac{(0.0026)(100)}{0.793} = 3.28\ \text{k}\Omega$

$r_0 = \dfrac{V_A}{I_{CQ}} = \dfrac{125}{0.793} = 158\ \text{k}\Omega$

a. $R_E \| R_L \| r_0 = 2\|0.5\|158 = 0.4\|158 \approx 0.4$

$$A_v = \frac{(1+\beta)(R_E\|R_L\|r_0)}{r_\pi + (1+\beta)(R_E\|R_L\|r_0)}$$
$$= \frac{(101)(0.4)}{3.28 + (101)(0.4)} \Rightarrow \underline{A_v = 0.925}$$

b. $R_{ib} = r_\pi + (1+\beta)(R_E\|R_L\|r_0)$

$R_{ib} = 3.28 + (101)(0.4)$

$\Rightarrow \underline{R_{ib} = 43.7\ \text{k}\Omega}$

$R_0 = \dfrac{r_\pi}{1+\beta} \,\Big\|\, R_E \,\Big\|\, r_0 = \dfrac{3.28}{101} \,\Big\|\, 2 \,\Big\|\, 98.3$

$\Rightarrow \underline{R_0 = 32.0\ \Omega}$

c. $I_B(\max) \to$

$R_E(\min) = 1.9\ \text{k}\Omega$

$R_2(\min) = 47.5\ \text{k}\Omega$

$R_1(\max) = 52.5\ \text{k}\Omega$

$R_{TH} = 24.9\ \text{k}\Omega$

$V_{TH} = \left(\dfrac{R_2}{R_1+R_2}\right)V_{CC} = \left(\dfrac{47.5}{100}\right)(5) = 2.375$

$I_{BQ} = \dfrac{5 - 0.7 - 2.375}{24.9 + (101)(1.9)} = \dfrac{1.925}{216.8}$

$I_{CQ} = 0.888\ \text{mA}$

$R_E(\max) = 2.1\ \text{k}\Omega$

$R_2(\max) = 52.5\ \text{k}\Omega$

$R_1(\min) = 47.5\ \text{k}\Omega$

$R_{TH} = 24.9\ \text{k}\Omega$

$V_{TH} = \left(\dfrac{52.5}{100}\right)(5) = 2.625$

$I_{CQ} = (100)\left[\dfrac{5 - 0.7 - 2.625}{24.9 + (101)(2.1)}\right] = \dfrac{(100)(1.675)}{237}$

$I_{CQ} = 0.707\ \text{mA}$

$r_\pi(\max) = \dfrac{(100)(0.026)}{0.707} = 3.68\ \text{k}\Omega$

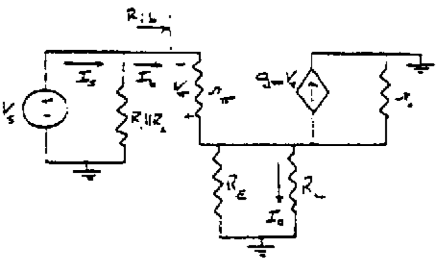
$R_0 = 1.96 \,\Big\|\, \dfrac{3.68}{101} = 1.96\|0.0364 = 35.7\ \Omega$

$r_\pi(\min) = 2.93\ \text{k}\Omega$

$R_0 = 1.96 \,\Big\|\, \dfrac{2.93}{101} = 1.96\|0.0290 = 28.6\ \Omega$

$\Rightarrow \underline{28.6 \le R_0 \le 35.7\ \Omega}$

E4.23



For $V_{ECQ} = 2.5$ V,

$I_{EQ} = \dfrac{5 - 2.5}{R_E} = \dfrac{5 - 2.5}{0.5} = 5\ \text{mA}$

$I_{CQ} = \left(\dfrac{75}{76}\right)(5) = 4.93\ \text{mA} \Rightarrow I_{BQ} = 0.0658\ \text{mA}$

$V_\pi = -I_b r_\pi$

$r_\pi = \dfrac{\beta V_T}{I_{CQ}} = \dfrac{(75)(0.026)}{4.93} = 0.396\ \text{k}\Omega$

$r_0 = \dfrac{V_A}{I_{CQ}} = \dfrac{75}{4.93} = 15.2\ \text{k}\Omega$

$g_m V_\pi = g_m(-I_b r_\pi) = -\beta I_b$

$I_0 = \left(\dfrac{R_E\|r_0}{R_E\|r_0 + R_L}\right) \times (1+\beta) I_b$

$I_b = \left(\dfrac{R_1\|R_2}{R_1\|R_2 + Z_{ib}}\right) I_S$

$A_I = \dfrac{I_0}{I_S} = \left(\dfrac{R_E\|r_0}{R_E\|r_0 + R_L}\right)(1+\beta)\left(\dfrac{R_1\|R_2}{R_1\|R_2 + Z_{ib}}\right)$

a. $R_E = R_L = 0.5\ \text{k}\Omega$

$R_{ib} = r_\pi + (1+\beta)(R_E\|R_L\|r_0)$

$= 0.396 + (76)[0.5\|0.5\|15.2]$

$= 0.396 + (76)(0.246)$

$\Rightarrow R_{ib} = 19.1\ \text{k}\Omega$

$R_E\|r_0 = 0.5\|15.2 = 0.484\ \text{k}\Omega$

$A_I = 10 = \left(\dfrac{0.484}{0.484 + 0.5}\right)(76)\left(\dfrac{R_1\|R_2}{R_1\|R_2 + 19.1}\right)$

$10 = 37.38\left(\dfrac{R_1\|R_2}{R_1\|R_2 + 19.1}\right)$

$0.2675(R_1\|R_2 + 19.1) = R_1\|R_2$

$R_1\|R_2 = 6.975\ \text{k}\Omega$

$V_{TH} = \left(\dfrac{R_2}{R_1+R_2}\right)V_{CC} = \dfrac{1}{R_1}(R_1\|R_2)V_{CC}$

$= \dfrac{1}{R_1}(6.975)(5)$

$$I_{BQ} = \frac{5 - V_{EB}(\text{on}) - V_{TH}}{R_{TH} + (1+\beta)R_E}$$

$$0.0658 = \frac{5 - 0.7 - V_{TH}}{6.975 + (76)(0.5)}$$

$$2.96 = 4.3 - V_{TH} \Rightarrow V_{TH} = 1.34 = \frac{1}{R_1}(6.975)(5)$$

$$\Rightarrow \underline{R_1 = 26.0 \text{ k}\Omega}$$

$$\frac{R_1 R_2}{R_1 + R_2} = 6.975 = \frac{26 R_2}{26 + R_2}$$

$$6.975(26 + R_2) = 26 R_2$$

$$\Rightarrow \underline{R_2 = 9.53 \text{ k}\Omega}$$

b. For $R_E = 4R_L = 4(0.5) \Rightarrow R_E = 2$ kΩ

$$I_{EQ} = \frac{5 - 2.5}{2} = 1.25 \text{ mA} \rightarrow I_{CQ} = 1.23 \text{ mA}$$

$$\rightarrow I_{BQ} = 0.0164 \text{ mA}$$

$$r_\pi = \frac{(75)(0.026)}{1.23} = 1.59 \text{ k}\Omega$$

$$r_0 = \frac{75}{1.23} = 60.9 \text{ k}\Omega$$

$$Z_{ib} = r_\pi + (1+\beta)[R_E \| R_L \| r_0]$$

$$= 1.59 + (76)[2\|0.5\|60.9]$$

$$\Rightarrow Z_{ib} = 31.8 \text{ k}\Omega$$

$$R_E \| r_0 = 2\|60.9 = 1.94 \text{ k}\Omega$$

$$A_I = \left(\frac{1.94}{1.94 + 0.5}\right)(76)\left(\frac{R_1\|R_2}{R_1\|R_2 + 31.8}\right) = 10$$

$$10 = 60.4\left(\frac{R_1\|R_2}{R_1\|R_2 + 31.8}\right)$$

$$0.166(R_1\|R_2 + 31.8) = R_1\|R_2$$

$$R_1\|R_2 = 6.33 \text{ k}\Omega$$

Then $I_{BQ} = 0.0164 = \dfrac{4.3 - V_{TH}}{6.33 + (76)(2)}$

$$V_{TH} = 1.70 = \frac{1}{R_1}(R_1\|R_2)V_{CC} = \frac{1}{R_1}(6.33)(5)$$

$$\Rightarrow \underline{R_1 = 18.6 \text{ k}\Omega}$$

$$\frac{R_1 R_2}{R_1 + R_2} = 6.33 = \frac{(18.6)R_2}{18.6 + R_2}$$

$$6.33(18.6 + R_2) = (18.6)R_2$$

$$\Rightarrow \underline{R_2 = 9.6 \text{ k}\Omega}$$

E4.24

a. $I_{EQ} = \dfrac{10 - 0.7}{10} = 0.93$ mA

$$I_{CQ} = \left(\frac{\beta}{1+\beta}\right)I_{EQ} = \left(\frac{100}{101}\right)(0.93)$$

$$\Rightarrow \underline{I_{CQ} = 0.921 \text{ mA}}$$

$$V_{ECQ} = 10 + 10 - I_{CQ}R_C - I_{EQ}R_E$$

$$V_{ECQ} = 20 - (0.921)(5) - (0.93)(10)$$

$$\Rightarrow \underline{V_{ECQ} = 6.1 \text{ V}}$$

b. $r_\pi = \dfrac{\beta V_T}{I_{CQ}} = \dfrac{(100)(0.026)}{0.921} = 2.82$ kΩ

$$g_m = \frac{I_{CQ}}{V_T} = \frac{0.921}{0.026} = 35.42 \text{ mA/V}$$

$i_0 = g_m V_\pi$ and $V_\pi = v_S$

$$i_i = \frac{v_S}{R_E\|r_\pi} + g_m V_\pi = v_S\left(\frac{1}{R_E\|r_\pi} + g_m\right)$$

$$A_I = \frac{i_0}{i_i} = \frac{g_m v_S}{v_S\left(\frac{1}{R_E\|r_\pi} + g_m\right)} = \frac{g_m(R_E\|r_\pi)}{1 + g_m(R_E\|r_\pi)}$$

$$= \frac{(35.42)(10 \text{ k}\Omega\|2.82 \text{ k}\Omega)}{1 + (35.42)(10 \text{ k}\Omega\|2.82 \text{ k}\Omega)}$$

$$\Rightarrow \underline{A_I = 0.987}$$

$A_v = \dfrac{v_0}{v_S}$ and $v_0 = g_m V_\pi R_C = g_m v_S R_C$

$$A_v = g_m R_C = (35.42)(5) \Rightarrow \underline{A_v = 177.1}$$

c. $V_{ECQ} = 6.1$ V $\Rightarrow V_{ECQ} = V_E - V_C$

$$V_C = V_E - V_{ECQ} = 0.7 - 6.1 = -5.4 \text{ V}$$

$$v_C = V_C + i_0 R_C$$

For $v_{EC} = 0.5 \Rightarrow v_C = +0.2$

$$+0.2 = -5.4 + i_0 R_C$$

$$i_0 = \frac{0.2 + 5.4}{5} = 1.12 \text{ mA}$$

$\Rightarrow$ Current limited

$i_0(\text{max}) = 0.921$

$\Rightarrow v_0(\text{peak}) = (0.921)(5) = 4.61$

$\Rightarrow$ $\underline{9.21 \text{ V}}$ peak-to-peak

E4.25

a. $I_{BQ} = \dfrac{V_{EE} - V_{BE}(\text{on})}{R_B + (1+\beta)R_E} = \dfrac{10 - 0.7}{100 + (101)(10)}$

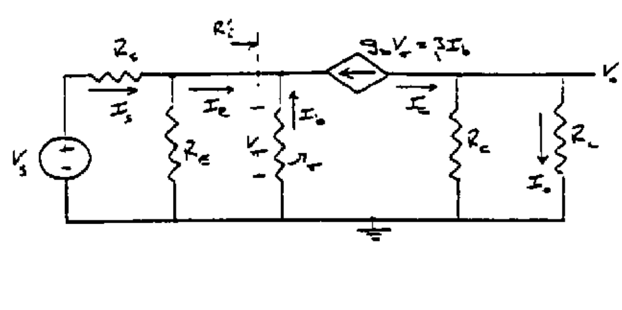
$$\Rightarrow I_{BQ} = 8.38\ \mu\text{A}, \quad I_{CQ} = 0.838 \text{ mA}$$

$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{(100)(0.026)}{0.838} \Rightarrow \underline{r_\pi = 3.10 \text{ k}\Omega}$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{0.838}{0.026} \Rightarrow \underline{g_m = 32.23 \text{ mA/V}}$$

$$r_0 = \frac{V_A}{I_{CQ}} = \frac{\infty}{0.838} \Rightarrow \underline{r_0 = \infty}$$

b.



$$g_m V_\pi + \frac{V_\pi}{r_\pi} = \left(\frac{-V_\pi}{R_E}\right) + \frac{(-V_\pi - V_S)}{R_S}$$

$$V_\pi\left[\left(\frac{1+\beta}{r_\pi}\right) + \frac{1}{R_E} + \frac{1}{R_S}\right] = -\frac{V_S}{R_S}$$

$$V_\pi = -\frac{V_S}{R_S}\left[\left(\frac{1+\beta}{r_\pi}\right) \| R_E \| R_S\right]$$

$$V_0 = -g_m V_\pi (R_C \| R_L)$$

$$A_v = \frac{V_0}{V_S} = g_m \frac{(R_C \| R_L)}{R_S}\left[\left(\frac{r_\pi}{1+\beta}\right) \| R_E \| R_S\right]$$

$$= \frac{(32.23)[10\|1]}{(1)}\left\{\frac{3.10}{101} \| 10 \| 1\right\}$$

$$= (32.23)(0.909)(0.0297) \Rightarrow \underline{A_v = 0.870}$$

$$R_i' = \frac{r_\pi}{1+\beta} = \frac{3.10}{101} = 0.0307 \text{ k}\Omega$$

$$I_e = \left(\frac{R_E}{R_E + R_i}\right) I_S \approx I_S$$

$$I_C = \left(\frac{\beta}{1+\beta}\right) I_e, \quad I_0 = \left(\frac{R_C}{R_C + R_L}\right) I_C$$

$$I_e = \left(\frac{R_C}{R_C + R_L}\right)\left(\frac{\beta}{1+\beta}\right) I_S$$

$$A_I = \frac{I_0}{I_S} = \left(\frac{10}{10+1}\right)\left(\frac{100}{101}\right) \Rightarrow \underline{A_I = 0.900}$$

c. $R_i = R_E \| R_i' = 10 \| 0.0307$

$\Rightarrow \underline{R_i \approx 30.7\ \Omega}$

$\underline{R_0 = R_C = 10\text{ k}\Omega}$

E4.26

$$5 = I_B R_B + V_{BE}(\text{on}) + I_E R_E$$

$$I_B = \frac{5 - 0.7}{R_B + (101)R_E} = \frac{4.3}{R_B + (101)R_E}$$

$$I_C = \frac{(100)(4.3)}{R_B + (101)R_E}$$

$$5 = I_C R_C + V_{CE} + I_E R_E - 5$$

$$V_{CE} = 10 - I_C\left(R_C + \left(\frac{101}{100}\right) R_E\right)$$

ac analysis

$$V_0 = -g_m V_\pi (R_C \| R_L)$$

$$V_S = -V_\pi - \frac{V_\pi}{r_\pi} \cdot R_B = -V_\pi\left(1 + \frac{R_B}{r_\pi}\right)$$

or $V_\pi = -\left(\dfrac{r_\pi}{r_\pi + R_B}\right) V_S$

$$\frac{V_0}{V_S} = -g_m\left[-\left(\frac{r_\pi}{r_\pi + R_B}\right)\right](R_C \| R_L)$$

$$A_v = \frac{V_0}{V_S} = \frac{\beta}{r_\pi + R_B}(R_C \| R_L)$$

For $I_C = 1$ mA,

$$r_\pi = \frac{\beta V_T}{I_C} = \frac{(100)(0.026)}{1} = 2.6 \text{ k}\Omega$$

$$A_v = 20 = \frac{(100)(1)}{2.6 + R_B}$$

$$R_B = \frac{(100)(1)}{20} - 2.6 \Rightarrow \underline{R_B = 2.4 \text{ k}\Omega}$$

$$I_C = 1 = \frac{(100)(4.3)}{2.4 + (101)R_E}$$

$$R_E = \frac{\frac{(100)(4.3)}{1} - 2.4}{(101)} \Rightarrow R_E = 4.23 \text{ k}\Omega$$

E4.27

a. $R_{TH} = 70\|6 = 5.526$ kΩ

$$V_{TH} = \left(\frac{6}{6+70}\right)(10) - 5 = -4.21 \text{ V}$$

$$I_{B1} = \frac{5 - 4.21 - 0.70}{5.526 + (126)(0.2)} = \frac{0.090}{30.726}$$

$\Rightarrow I_{B1} = 2.93\ \mu$A. $\underline{I_{CQ1} = 0.366 \text{ mA}}$

$$\frac{5 - V_{C1}}{5} = I_{C1} + \frac{(V_{C1} - 0.7) - (-5)}{(1+\beta)1.5}$$

$$\frac{6 - V_{C1}}{5} = 0.366 + \frac{V_{C1}}{(126)(1.5)} + \frac{4.3}{(126)(1.5)}$$

$$1 - 0.366 - \frac{4.3}{(126)(1.5)} = \frac{V_{C1}}{5} + \frac{V_{C1}}{(126)(1.5)}$$

$$0.6112 = V_{C1}(0.2053) \Rightarrow V_{C1} = 2.977 \text{ V}$$

$$I_{E1} = 0.369 \text{ mA}$$

$$V_{E1} = (0.369)(0.2) - 5 \Rightarrow V_{E1} = -4.926 \text{ V}$$

$$\Rightarrow V_{CE1} = V_{C1} - V_{E1} = 2.977 - (-4.926)$$

$$\Rightarrow \underline{V_{CE1} = 7.90 \text{ V}}$$

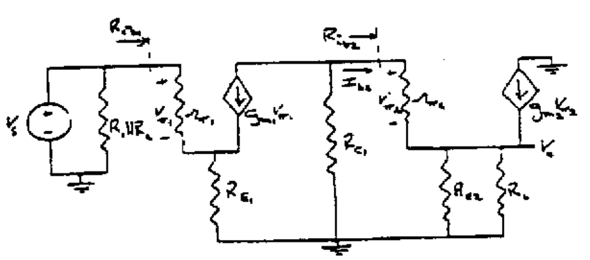
$$I_{EQ2} = \frac{(V_{C1} - 0.7) - (-5)}{1.5} = \frac{5 + 2.98 - 0.7}{1.5}$$

$$= 4.85 \text{ mA}$$

$$I_{CQ2} = \left(\frac{\beta}{1+\beta}\right) I_{EQ2} \Rightarrow \underline{I_{CQ2} = 4.81 \text{ mA}}$$

$$V_{E2} = V_{C1} - 0.7 = 2.98 - 0.7 = 2.28$$

$$V_{CEQ2} = 5 - V_{E2} = 5 - 2.28 \Rightarrow \underline{V_{CEQ2} = 2.72 \text{ V}}$$



$$r_{\pi1} = \frac{\beta V_T}{I_{CQ1}} = \frac{(125)(0.026)}{0.366} = 8.88 \text{ k}\Omega$$

$$r_{\pi2} = \frac{\beta V_T}{I_{CQ2}} = \frac{(125)(0.026)}{4.81} = 0.676 \text{ k}\Omega$$

$$g_{m1} = \frac{I_{CQ1}}{V_T} = \frac{0.366}{0.026} = 14.1 \text{ mA/V}$$

$$g_{m2} = \frac{I_{CQ2}}{V_T} = \frac{4.81}{0.026} = 185 \text{ mA/V}$$

$$R_{ib1} = r_{\pi 1} + (1+\beta)R_{E1} = 8.88 + (126)(0.2)$$
$$= 34.08 \text{ k}\Omega$$
$$R_{ib2} = r_{\pi 2} + (1+\beta)(R_{E2}\|R_L)$$
$$= 0.676 + (126)(1.5\|10) = 165 \text{ k}\Omega$$

$$V_0 = (1+\beta)I_{b2}(R_{E2}\|R_L)$$
$$I_{b2} = \left(\frac{R_{C1}}{R_{C1}+R_{ib2}}\right)(-g_{m1}V_{\pi 1})$$
$$V_{\pi 1} = \frac{V_S}{Z_1}\cdot r_{\pi 1}$$
$$A_v = (1+\beta)(R_{E2}\|R_L)\left(\frac{R_{C1}}{R_{C1}+R_{ib2}}\right)\left(\frac{-g_{m1}r_{\pi 1}}{R_{ib1}}\right)$$
$$A_v = \frac{V_0}{V_S}$$
$$= -(126)(125)(1.5\|10)\left(\frac{5}{5+165}\right)\left(\frac{1}{34.08}\right)$$
$$= -(126)(125)(1.30)\left(\frac{5}{170}\right)\left(\frac{1}{34.08}\right)$$
$$\underline{A_v = -17.7}$$

c. $R_i = R_1\|R_2\|R_{ib1} = (5.53)\|(34.1)$

$$\Rightarrow \underline{R_i = 4.76 \text{ k}\Omega}$$
$$R_0 = \left(\frac{r_{\pi 2}+R_{C1}}{1+\beta}\right)\Big\| R_{E2} = \left(\frac{0.676+5}{126}\right)\Big\| 1.5$$
$$= 0.0450\|1.5$$
$$\Rightarrow \underline{R_0 = 43.7 \ \Omega}$$

E4.28

a. $I_{CQ2} = \left(\frac{100}{101}\right)(1 \text{ mA}) \Rightarrow I_{CQ2} = 0.990 \text{ mA}$

$$I_{EQ1} = \frac{I_{EQ2}}{1+\beta} = \frac{1}{101} \Rightarrow I_{EQ1} = 0.0099 \text{ mA}$$
$$I_{BQ1} = \frac{I_{EQ1}}{1+\beta} = \frac{0.0099}{101}$$
$$\Rightarrow I_{BQ1} = 0.000098 \text{ mA}, \quad I_{CQ1} = 0.0098 \text{ mA}$$
$$V_{B1} = -I_{BQ1}R_B = -(0.000098)(10)$$
$$= -0.00098 \text{ V} \approx 0$$
$$V_{E1} = -0.7 \text{ V}, \quad V_{E2} = -1.4 \text{ V}$$

$$I_1 = I_{CQ2} + I_{CQ1} = 0.990 + 0.0098$$
$$I_1 \cong 1 \text{ mA} \Rightarrow V_0 = 5 - (1)(4) = 1 \text{ V}$$
$$V_{CEQ2} = 1 - (-1.4) = 2.4$$
$$\Rightarrow \underline{V_{CEQ2} = 2.4 \text{ V}}, \quad I_{CQ2} = 0.990 \text{ mA}$$
$$V_{CEQ1} = 1 - (-0.7) = 1.7$$
$$\Rightarrow \underline{V_{CEQ1} = 1.7 \text{ V}}, \quad I_{CQ1} = 0.0098 \text{ mA}$$

b. $r_\pi = \frac{\beta V_T}{I_{CQ}}$ and $g_m = \frac{I_{CQ}}{V_T}$

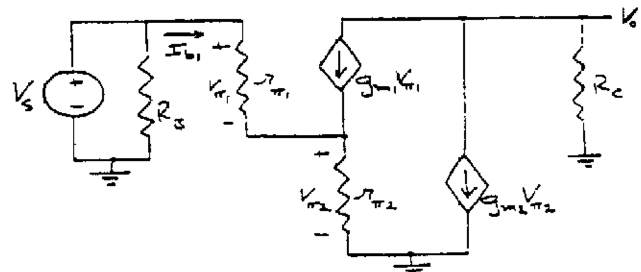
For Q_1 :

$$r_{\pi 1} = \frac{(100)(0.026)}{0.0098} \Rightarrow r_{\pi 1} = 265 \text{ k}\Omega$$
$$g_{m1} = \frac{0.0098}{0.026} \Rightarrow g_{m1} = 0.377 \text{ mA/V}$$

For Q_2 :

$$r_{\pi 2} = \frac{(100)(0.026)}{0.990} \Rightarrow r_{\pi 2} = 2.63 \text{ k}\Omega$$
$$g_{m2} = \frac{0.99}{0.026} \Rightarrow g_{m2} = 38.1 \text{ mA/V}$$
$$r_{01} = r_{02} = \infty$$

c.



$$V_0 = -(g_{m1}V_{\pi 1} + g_{m2}V_{\pi 2})R_C$$
$$V_S = V_{\pi 1} + V_{\pi 2}$$
$$V_{\pi 2} = \left(\frac{V_{\pi 1}}{r_{\pi 1}} + g_{m1}V_{\pi 1}\right)r_{\pi 2} = \frac{(1+\beta)}{r_{\pi 1}}V_{\pi 1}r_{\pi 2}$$

Then

$$V_0 = -\left[g_{m1}V_{\pi 1} + g_{m2}\left(\frac{(1+\beta)r_{\pi 2}}{r_{\pi 1}}\right)V_{\pi 1}\right]\cdot R_C$$

Also

$$V_S = V_{\pi 1} + \left(\frac{1+\beta}{r_{\pi 1}}\right)V_{\pi 1}r_{\pi 2}$$
$$= V_{\pi 1}\left[1 + (1+\beta)\left(\frac{r_{\pi 2}}{r_{\pi 1}}\right)\right]$$
$$V_{\pi 1} = \frac{V_S}{1+(1+\beta)\left(\frac{r_{\pi 2}}{r_{\pi 1}}\right)}$$
$$V_0 = -\left[g_{m1} + g_{m2}(1+\beta)\left(\frac{r_{\pi 2}}{r_{\pi 1}}\right)\right]R_C$$
$$+ \frac{V_S}{1+(1+\beta)\left(\frac{r_{\pi 2}}{r_{\pi 1}}\right)}$$

$$A_v = -\frac{\left[g_{m1} + g_{m2}(1+\beta)\left(\frac{r_{\pi 2}}{r_{\pi 1}}\right)\right]R_C}{1+(1+\beta)\left(\frac{r_{\pi 2}}{r_{\pi 1}}\right)}$$

$$A_v = -\frac{\left[0.377 + (38.08)(101)\left(\frac{2.626}{265.3}\right)\right](4)}{1+(101)\left(\frac{2.626}{265.3}\right)}$$

$$A_v = -\frac{153.8}{1.9997} \Rightarrow \underline{A_v = -76.9}$$

d. $R_i = r_{\pi 1} + (1+\beta)r_{\pi 2}$

$R_i = 265.3 + (101)(2.626)$

$\Rightarrow \underline{R_i = 531\text{ k}\Omega}$

E4.29

a. $I_{E1} = \dfrac{V_{E1} - (-10)}{20} + \dfrac{(V_{E1} - 0.7) - (-10)}{(1+\beta)(10)}$

$-I_{B1}R_B - V_{BE}(\text{on}) = V_{E1}$

So

$$(1+\beta)I_{B1} = \frac{10 - I_{B1}R_B - 0.7}{20} + \frac{10 - 0.7 - I_{B1}R_B - 0.7}{(101)(10)}$$

$$(101)I_{B1} + I_{B1}\left(\frac{20}{20}\right) + I_{B1}\cdot\frac{20}{(101)(10)} = \frac{9.3}{20} + \frac{8.6}{(101)(10)}$$

$(102)I_{B1} = 0.465 + 0.00851$

$I_{B1} = 0.00464\text{ mA} \Rightarrow V_{B1} = -0.09281$

$\Rightarrow V_{E1} = -0.793\text{ V} \Rightarrow V_{E2} = -1.493\text{ V}$

$I_{C1} = 0.464\text{ mA},\ I_{E1} = 0.469\text{ mA}$

$I_1 = \dfrac{10 - 0.793}{20} = 0.46035\text{ mA}$

$\Rightarrow I_{B2} = I_{E1} - I_1$

$I_{B2} = 0.00865\text{ mA} \Rightarrow I_{C2} = 0.865\text{ mA}$

or $I_{E2} = \dfrac{10 - 1.493}{10} = 0.851 \Rightarrow I_{C2} = 0.842\text{ mA}$

$I_C = I_{C1} + I_{C2} = 0.464 + 0.842$

$= 1.306\text{ mA}$

$V_0 = 10 - (1.306)(2) = 7.39\text{ V}$

$V_{CEQ2} = 7.39 - (-1.493)$

$\Rightarrow \underline{V_{CEQ2} = 8.88\text{ V}},\ \underline{I_{CQ2} = 0.842\text{ mA}}$

$V_{CEQ1} = 7.39 - (-0.793)$

$\Rightarrow \underline{V_{CEQ1} = 8.18\text{ V}},\ \underline{I_{CQ1} = 0.464\text{ mA}}$

b. $r_\pi = \dfrac{\beta V_T}{I_{CQ}},\quad g_m = \dfrac{I_{CQ}}{V_T}$

For Q_1:

$r_{\pi 1} = \dfrac{(100)(0.026)}{0.464} \Rightarrow r_{\pi 1} = 5.60\text{ k}\Omega$

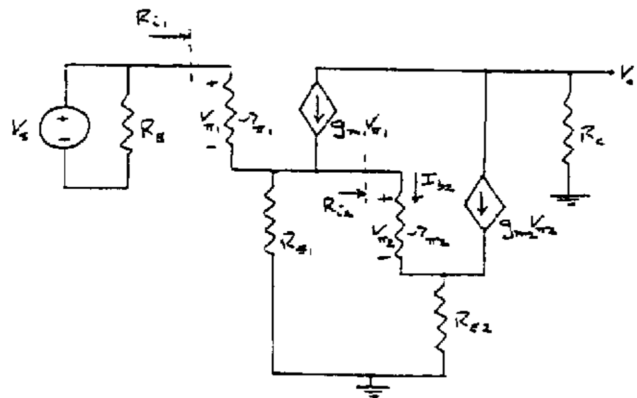
$g_{m1} = \dfrac{0.464}{0.026} \Rightarrow g_{m1} = 17.8\text{ mA/V}$

$r_{\pi 2} = \dfrac{(100)(0.026)}{0.842} \Rightarrow r_{\pi 2} = 3.09\text{ k}\Omega$

$g_{m2} = \dfrac{0.842}{0.026} \Rightarrow g_{m2} = 32.4\text{ mA/V}$

$r_{01} = r_{02} = \infty$

c.



$R_{i2} = r_{\pi 2} + (1+\beta)R_{E2} = 3.09 + (101)(10)$

$= 1013.1\text{ k}\Omega$

$R_{i1} = r_{\pi 1} + (1+\beta)[R_{E1}\|R_{i2}]$

$= 5.60 + (101)[20\|1013.1]$

d. $\underline{R_{i1} = 1.986\text{ M}\Omega}$

Note that $g_{m1}V_{\pi 1} = \beta I_{b1}$ and $g_{m2}V_{\pi 2} = \beta I_{b2}$

So $V_0 = -[\beta I_{b1} + \beta I_{b2}]R_C$

$I_{b1} = \dfrac{V_S}{R_{i1}}$ and $I_{b2} = \left(\dfrac{R_{E1}}{R_{E1} + R_{i2}}\right)(1+\beta)I_{b1}$

So

$$V_0 = -[I_{b1} + I_{b2}]\beta R_C$$

$$= -\left\{I_{b1} + \left(\frac{R_{E1}}{R_{E1} + R_{i2}}\right)(1+\beta)I_{b1}\right\}\beta R_C$$

$$A_v = \frac{V_0}{V_S} = -\left[1 + \left(\frac{R_{E1}}{R_{E1} + R_{i2}}\right)(1+\beta)\right]\frac{\beta R_C}{R_{i1}}$$

$$= -\left[1 + \left(\frac{20}{20 + 1013.1}\right)(101)\right]\frac{(100)(2)}{1986}$$

$\underline{A_v = -0.298}$

E4.30

a. dc analysis

$\beta = 100,\ V_{BE}(\text{on}) = 0.7\text{ V},\ V_A = \infty$

Want: $I_{CQ2} = 0.5\text{ mA},\ V_{CE1} = V_{CE2} = 4\text{ V}$

$R_1 + R_2 + R_3 = 100\text{ k}\Omega$

Neglecting base currents:

$$I_1 = \frac{12}{100} = 0.12 \text{ mA}$$

$$V_{E1} = I_{CQ2}R_E = (0.5)(0.5) = 0.25 \text{ V}$$

$$V_{C1} = V_{CEQ1} + V_{E1} = 4 + 0.25 = 4.25$$

So

$$V_{C2} = V_{C1} + V_{CEQ2} = 4.25 + 4 = 8.25 \text{ V}$$

$$R_C = \frac{V_{CC} - V_{C2}}{I_{CQ}} = \frac{12 - 8.25}{0.5} \Rightarrow \underline{R_C = 7.5 \text{ k}\Omega}$$

$$V_{B1} = V_{E1} + 0.7 = 0.25 + 0.7 = 0.95 \text{ V}$$

$$V_{B1} = \left(\frac{R_3}{R_1 + R_2 + R_3}\right)(12) \Rightarrow 0.95 = \frac{R_3}{100}(12)$$

$$\Rightarrow \underline{R_3 = 7.92 \text{ k}\Omega}$$

$$V_{B2} = V_{C1} + 0.7 = 4.25 + 0.7 = 4.95$$

$$V_{B2} = \left(\frac{R_2 + R_3}{R_1 + R_2 + R_3}\right)(12)$$

$$\Rightarrow 4.95 = \frac{R_2 + 7.92}{100}(12)$$

$$R_2 = \frac{(4.95)(100)}{12} - 7.92 \Rightarrow \underline{R_2 = 33.3 \text{ k}\Omega}$$

$$R_1 = 100 - R_2 - R_3 = 100 - 33.3 - 7.92$$

$$\Rightarrow \underline{R_1 = 58.8 \text{ k}\Omega}$$

b. For both Q_1 and Q_2

$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{(100)(0.026)}{0.5}$$

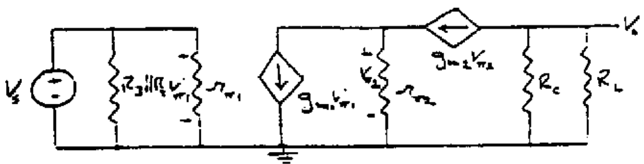
$$\Rightarrow \underline{r_{\pi 1} = r_{\pi 2} = 5.2 \text{ k}\Omega}$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{0.5}{0.026}$$

$$\Rightarrow \underline{g_{m1} = g_{m2} = 19.23 \text{ mA/V}}$$

$$\underline{r_{o1} = r_{o2} = \infty}$$

c.



$$v_0 = -g_{m2}V_{\pi 2}(R_C \| R_L)$$

$$\frac{V_{\pi 2}}{r_{\pi 2}} + g_{m2}V_{\pi 2} = g_{m1}V_{\pi 1}$$

$$V_{\pi 2}\left(\frac{1 + \beta}{r_{\pi 2}}\right) = g_{m1}V_{\pi 1}$$

$$V_{\pi 2} = g_{m1}V_{\pi 1}\left(\frac{r_{\pi 2}}{1 + \beta}\right) \text{ and } V_{\pi 1} = v_S$$

So

$$A_v = \frac{V_0}{V_S} = -g_{m2}(R_C \| R_L) \cdot g_{m1}\left(\frac{r_{\pi 2}}{1 + \beta}\right)$$

$$= -g_{m2}(R_C \| R_L)\left(\frac{\beta}{1 + \beta}\right)$$

$$A_v = -\left(\frac{100}{101}\right)(19.23)(7.5 \| 2) \Rightarrow \underline{A_v = -30.1}$$

E4.31

a. dc analysis

$$\beta = 80, \ V_{BE}(\text{on}) = 0.7, \ V_A = \infty$$

$$I_{BQ} = \frac{2.32 - 0.7}{24.2 + (81)(0.5)} = \frac{1.62}{64.7}$$

$$I_{BQ} = 0.0250 \text{ mA}, \ I_{CQ} = 2.00 \text{ mA}$$

Power dissipated in $R_C = I_{CQ}^2 R_C = (1.0)^2(2)$

$$\Rightarrow \underline{P_C = 8.0 \text{ mW}}$$

Power dissipated in $\underline{R_L = 0}$, $\underline{P_L = 0}$

$$V_{CE} = V_{CC} - I_C\left[R_C + \left(\frac{1 + \beta}{\beta}\right)R_E\right]$$

$$= 12 - 2\left[2 + \left(\frac{81}{80}\right)(0.5)\right]$$

$$V_{CE} = 6.99 \text{ V}$$

$$P_T = I_B V_{BE} + I_C V_{CE} = (0.0259)(0.7) + (2)(6.99)$$

$$\Rightarrow \underline{P_T = 14.0 \text{ mW}}$$

b. $r_\pi = \dfrac{\beta V_T}{I_{CQ}} = \dfrac{(80)(0.026)}{2.0} \Rightarrow r_\pi = 1.04 \text{ k}\Omega$

For $v_s = 18 \cos \omega t$ mV

From the text, power dissipation in the transistor

$$P_T = V_{CEQ}I_{CQ} - \left(\frac{\beta}{r_\pi}\right)^2\left(\frac{V_P}{\sqrt{2}}\right)^2(R_C \| R_L)$$

$$= (6.99)(2 \times 10^{-3})$$

$$- \left(\frac{80}{1.04 \times 10^3}\right)^2\left(\frac{0.018}{\sqrt{2}}\right)^2(2 \times 10^3 \| 2 \times 10^3)$$

$$P_T = (14 - 0.96) \text{ m}\omega \Rightarrow \underline{P_T = 13.0 \text{ mW}}$$

From notes

$$|v_{ce}| = \frac{\beta}{r_\pi}(R_C \| R_L)V_P \cos \omega t$$

Power dissipated in R_L

$$P_L = \frac{|v_{ce}|^2}{R_L}\bigg|_{\text{rms}} = \left[\frac{\beta}{r_\pi}(R_C \| R_L)\right]^2 \times \frac{1}{R_L} \times \frac{V_P^2}{2}$$

$$= \left[\frac{80}{1.04}(1.0)\right]^2 \times \frac{1}{2 \times 10^3} \times \left(\frac{0.018}{2}\right)^2$$

$$\Rightarrow \underline{P_L = 0.479 \text{ mW}}$$

$R_C = 2$ kΩ also so $P_C = 8.0 + 0.479$

$$\Rightarrow \underline{P_C = 8.48 \text{ mW}}$$

E4.32

$\beta = 100$, $V_{BE}(\text{on}) = 0.7$ V, $V_A = \infty$

a. $R_{TH} = R_1 \| R_2 = 10 \| 53.8 = 8.43$ kΩ

$$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right)(5) = \left(\frac{10}{10 + 53.8}\right)(5)$$

$V_{TH} = 0.7837$

$$I_{BQ} = \frac{0.7837 - 0.7}{8.43} = 0.00993 \text{ mA}$$

$I_{CQ} = 0.993$ mA

$V_{CEQ} = V_{CC} - I_{CQ} R_C$

$2.5 = 5 - (0.993) R_C \Rightarrow \underline{R_C = 2.52 \text{ k}\Omega}$

b. Power in $R_C = P_R = I_C^2 R_C = (0.993)^2 (2.52)$

$\Rightarrow \underline{P_R = 2.48 \text{ mW}}$

Power in $Q \equiv P_Q \approx I_{CQ} V_{CEQ} = (0.993)(2.5)$

$\Rightarrow \underline{P_Q = 2.48 \text{ mW}}$

c. $i_C = 0.993 \cos \omega t$

ac power $= \frac{1}{2} \times (0.993)^2 \times R_C = 1.24$ mW

in R_C

$$\frac{1.24}{2.48 + 2.48} = \underline{0.25}$$

Chapter 4

Problem Solutions

4.1

a. $g_m = \frac{I_{CQ}}{V_T} = \frac{2}{0.026} \Rightarrow \underline{g_m = 76.9\ \text{mA/V}}$

$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{(180)(0.026)}{2} \Rightarrow \underline{r_\pi = 2.34\ \text{k}\Omega}$

$r_0 = \frac{V_A}{I_{CQ}} = \frac{150}{2} \Rightarrow \underline{r_0 = 75\ \text{k}\Omega}$

b. $g_m = \frac{0.5}{0.026} \Rightarrow \underline{g_m = 19.2\ \text{mA/V}}$

$r_\pi = \frac{(180)(0.026)}{0.5} \Rightarrow \underline{r_\pi = 9.36\ \text{k}\Omega}$

$r_0 = \frac{150}{0.5} \Rightarrow \underline{r_0 = 300\ \text{k}\Omega}$

4.2

$g_m = \frac{I_{CQ}}{V_T} \Rightarrow 200 = \frac{I_{CQ}}{0.026} \Rightarrow \underline{I_{CQ} = 5.2\ \text{mA}}$

$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{(125)(0.026)}{5.2} \Rightarrow \underline{r_\pi = 0.625\ \text{k}\Omega}$

$r_0 = \frac{V_A}{I_{CQ}} = \frac{200}{5.2} \Rightarrow \underline{r_0 = 38.5\ \text{k}\Omega}$

4.3

(a) $I_{BQ} = \frac{2-0.7}{250} = 0.0052\ mA$

$I_C = (120)(0.0052) = 0.624\ mA$

$g_m = \frac{0.624}{0.026} \Rightarrow \underline{g_m = 24\ mA/V}$

$r_\pi = \frac{(120)(0.026)}{0.624} \Rightarrow \underline{r_\pi = 5\ k\Omega}$

$\underline{r_o = \infty}$

(b) $A_v = -g_m R_C\left(\frac{r_\pi}{r_\pi + R_B}\right) = -(24)(4)\left(\frac{5}{5+250}\right) \Rightarrow$

$\underline{A_v = -1.88}$

(c) $v_s = \frac{v_O}{A_v} = \frac{v_O}{-1.88} \Rightarrow$

$\underline{v_s = -0.426 \sin 100t\quad V}$

4.4

$g_m = \frac{I_{CQ}}{V_T},\ 1.08 \le I_{CQ} \le 1.32\ \text{mA}$

$\frac{1.08}{0.026} \le g_m \le \frac{1.32}{0.026} \Rightarrow \underline{41.5 \le g_m \le 50.8\ \text{mA/V}}$

$r_\pi = \frac{\beta V_T}{I_{CQ}};\ r_\pi(\text{max}) = \frac{(120)(0.026)}{1.08} = 2.89\ \text{k}\Omega$

$r_\pi(\text{min}) = \frac{(80)(0.026)}{1.32} = 1.58\ \text{k}\Omega$

$\underline{1.58 \le r_\pi \le 2.89\ \text{k}\Omega}$

4.5

a. $r_\pi = 5.4 = \frac{\beta V_T}{I_{CQ}} = \frac{(120)(0.026)}{I_{CQ}}$

$\Rightarrow I_{CQ} = 0.578\ \text{mA}$

$V_{CEQ} = \frac{1}{2}V_{CC} = \frac{1}{2}(5) = 2.5\ \text{V}$

$V_{CEQ} = V_{CC} - I_{CQ}R_C \Rightarrow 2.5 = 5.0 - (0.578)R_C$

$\Rightarrow \underline{R_C = 4.33\ \text{k}\Omega}$

$I_{BQ} = \frac{I_{CQ}}{\beta} = \frac{0.578}{120} = 0.00482\ \text{mA}$

$V_{BB} = I_{BQ}R_B + V_{BE}(\text{on})$

$= (0.00482)(25) + 0.70$

$\Rightarrow \underline{V_{BB} = 0.821}$

b. $r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{(120)(0.026)}{0.578} = 5.40\ \text{k}\Omega$

$g_m = \frac{I_{CQ}}{V_T} = \frac{0.578}{0.026} = 22.2\ \text{mA/V}$

$r_0 = \frac{V_A}{I_{CQ}} = \frac{100}{0.578} = 173\ \text{k}\Omega$

$V_0 = -g_m(r_0 \| R_C)V_\pi,\quad V_\pi = \left(\frac{r_\pi}{r_\pi + R_B}\right)V_S$

$A_v = -g_m\left(\frac{r_\pi}{r_\pi + R_B}\right)(r_0 \| R_C) = -\frac{\beta(r_0 \| R_C)}{r_\pi + R_B}$

$A_v = -\frac{(120)[173 \| 4.33]}{5.40 + 25} = -\frac{(120)(4.22)}{30.4}$

$\Rightarrow \underline{A_v = -16.7}$

4.6

a. $V_{ECQ} = \frac{1}{2}V_{CC} = 5\ \text{V}$

$V_{ECQ} = 10 - I_{CQ}R_C \Rightarrow 5 = 10 - (0.5)R_C$

$\Rightarrow \underline{R_C = 10\ \text{k}\Omega}$

$I_{BQ} = \frac{I_{CQ}}{\beta} = \frac{0.5}{100} = 0.005$

$V_{EB}(\text{on}) + I_{BQ}R_B = V_{BB} = (0.70) + (0.005)(50)$

$\Rightarrow \underline{V_{BB} = 0.95\ \text{V}}$

b. $g_m = \frac{I_{CQ}}{V_T} = \frac{0.5}{0.026} \Rightarrow \underline{g_m = 19.2\ \text{mA/V}}$

$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{(100)(0.026)}{0.5} \Rightarrow \underline{r_\pi = 5.2\ \text{k}\Omega}$

$r_0 = \frac{V_A}{I_{CQ}} = \frac{\infty}{0.5} \Rightarrow \underline{r_0 = \infty}$

c. $A_v = -\frac{\beta R_C}{r_\pi + R_B} = -\frac{(100)(10)}{5.2 + 50} \Rightarrow \underline{A_v = -18.1}$

4.7

a. $I_E = 0.35$ mA, $I_B = \dfrac{0.35}{101} = 0.00347$ mA

$V_B = -I_B R_B = -(0.00347)(10)$

$\Rightarrow \underline{V_B = -0.0347 \text{ V}}$

$V_E = V_B - V_{BE}(\text{on}) \Rightarrow \underline{V_E = -0.735 \text{ V}}$

b. $V_C = V_{CEQ} + V_E = 3.5 - 0.735 = 2.77$ V

$$I_C = \left(\frac{\beta}{1+\beta}\right) I_E = \left(\frac{100}{101}\right)(0.35) = 0.347 \text{ mA}$$

$$R_C = \frac{V^+ - V_C}{I_C} = \frac{5 - 2.77}{0.347} \Rightarrow \underline{R_C = 6.43 \text{ k}\Omega}$$

(c) $A_v = -g_m \left(\dfrac{R_B \| r_\pi}{R_B \| r_\pi + R_S}\right)(R_C \| r_o)$

$$g_m = \frac{0.347}{0.026} = 13.3\, mA/V \;,\; r_o = \frac{100}{0.347} = 288\, k\Omega$$

$$r_\pi = \frac{(100)(0.026)}{0.347} = 7.49\, k\Omega$$

$R_B \| r_\pi = 10 \| 7.49 = 4.28\, k\Omega$

$$A_v = -(13.3)\left(\frac{4.28}{4.28 + 0.1}\right)(6.43 \| 288) \Rightarrow$$

$A_v = -81.7$

d. $A_v = -g_m \left(\dfrac{R_B \| r_\pi}{R_B \| r_\pi + R_S}\right)(R_C \| r_o)$

$R_B \| r_\pi = 10 \| 7.49 = 4.28$ kΩ

$$A_v = -(13.3)\left(\frac{4.28}{4.28 + 0.5}\right)(6.43 \| 288)$$

$\Rightarrow \underline{A_v = -74.9}$

4.8

a. $R_{TH} = R_1 \| R_2 = 6 \| 1.5 = 1.2$ kΩ

$$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right) V^+ = \left(\frac{1.5}{1.5 + 6}\right)(5) = 1.0 \text{ V}$$

$$I_{BQ} = \frac{V_{TH} - V_{BE}(\text{on})}{R_{TH} + (1+\beta) R_E} = \frac{1.0 - 0.7}{1.2 + (181)(0.1)}$$

$= 0.0155$ mA

$\underline{I_{CQ} = 2.80 \text{ mA}}$, $I_{EQ} = 2.81$

$V_{CEQ} = V^+ - I_{CQ} R_C - I_{EQ} R_E$

$= 5 - (2.8)(1) - (2.81)(0.1)$

$\Rightarrow \underline{V_{CEQ} = 1.92 \text{ V}}$

b. $r_\pi = \dfrac{(180)(0.026)}{2.80} \Rightarrow \underline{r_\pi = 1.67 \text{ k}\Omega}$

$g_m = \dfrac{2.80}{0.026} \Rightarrow \underline{g_m = 108 \text{ mA/V}}$, $r_0 = \infty$

(c) $A_v = -g_m \left(\dfrac{R_1 \| R_2 \| r_\pi}{R_1 \| R_2 \| r_\pi + R_S}\right)(R_C \| R_L)$

$R_1 \| R_2 \| r_\pi = 6 \| 1.5 \| 1.67 = 0.698\, k\Omega$

$$A_v = -(108)\left(\frac{0.698}{0.698 + 0.2}\right)(1 \| 1.2) \Rightarrow$$

$A_v = -45.8$

4.9

a. $I_{CQ} \approx I_{EQ}$

$V_{CEQ} = 5 = 10 - I_{CQ}(R_C + R_E)$

$= 10 - I_{CQ}(1.2 + 0.2)$

$I_{CQ} = 3.57$ mA

$I_{BQ} = \dfrac{3.57}{150} = 0.0238$ mA

$R_1 \| R_2 = R_{TH} = (0.1)(1+\beta) R_E$

$= (0.1)(151)(0.2) = 3.02$ kΩ

$V_{TH} = \dfrac{1}{R_1} \cdot R_{TH} \cdot (10) - 5$

$V_{TH} = I_{BQ} R_{TH} + V_{BE}(\text{on}) + (1+\beta) I_{BQ} R_E - 5$

$\dfrac{1}{R_1}(3.02)(10) - 5 = (0.0238)(3.02) + 0.7$

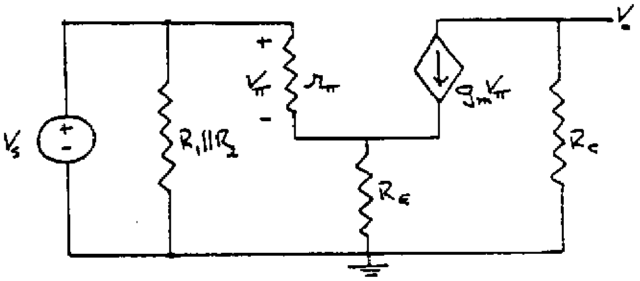
$+ (151)(0.0238)(0.2) - 5$

$\dfrac{1}{R_1}(30.2) = 1.49 \Rightarrow R_1 = 20.3\, k\Omega$

$\dfrac{20.3 R_2}{20.3 + R_2} = 3.02 \Rightarrow \underline{R_2 = 3.55 \text{ k}\Omega}$

b. $r_\pi = \dfrac{(150)(0.026)}{3.57} = 1.09$ kΩ

$g_m = \dfrac{3.57}{0.026} = 137$ mA/V



$$A_v = \frac{-\beta R_C}{r_\pi + (1+\beta) R_E} = -\frac{(150)(1.2)}{1.09 + (151)(0.2)}$$

$\Rightarrow \underline{A_v = -5.75}$

4.10

a. $V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right) V_{CC} = \left(\frac{50}{50 + 10}\right)(12) = 10 \text{ V}$

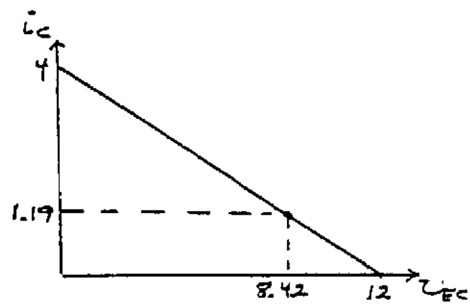
$R_{TH} = R_1 \| R_2 = 50 \| 10 = 8.33 \text{ k}\Omega$

$I_{BQ} = \frac{12 - 0.7 - 10}{8.33 + (101)(1)} = 0.0119 \text{ mA}$

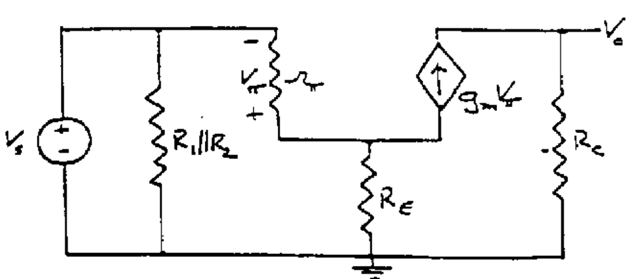
$\underline{I_{CQ} = 1.19 \text{ mA}}$, $I_{EQ} = 1.20 \text{ mA}$

$V_{ECQ} = 12 - (1.20)(1) - (1.19)(2)$

$\underline{V_{ECQ} = 8.42 \text{ V}}$



b.



$r_\pi = \frac{(100)(0.026)}{1.19} = 2.18 \text{ k}\Omega$

$V_0 = g_m V_\pi R_C$

$V_S = -V_\pi - \left(\frac{V_\pi}{r_\pi} + g_m V_\pi\right) R_E$

$= -V_\pi \left[\frac{r_\pi + (1 + \beta) R_E}{r_\pi}\right]$

$A_v = \frac{-\beta R_C}{r_\pi + (1 + \beta) R_E} = \frac{-(100)(2)}{2.18 + (101)(1)}$

$\Rightarrow \underline{A_v = -1.94}$

c. Approximation: Assume r_π does not vary significantly.

$R_C = 2 \text{ k}\Omega \pm 5\% = 2.1 \text{ k}\Omega$ or $1.9 \text{ k}\Omega$

$R_E = 1 \text{ k}\Omega \pm 5\% = 1.05 \text{ k}\Omega$ or $0.95 \text{ k}\Omega$

For $R_C(\max) = 2.1 \text{ k}\Omega$ and $R_E(\min)$

$$A_v = \frac{-(100)(2.1)}{2.18 + (101)(0.95)} = -2.14$$

For $R_C(\min) = 1.9 \text{ k}\Omega$ and $R_E(\max) = 1.05 \text{ k}\Omega$

$$A_v = \frac{-(100)(1.9)}{2.18 + (101)(1.05)} = -1.76$$

So $\underline{1.76 \le |A_v| \le 2.14}$

4.11

(a) $V_{CC} = \left(\frac{1+\beta}{\beta}\right) I_{CQ} R_E + V_{ECQ} + I_{CQ} R_C$

$12 = \left(\frac{101}{100}\right) I_{CQ}(1) + 6 + I_{CQ}(2)$

so that $\underline{I_{CQ} = 1.99 \, mA}$

$I_{BQ} = \frac{1.99}{100} = 0.0199 \, mA$

$R_{TH} = (0.1)(1+\beta) R_E = (0.1)(101)(1) = 10.1 \, k\Omega$

$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right) V_{CC} = \frac{1}{R_1} \cdot R_{TH} \cdot V_{CC} = \frac{1}{R_1}(10.1)(12)$

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

$12 = (101)(0.0199)(1) + 0.7 + (0.0199)(10.1) + \frac{121.2}{R_1}$

which yields $\underline{R_1 = 13.3 \, k\Omega}$ and $\underline{R_2 = 42 \, k\Omega}$

(b) $A_v = \frac{-\beta R_C}{r_\pi + (1+\beta) R_E} = \frac{-(100)(2)}{1.31 + (101)(1)} \Rightarrow$

$\underline{A_v = -1.95}$

4.12

$I_{CQ} = 0.25 \text{ mA}$, $I_{EQ} = 0.2525 \text{ mA}$

$I_{BQ} = 0.0025 \text{ mA}$

$I_{BQ} R_B + V_{BE}(\text{on}) + I_{EQ}(R_S + R_E) - 5 = 0$

$(0.0025)(50) + 0.7 + (0.2525)(0.1 + R_E) = 5$

$\underline{R_E = 16.4 \text{ k}\Omega}$

$V_E = -(0.0025)(50) - 0.7 = -0.825 \text{ V}$

$V_C = V_{CEQ} + V_E = 3 - 0.825 = 2.175 \text{ V}$

$R_C = \frac{5 - 2.175}{0.25} \Rightarrow \underline{R_C = 11.3 \text{ k}\Omega}$

$A_v = \frac{-\beta R_C}{r_\pi + (1 + \beta) R_S}$

$r_\pi = \frac{(100)(0.026)}{0.25} = 10.4 \text{ k}\Omega$

$A_v = \frac{-(100)(11.3)}{10.4 + (101)(0.1)} \Rightarrow \underline{A_v = -55.1}$

$R_i = R_B \| [r_\pi + (1 + \beta) R_S]$

$= 50 \| [10.4 + (101)(0.1)]$

$R_i = 50 \| 20.5 \Rightarrow \underline{R_i = 14.5 \text{ k}\Omega}$

4.13

a. $9 = I_{EQ}R_E + V_{EB}(\text{on}) + I_{BQ}R_S$

$I_{EQ} = 0.75 \text{ mA}, \; I_{BQ} = \dfrac{0.75}{81} = 0.00926 \text{ mA}$

$I_{CQ} = 0.741 \text{ mA}$

$9 = (0.75)R_E + 0.7 + (0.00926)(2)$

$\Rightarrow \underline{R_E = 11.0 \text{ k}\Omega}$

b. $V_E = 9 - (0.75)(11) = 0.75 \text{ V}$

$V_C = V_E - V_{ECQ} = 0.75 - 7 = -6.25 \text{ V}$

$R_C = \dfrac{V_C - (-9)}{I_{CQ}} = \dfrac{9 - 6.25}{0.741} \Rightarrow \underline{R_C = 3.71 \text{ k}\Omega}$

c. $A_v = -g_m\left(\dfrac{r_\pi}{r_\pi + R_S}\right)(R_C \| R_L \| r_0)$

$r_\pi = \dfrac{(80)(0.026)}{0.741} = 2.81 \text{ k}\Omega$

$r_0 = \dfrac{80}{0.741} = 108 \text{ k}\Omega$

$A_v = \dfrac{-80}{2.81 + 2}(3.71 \| 10 \| 108)$

$\underline{A_v = -43.9}$

d. $R_i = R_S + r_\pi = 2 + 2.81 \Rightarrow \underline{R_i = 4.81 \text{ k}\Omega}$

4.14

(a) $V_{CC} \cong I_{CQ}(R_C + R_E) + V_{CEQ}$

$9 = I_{CQ}(2.2 + 2) + 3.75$ So that

$\underline{I_{CQ} = 1.25\, mA}$

Then

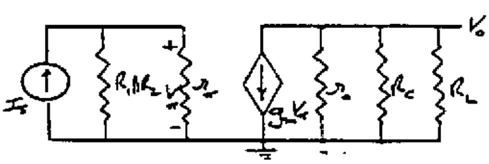
(b) $g_m = \dfrac{1.25}{0.026} = 48.1\, mA/V$

$r_\pi = \dfrac{(120)(0.026)}{1.25} = 2.50\, k\Omega$

$r_o = \dfrac{100}{1.25} = 80\, k\Omega$

Assume circuit is to be designed to be bias stable.

$R_{TH} = R_1 \| R_2 = (0.1)(1+\beta)R_E = (0.1)(121)(2) = 24.2\,\Omega$



$V_o = -g_m V_\pi (r_o \| R_C \| R_L)$

$V_\pi = I_S (R_1 \| R_2 \| r_\pi)$

Then

$R_m = \dfrac{V_o}{I_s} = -g_m (R_1 \| R_2 \| r_\pi)(r_o \| R_C \| R_L)$

$R_m = -48.1(24.2 \| 2.5)(80 \| 2.2 \| 1) = -48.1(2.27)(0.682)$

or

$R_m = \dfrac{V_o}{I_s} = -74.5\, k\Omega = -74.5\, V/mA$

4.15

a. $I_{EQ} = 0.80 \text{ mA}, \; I_{BQ} = \dfrac{0.80}{66} = 0.0121 \text{ mA}$

$I_{CQ} = 0.788 \text{ mA}$

$V_B = I_{BQ}R_B \Rightarrow R_B = \dfrac{0.3}{0.0121} \Rightarrow \underline{R_B = 24.8 \text{ k}\Omega}$

$R_C = \dfrac{V_C - (-5)}{I_{CQ}} = \dfrac{5 - 3}{0.788} \Rightarrow \underline{R_C = 2.54 \text{ k}\Omega}$

b. $g_m = \dfrac{0.788}{0.026} = 30.3 \text{ mA/V}$

$r_\pi = \dfrac{(65)(0.026)}{0.788} = 2.14 \text{ k}\Omega$

$r_0 = \dfrac{75}{0.788} = 95.2 \text{ k}\Omega$

$i_0 = \left(\dfrac{R_C \| r_0}{R_C \| r_0 + R_L}\right) g_m V_\pi, \quad V_\pi = -v_S$

$G_f = \dfrac{i_0}{v_S} = -g_m\left(\dfrac{R_C \| r_0}{R_C \| r_0 + R_L}\right)$

$= -(30.3)\left(\dfrac{2.54 \| 95.2}{2.54 \| 95.2 + 4}\right)$

$\underline{G_f = -11.6 \text{ mA/V}}$

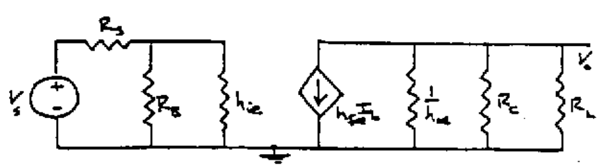
4.16

$I_{BQ} = \dfrac{4 - 0.7}{5 + (101)(5)} = 0.00647$

$I_{CQ} = 0.647 \text{ mA}$

a. $80 \le h_{fe} \le 120, \quad 10 \le h_{oe} \le 20\ \mu\text{S}$

$\underbrace{2.45 \text{ k}\Omega}_{\text{low gain}} \le h_{ie} \le \underbrace{3.7 \text{ k}\Omega}_{\text{high gain}}$



$V_0 = -h_{fe}I_b\left(\dfrac{1}{h_{oe}} \| R_C \| R_L\right)$

$I_b = \dfrac{\dfrac{R_B}{R_B + R_S} \cdot V_S}{R_{TH} + h_{ie}}$

$R_{TH} = R_B \| R_S = 5 \| 1 = 0.833 \text{ k}\Omega$

High-gain

$$I_b = \frac{\left(\frac{5}{5+1}\right)V_S}{0.833 + 3.7} = 0.1838V_S$$

Low-gain

$$I_b = \frac{\left(\frac{5}{5+1}\right)V_S}{0.833 + 2.45} = 0.2538V_S$$

For

$$h_{oe} = 10 \Rightarrow \frac{1}{h_{oe}} \parallel R_C \parallel R_L = \frac{1}{0.010} \parallel 4 \parallel 4$$

$$= 100\|2 = 1.96 \text{ k}\Omega$$

For

$$h_{oe} = 20 \Rightarrow \frac{1}{0.020} \parallel 4 \parallel 4 = 50\|2 = 1.92 \text{ k}\Omega$$

$$|A_v|_{max} = (120)(0.1838)(1.96) = 43.2$$

$$|A_v|_{min} = (80)(0.2538)(1.92) = 39.0$$

$\underline{39.0 \le |A_v| \le 43.2}$

b. $R_i = R_B\|h_{ie} = 5\|3.7 = 2.13 \text{ k}\Omega$

or $R_i = 5\|2.45 = 1.64 \text{ k}\Omega$

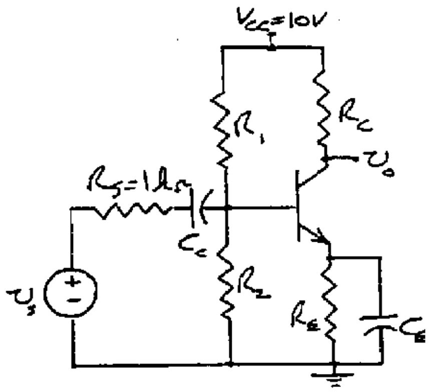
$\underline{1.64 < R_i < 2.13 \text{ k}\Omega}$

$$R_o = \frac{1}{h_{oe}} \parallel R_C = \frac{1}{0.010} \parallel 4 = 100\|4 = 3.85 \text{ k}\Omega$$

or $R_o = \frac{1}{0.020} \parallel 4 = 50\|4 = 3.70 \text{ k}\Omega$

$\underline{3.70 \le R_o \le 3.85 \text{ k}\Omega}$

4.17



Assume an npn transistor with $\beta = 100$ and $V_A = \infty$. Let $V_{CC} = 10V$.

$$|A_v| = \frac{0.5}{0.01} = 50$$

Bias at $I_{CQ} = 1\,mA$ and let $R_E = 1\,k\Omega$

For a bias stable circuit

$$R_{TH} = (0.1)(1+\beta)R_E = (0.1)(101)(1) = 10.1\,k\Omega$$

$$V_{TH} = \frac{1}{R_1} \cdot R_{TH} \cdot V_{CC} = \frac{1}{R_1}(10.1)(10) = \frac{101}{R_1}$$

$$I_{BQ} = \frac{1}{100} = 0.01\,mA$$

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

$$\frac{101}{R_1} = (0.01)(10.1) + 0.7 + (101)(0.01)(1)$$

which yields $\underline{R_1 = 55.8\,k\Omega}$ and $\underline{R_2 = 12.3\,k\Omega}$

Now

$$r_\pi = \frac{(100)(0.026)}{1} = 2.6\,k\Omega$$

$$g_m = \frac{1}{0.026} = 38.46\,mA/V$$

$$V_o = -g_m V_\pi R_C$$

where

$$V_\pi = \left(\frac{R_1\|R_2\|r_\pi}{R_1\|R_2\|r_\pi + R_S}\right)\cdot V_s = \left(\frac{10.1\|2.6}{10.1\|2.6+1}\right)\cdot V_s$$

or

$$V_\pi = 0.674V_s$$

Then

$$A_v = \frac{V_o}{V_s} = -(0.674)g_m R_C = -(0.674)(38.46)R_C = -50$$

which yields $\underline{R_C = 1.93\,k\Omega}$

With this R_C, the dc bias is OK.

4.18

a. $$I_{BQ} = \frac{6 - 0.7}{10 + (101)(3)} = 0.0169 \text{ mA}$$

$\underline{I_{CQ} = 1.69 \text{ mA}}$, $I_{EQ} = 1.71$ mA

$$V_{CEQ} = (16 + 6) - (1.69)(6.8) - (1.71)(3)$$

$\underline{V_{CEQ} = 5.38 \text{ V}}$

b. $g_m = \frac{1.69}{0.026} \Rightarrow \underline{g_m = 65 \text{ mA/V}}$

$r_\pi = \frac{(100)(0.026)}{1.69} \Rightarrow \underline{r_\pi = 1.54 \text{ k}\Omega}$, $\underline{r_o = \infty}$

(c) $$A_v = \frac{-\beta(R_C\|R_L)}{r_\pi + (1+\beta)R_E}\cdot\frac{R_B\|R_{ib}}{R_B\|R_{ib} + R_S}$$

$$R_{ib} = r_\pi + (1+\beta)R_E = 1.54 + (101)(3) = 304.5\,k\Omega$$

$$R_B\|R_{ib} = 10\|304.5 = 9.68\,k\Omega$$

Then

$$A_v = \frac{-(100)(6.8\|6.8)}{1.54 + (101)(3)}\cdot\left(\frac{9.68}{9.68+0.5}\right) \Rightarrow$$

$\underline{A_v = -1.06}$

$$i_o = \left(\frac{R_C}{R_C + R_L}\right)(-\beta i_b)$$

$$i_b = \left(\frac{R_B}{R_B + r_\pi + (1+\beta)R_E}\right)i_S$$

$$A_i = -(\beta)\left(\frac{R_C}{R_C + R_L}\right)\left(\frac{R_B}{R_B + r_\pi + (1+\beta)R_E}\right)$$

$$= -(100)\left(\frac{6.8}{6.8 + 6.8}\right)\left(\frac{10}{10 + 1.54 + (101)(3)}\right)$$

$\Rightarrow \underline{A_i = -1.59}$

(d) $R_{is} = R_S + R_B \| R_{ib} = 0.5 + 10 \| 304.5 = 10.2\ k\Omega$

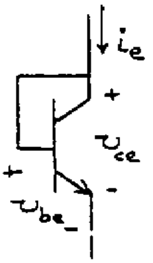
(e) $A_v = \dfrac{-\beta(R_C \| R_L)}{r_\pi + (1+\beta)R_E} \cdot \dfrac{R_B \| R_{ib}}{R_B \| R_{ib} + R_S}$

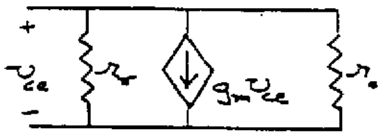
$A_v = \dfrac{-(100)(6.8 \| 6.8)}{1.54 + (101)(3)} \cdot \left(\dfrac{9.68}{9.68+1}\right) \Rightarrow$

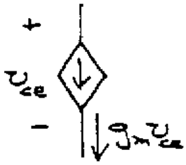
$A_v = -1.01$

A_i = same as (c) $\Rightarrow \underline{A_i = -1.59}$

4.19





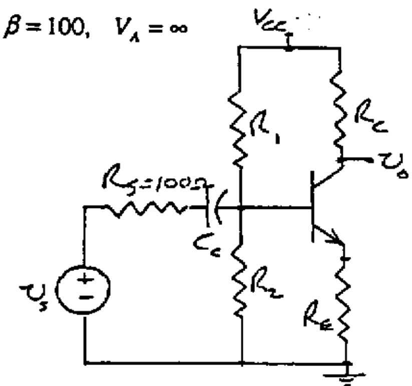


$r = \dfrac{v_{ce}}{g_m v_{ce}} = \dfrac{1}{g_m}$

So $\underline{r_e = r_\pi \left\| \left(\dfrac{1}{g_m}\right) \right\| r_o}$

4.20

Let $\beta = 100$, $V_A = \infty$



Let $V_{CC} = 2.5\ V$

$P = (I_R + I_C)V_{CC} \Rightarrow 0.12 = (I_R + I_C)(2.5) \Rightarrow$

$I_R + I_C = 48\ \mu A$, Let $I_R = 8\ \mu A$, $I_C = 40\ \mu A$

$R_1 + R_2 \cong \dfrac{V_{CC}}{I_R} = \dfrac{2.5}{8} \Rightarrow 312.5\ k\Omega$

$I_{BQ} = \dfrac{40}{100} = 0.4\ \mu A$

Let $R_E = 2\ k\Omega$. For a bias stable circuit

$R_{TH} = (0.1)(1+\beta)R_E = (0.1)(101)(2) = 20.2\ k\Omega$

$V_{TH} = \dfrac{1}{R_1} \cdot R_{TH} \cdot V_{CC} = I_{BQ}R_{TH} + V_{BE}(on) + (1+\beta)I_{BQ}R_E$

$\dfrac{1}{R_1}(20.2)(2.5) = (0.0004)(20.2) + 0.7$

$+ (101)(0.0004)(2)$

which yields $R_1 = 64\ k\Omega$ and $R_2 = 29.5\ k\Omega$

$r_\pi = \dfrac{(100)(0.026)}{0.04} = 65\ k\Omega$ Neglect R_S

$A_v = \dfrac{V_o}{V_s} \cong \dfrac{-\beta R_C}{r_\pi + (1+\beta)R_E}$

$-10 = \dfrac{-100R_C}{65 + (101)(2)} \Rightarrow \underline{R_C = 26.7\ k\Omega}$

With this R_C, dc biasing is OK.

4.21

Need a voltage gain of $\dfrac{100}{5} = 20$.

Assume a sign inversion from a common-emitter is not important. Use the configuration for Figure 4.28. Need an input resistance of

$R_i = \dfrac{5x10^{-3}}{0.2x10^{-6}} = 25x10^3 = 25\ k\Omega$

$R_i = R_{TH} \| R_{ib}$. Let $R_{TH} = 50\ k\Omega$, $R_{ib} = 50\ k\Omega$

$R_{ib} = r_\pi + (1+\beta)R_E \cong (1+\beta)R_E$

For $\beta = 100$, $R_E = \dfrac{R_{ib}}{1+\beta} = \dfrac{50}{101} = 0.495\ k\Omega$

Let $\underline{R_E = 0.5\ k\Omega}$, $\underline{V_{CC} = 10\ V}$, $\underline{I_{CQ} = 0.2\ mA}$

Then $I_{BQ} = \dfrac{0.2}{100} = 0.002\ mA$

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

$\dfrac{1}{R_1} \cdot R_{TH} \cdot V_{CC} = \dfrac{1}{R_1}(50)(10) = (0.002)(50) + 0.7$

$+ (101)(0.002)(0.5)$

which yields $R_1 = 555\ k\Omega$ and $R_2 = 55\ k\Omega$

Now

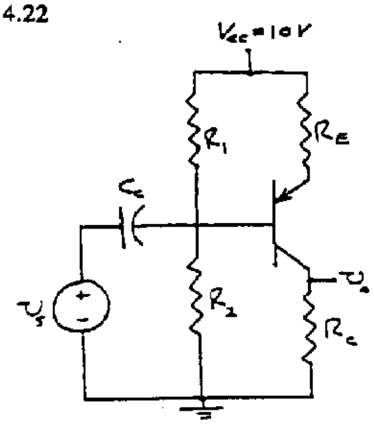
$A_v = \dfrac{-\beta R_C}{r_\pi + (1+\beta)R_E}$, $r_\pi = \dfrac{(100)(0.026)}{0.2} = 13\ k\Omega$

so

$-20 = \dfrac{-(100)R_C}{13 + (101)(0.5)} \Rightarrow \underline{R_C = 12.7\ k\Omega}$

[Note: $I_{CQ}R_C = (0.2)(12.7) = 2.54\ V$. So dc biasing is OK.]

4.22



$\beta = 80, \quad A_v = \dfrac{-\beta R_C}{r_\pi + (1+\beta)R_E}$

First approximation:

$(A_v) \approx \dfrac{R_C}{R_E} = 10 \Rightarrow R_C = 10R_E$

Set $R_C = 12R_E$

$V_{EC} \approx V_{CC} - I_C(R_C + R_E) = 10 - I_C(13R_E)$

For $V_{EC} = \dfrac{1}{2}V_{CC} = 5$

$5 = 10 - I_C(13R_E)$

For $I_C = 0.7$ mA

$I_E = 0.709, \quad I_B = 0.00875$ mA

$\Rightarrow R_E = 0.55\ \text{k}\Omega \to R_C = 6.6\ \text{k}\Omega$

Bias stable $\Rightarrow$

$R_1 \| R_2 = R_{TH} = (0.1)(1+\beta)R_E$

$= (0.1)(81)(0.55) = 4.46\ \text{k}\Omega$

$10 = (0.709)(0.55) + 0.7 + (0.00875)(4.46)$

$+ \dfrac{1}{R_1}(4.46)(10)$

$8.87 = \dfrac{1}{R_1}(4.46) \Rightarrow \underline{R_1 = 5.03\ \text{k}\Omega}$

$\dfrac{5.03R_2}{5.03 + R_2} = 4.46 \Rightarrow \underline{R_2 = 39.4\ \text{k}\Omega}$

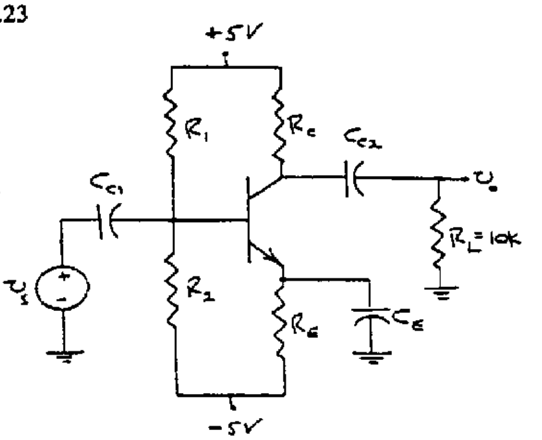
$\dfrac{10}{R_1 + R_2} = \dfrac{10}{5.03 + 39.4} = 0.225$ mA

$0.7 + 0.225 \cong 0.925$ mA from V_{CC} source.

Now $r_\pi = \dfrac{(80)(0.026)}{0.7} = 2.97\ \text{k}\Omega$

$|A_v| = \dfrac{(80)(6.6)}{2.97 + (81)(0.55)} = 11.1$

4.23



$\beta = 120$

Let $I_{CQ} = 0.35$ mA, $I_{EQ} = 0.353$ mA

$I_{BQ} = 0.00292$ mA

Let $R_E = 2\ \text{k}\Omega$. For $V_{CEQ} = 4\ \text{V} \Rightarrow$

$10 = 4 + (0.35)R_C + (0.353)(2)$

$\underline{R_C = 15.1\ \text{k}\Omega}, \quad r_\pi = \dfrac{(120)(0.026)}{0.35} = 8.91\ \text{k}\Omega$

$A_v = \dfrac{-\beta(R_C \| R_L)}{r_\pi} = -\dfrac{(120)(15.1\|10)}{8.91}$

$\underline{A_v = -81.0}$

For bias stable circuit:

$R_1 \| R_2 = R_{TH} = (0.1)(1+\beta)R_E$

$= (0.1)(121)(2) = 24.2\ \text{k}\Omega$

$V_{TH} = \left(\dfrac{R_2}{R_1 + R_2}\right)(10) - 5 = \dfrac{1}{R_1} \cdot R_{TH} \cdot (10) - 5$

$V_{TH} = I_{BQ}R_{TH} + V_{BE}(\text{on}) + (1+\beta)I_{BQ}R_E - 5$

$\dfrac{1}{R_1}(24.2)(10) - 5 = (0.00292)(24.2) + 0.7$

$+ (121)(0.00292)(2) - 5$

$\dfrac{1}{R_1}(242) = 1.477, \quad \underline{R_1 = 164\ \text{k}\Omega}$

$\dfrac{164R_2}{164 + R_2} = 24.2 \Rightarrow \underline{R_2 = 28.4\ \text{k}\Omega}$

$\dfrac{10}{164 + 28.4} = 0.052, \quad 0.35 + 0.052 = \underline{0.402\ \text{mA}}$

4.24

From Prob. 4-10:

$R_{TH} = R_1 \| R_2 = 10 \| 50 = 8.33\ \text{k}\Omega$

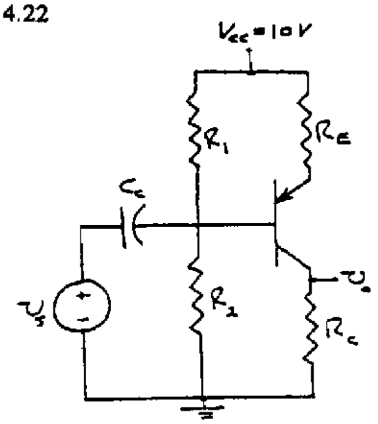
$V_{TH} = \left(\dfrac{R_2}{R_1 + R_2}\right)(12) = \left(\dfrac{50}{50 + 10}\right)(12) = 10\ \text{V}$

$I_{BQ} = \dfrac{12 - 0.7 - 10}{8.33 + (101)(1)} = 0.0119$ mA

$I_{CQ} = 1.19$ mA, $I_{EQ} = 1.20$ mA

$V_{ECQ} = 12 - (1.19)(2) - (120)(1) = 8.42$ V

4.22



$\beta = 80, \quad A_v = \dfrac{-\beta R_C}{r_\pi + (1+\beta)R_E}$

First approximation:

$(A_v) \approx \dfrac{R_C}{R_E} = 10 \Rightarrow R_C = 10R_E$

Set $R_C = 12R_E$

$V_{EC} \approx V_{CC} - I_C(R_C + R_E) = 10 - I_C(13R_E)$

For $V_{EC} = \frac{1}{2}V_{CC} = 5$

$5 = 10 - I_C(13R_E)$

For $I_C = 0.7$ mA

$I_E = 0.709, \quad I_B = 0.00875$ mA

$\Rightarrow R_E = 0.55\ \text{k}\Omega \to R_C = 6.6\ \text{k}\Omega$

Bias stable $\Rightarrow$

$R_1 \| R_2 = R_{TH} = (0.1)(1 + \beta)R_E$

$= (0.1)(81)(0.55) = 4.46\ \text{k}\Omega$

$10 = (0.709)(0.55) + 0.7 + (0.00875)(4.46)$

$+ \dfrac{1}{R_1}(4.46)(10)$

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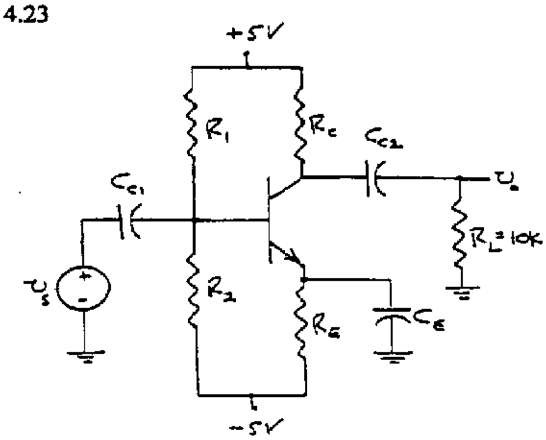
$\dfrac{10}{R_1 + R_2} = \dfrac{10}{5.03 + 39.4} = 0.225$ mA

$0.7 + 0.225 \cong 0.925$ mA from V_{CC} source.

Now $r_\pi = \dfrac{(80)(0.026)}{0.7} = 2.97\ \text{k}\Omega$

$|A_v| = \dfrac{(80)(6.6)}{2.97 + (81)(0.55)} = 11.1$

4.23



$\beta = 120$

Let $I_{CQ} = 0.35$ mA, $\quad I_{EQ} = 0.353$ mA

$I_{BQ} = 0.00292$ mA

Let $R_E = 2\ \text{k}\Omega$. For $V_{CEQ} = 4$ V $\Rightarrow$

$10 = 4 + (0.35)R_C + (0.353)(2)$

$\underline{R_C = 15.1\ \text{k}\Omega}, \quad r_\pi = \dfrac{(120)(0.026)}{0.35} = 8.91\ \text{k}\Omega$

$A_v = \dfrac{-\beta(R_C \| R_L)}{r_\pi} = -\dfrac{(120)(15.1 \| 10)}{8.91}$

$\underline{A_v = -81.0}$

For bias stable circuit:

$R_1 \| R_2 = R_{TH} = (0.1)(1+\beta)R_E$

$= (0.1)(121)(2) = 24.2\ \text{k}\Omega$

$V_{TH} = \left(\dfrac{R_2}{R_1 + R_2}\right)(10) - 5 = \dfrac{1}{R_1} \cdot R_{TH} \cdot (10) - 5$

$V_{TH} = I_{BQ}R_{TH} + V_{BE}(\text{on}) + (1+\beta)I_{BQ}R_E - 5$

$\dfrac{1}{R_1}(24.2)(10) - 5 = (0.00292)(24.2) + 0.7$

$+ (121)(0.00292)(2) - 5$

$\dfrac{1}{R_1}(242) = 1.477, \quad \underline{R_1 = 164\ \text{k}\Omega}$

$\dfrac{164R_2}{164 + R_2} = 24.2 \Rightarrow \underline{R_2 = 28.4\ \text{k}\Omega}$

$\dfrac{10}{164 + 28.4} = 0.052, \quad 0.35 + 0.052 = \underline{0.402\ \text{mA}}$

4.24

From Prob. 4-10:

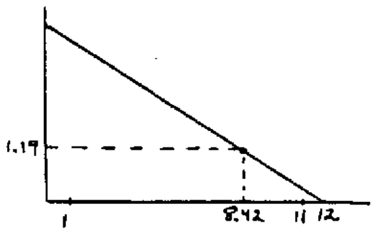
$R_{TH} = R_1 \| R_2 = 10 \| 50 = 8.33\ \text{k}\Omega$

$V_{TH} = \left(\dfrac{R_2}{R_1 + R_2}\right)(12) = \left(\dfrac{50}{50 + 10}\right)(12) = 10$ V

$I_{BQ} = \dfrac{12 - 0.7 - 10}{8.33 + (101)(1)} = 0.0119$ mA

$I_{CQ} = 1.19$ mA, $\quad I_{EQ} = 1.20$ mA

$V_{ECQ} = 12 - (1.19)(2) - (120)(1) = 8.42$ V



For $1 \le v_{EC} \le 11$

$\Delta v_{EC} = 11 - 8.42 = 2.58$

$\Rightarrow$ Output voltage swing $= 5.16$ V (peak-to-peak)

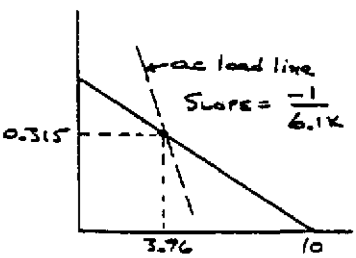
4.25

$$I_{BQ} = \frac{5 - 0.7}{50 + (101)(0.1 + 12.9)} = 0.00315 \text{ mA}$$

$\underline{I_{CQ} = 0.315 \text{ mA}}$, $I_{EQ} = 0.319$ mA

$V_{CEQ} = (5 + 5) - (0.315)(6) - (0.319)(13)$

$V_{CEQ} = 3.96$ V



$\Delta i_C = -\dfrac{1}{6.1}\Delta v_{EC}$

For $\Delta i_C = 0.315 - 0.05 = 0.265$

$\Rightarrow |\Delta v_{EC}| = 1.62$

$v_{EC}(\min) = 3.96 - 1.62 = 2.34$

Output signal swing determined by current:

Max. output swing $=$ $\underline{3.24 \text{ V peak-to-peak}}$

4.26

For $R_C = 6\,k\Omega$, $V_C = 5 - \left(\dfrac{100}{101}\right)(0.35)(6) = 2.92\,V$

$V_E = -I_{BQ}R_B - V_{BE}(on) = -\dfrac{0.35}{100}(10) - 0.7 = -0.735\,V$

Then $V_{CE} = V_C - V_E = 2.92 - (-0.735) = 3.66\,V$

$\Delta v_{CE} = \Delta i_C \cdot R_C \Rightarrow (4.5 - 3.66) = \Delta i_C(6)$

so that $\Delta i_C = 0.14\,mA$

(a) Total $\Delta v_{CE} = 2(4.5 - 3.66) = 1.68\,V$ peak-to-peak

(b) Total $\Delta i_C = 2(0.14) = 0.28\,mA$ peak-to-peak

4.27

$I_{EQ} = 0.80$ mA, $I_{CQ} = 0.792$ mA

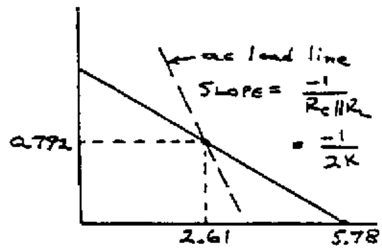
$I_{BQ} = 0.008$ mA

$V_E = 0.7 + (0.008)(10) = 0.78$ V

$V_C = I_{CQ}R_C - 5 = (0.792)(4) - 5 = -1.83$ V

$V_{ECQ} = 0.78 - (-1.83) = 2.61$ V

Load line: Assume V_E remains constant at ≈ 0.78 V



$\Delta i_C = \dfrac{-1}{2\text{ k}\Omega} \cdot v_{ec}$

Collector current swing $= 0.792 - 0.08$

$= 0.712$ mA

$|\Delta v_{ec}| = (0.712)(2) = 1.42$ V

Output swing determined by current.

Max. output swing $=$ $\underline{2.84 \text{ V peak-to-peak}}$

Swing in i_0 current $= \dfrac{2.84}{4}$

$=$ $\underline{0.71 \text{ mA peak-to-peak}}$

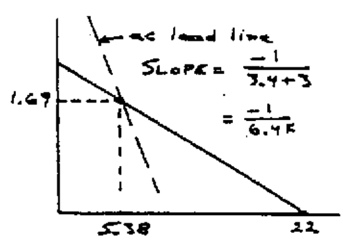
4.28

$$I_{BQ} = \frac{6 - 0.7}{10 + (101)(3)} = 0.0169 \text{ mA}$$

$\underline{I_{CQ} = 1.69 \text{ mA}}$, $I_{EQ} = 1.71$ mA

$V_{CEQ} = (16 + 6) - (1.69)(6.8) - (1.71)(3)$

$V_{CEQ} = 5.38$ V



$\Delta i_C = -\frac{1}{6.4}\Delta v_{ce}$

For $v_{ce}(\min) = 1$ V, $\Delta v_{ce} = 5.38 - 1 = 4.38$ V

$\Rightarrow |\Delta i_C| = \frac{4.38}{6.4} = 0.684$ mA

Output swing limited by voltage:

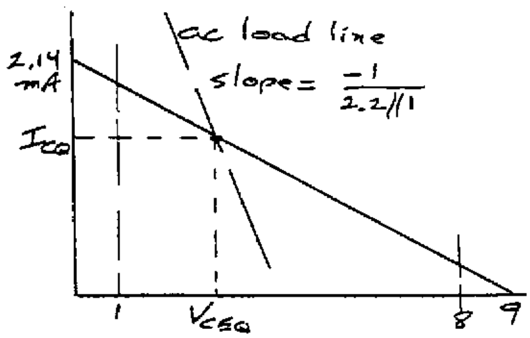
Δv_{ce} = Max. swing in output voltage

$= \underline{8.76 \text{ V peak-to-peak}}$

$\Delta i_0 = \frac{1}{2}\Delta i_C \Rightarrow \underline{\Delta i_0 = 0.342 \text{ mA}}$

(peak-to-peak)

4.29



$\Delta v_{CE}(\max) = V_{CEQ} - 1, \quad \Delta i_C(\max) = I_{CQ}$

$\Delta v_{CE} = \Delta i_C(0.6875)$. So

$V_{CEQ} - 1 = I_{CQ}(0.6875)$ and

$V_{CEQ} = V_{CC} - I_{CQ}(R_C + R_E) \Rightarrow V_{CEQ} = 9 - I_{CQ}(4.2)$

Then

$9 - I_{CQ}(4.2) - 1 = I_{CQ}(0.6875)$

So $\underline{I_{CQ} = 1.64 \text{ mA}}$ and $\underline{V_{CEQ} = 2.11 \text{ V}}$

$V_{TH} = \frac{1}{R_1}\cdot R_{TH}\cdot V_{CC}$ and $R_{TH} = (0.1)(1+\beta)R_E$

$R_{TH} = (0.1)(151)(2) = 30.2 \text{ k}\Omega$

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

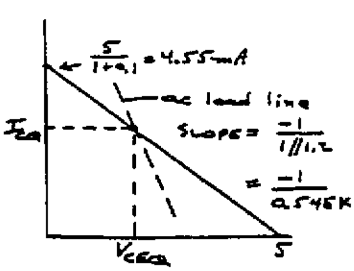
$I_{BQ} = \frac{1.64}{150} = 0.0109 \text{ mA}$

$\frac{1}{R_1}(30.2)(9) = (0.0109)(30.2) + 0.7 + (151)(0.0109)(2)$

which yields $\underline{R_1 = 62.9 \text{ k}\Omega}$ and $\underline{R_2 = 58.1 \text{ k}\Omega}$

4.30

dc load line



For maximum symmetrical swing

$\Delta i_C = I_{CQ} - 0.25$

$\Delta v_{CE} = V_{CEQ} - 0.5$

and $|\Delta i_C| = \frac{1}{0.545 \text{ k}\Omega}\cdot|\Delta v_{CE}|$

$I_{CQ} - 0.25 = \frac{V_{CEQ} - 0.5}{0.545}$

$V_{CEQ} = 5 - I_{CQ}(1.1)$

$0.545(I_{CQ} - 0.25) = [5 - I_{CQ}(1.1)] - 0.5$

$(0.545 + 1.1)I_{CQ} = 5 - 0.5 + 0.136$

$\underline{I_{CQ} = 2.82 \text{ mA}}, \quad I_{BQ} = 0.0157 \text{ mA}$

$R_{TH} = R_1\|R_2 = (0.1)(1+\beta)R_E$

$= (0.1)(181)(0.1) = 1.81 \text{ k}\Omega$

$V_{TH} = \frac{1}{R_1}\cdot R_{TH}\cdot V^+ = I_{BQ}R_{TH} + V_{BE}(\text{on}) + (1+\beta)I_{BQ}R_E$

$\frac{1}{R_1}(1.81)(5) = (0.0157)(1.81) + 0.7 + (181)(0.0157)(0.1)$

$\frac{1}{R_1}(9.05) = 1.01 \Rightarrow \underline{R_1 = 8.96 \text{ k}\Omega}$

$\frac{8.96R_2}{8.96 + R_2} = 1.81 \Rightarrow \underline{R_2 = 2.27 \text{ k}\Omega}$

4.31

$I_{CQ} = 0.647 \text{ mA}, \quad V_{CEQ} = 10 - (0.647)(9) = 4.18 \text{ V}$

$\Delta i_C = I_{CQ} = 0.647 \text{ mA}$

So $\Delta v_{CE} = \Delta i_C(4\|4) = (0.647)(2) = 1.294 \text{ V}$

Voltage swing is well within the voltage specification. Then

$\underline{\Delta v_{CE} = 2(1.294) = 2.59 \text{ V}}$ peak-to-peak

4.32

a. $R_{TH} = R_1\|R_2 = 10\|10 = 5 \text{ k}\Omega$

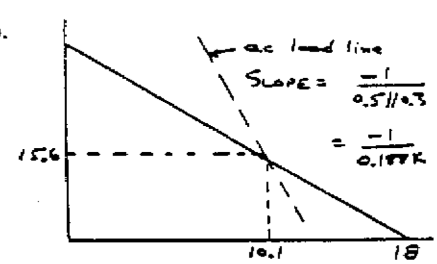
$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right)(18) - 9 = \left(\frac{10}{10+10}\right)(18) - 9 = 0$

$I_{BQ} = \frac{0 - 0.7 - (-9)}{5 + (181)(0.5)} = 0.0869 \text{ mA}$

$I_{CQ} = 15.6 \text{ mA}, \quad I_{EQ} = 15.7 \text{ mA}$

$V_{CEQ} = 18 - (15.7)(0.5) \Rightarrow \underline{V_{CEQ} = 10.1 \text{ V}}$

b.



c. $r_\pi = \dfrac{(180)(0.026)}{15.6} = 0.30\ \text{k}\Omega$

$$A_v = \frac{(1+\beta)(R_E\|R_L)}{r_\pi + (1+\beta)(R_E\|R_L)} \cdot \left(\frac{R_1\|R_2\|R_{ib}}{R_1\|R_2\|R_{ib} + R_S}\right)$$

$R_{ib} = r_\pi + (1+\beta)(R_E\|R_L) = 0.30 + (181)(0.5\|0.3)$

or $R_{ib} = 34.2\ k\Omega$

$R_1\|R_2\|R_{ib} = 5\|34.2 = 4.36\ k\Omega$

$$A_v = \frac{(181)(0.5\|0.3)}{0.3+(181)(0.5\|0.3)} \cdot \left(\frac{4.36}{4.36+1}\right) \Rightarrow \underline{A_v = 0.806}$$

d. $R_{ib} = r_\pi + (1+\beta)(R_E\|R_L)$

$R_{ib} = 0.30 + (181)(0.188) \Rightarrow \underline{R_{ib} = 34.3\ \text{k}\Omega}$

$$R_o = R_E \left\| \frac{r_\pi + R_1\|R_2\|R_S}{1+\beta} = 0.5 \right\| \frac{0.3+5\|1}{181} \Rightarrow$$

$\underline{R_o = 6.18\ \Omega}$

4.33

a. $R_{TH} = R_1\|R_2 = 10\|10 = 5\ \text{k}\Omega$

$V_{TH} = \left(\dfrac{R_2}{R_1+R_2}\right)(-10) = -5\ \text{V}$

$V_{TH} = I_{BQ}R_{TH} + V_{BE}(\text{on}) + (1+\beta)I_{BQ}R_E - 10$

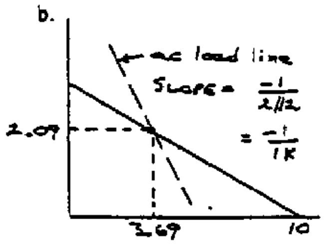
$I_{BQ} = \dfrac{-5-0.7-(-10)}{5+(121)(2)} = 0.0174\ \text{mA}$

$\underline{I_{CQ} = 2.09\ \text{mA}}$, $\underline{I_{EQ} = 2.11\ \text{mA}}$

$V_{CEQ} = 10 - (2.09)(1) - (2.11)(2)$

$\Rightarrow \underline{V_{CEQ} = 3.69\ \text{V}}$

b.



c. $r_\pi = \dfrac{(120)(0.026)}{2.09} = 1.49\ \text{k}\Omega$

$$A_v = \frac{(1+\beta)(R_E\|R_L)}{r_\pi + (1+\beta)(R_E\|R_L)} \cdot \left(\frac{R_1\|R_2\|R_{ib}}{R_1\|R_2\|R_{ib} + R_S}\right)$$

$R_{ib} = r_\pi + (1+\beta)(R_E\|R_L) = 1.49 + (121)(2\|2)$

$R_{ib} = 122.5\ k\Omega$, $R_1\|R_2\|R_{ib} = 5\|122.5 = 4.80\ k\Omega$

$$A_v = \frac{(121)(2\|2)}{1.49+(121)(2\|2)} \cdot \left(\frac{4.80}{4.80+5}\right) \Rightarrow$$

$\underline{A_v = 0.484}$

d. $R_{ib} = r_\pi + (1+\beta)(R_E\|R_L)$

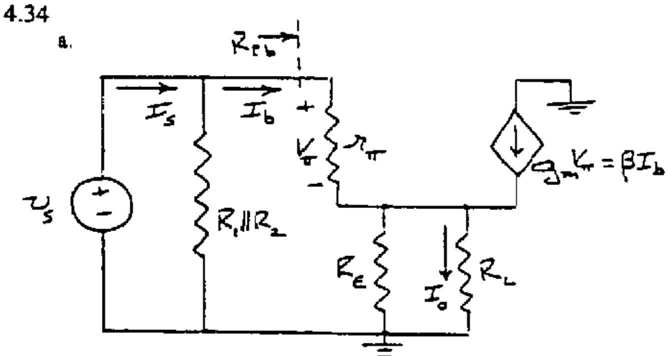
$R_{ib} = 1.49 + (121)(2\|2) \Rightarrow \underline{R_{ib} = 122\ \text{k}\Omega}$

$$R_o = R_E \left\| \frac{r_\pi + R_1\|R_2\|R_S}{1+\beta} = 2 \right\| \frac{1.49+5\|5}{121} \Rightarrow$$

$R_o = 32.5\ \Omega$

4.34

a.



$I_0 = (1+\beta)I_b\left(\dfrac{R_E}{R_E+R_L}\right)$

$I_b = I_S\left(\dfrac{R_1\|R_2}{R_1\|R_2 + R_{ib}}\right)$

$R_{ib} = r_\pi + (1+\beta)(R_E\|R_L)$

$V_{CC} = 10\ \text{V}$, For $\underline{V_{CEQ} = 5\ \text{V}}$

$5 = 10 - \left(\dfrac{1+\beta}{\beta}\right)I_{CQ}R_E$

$\beta = 80$, For $R_E = 0.5\ \text{k}\Omega$

$I_{CQ} = 9.88\ \text{mA}$, $I_{EQ} = 10\ \text{mA}$, $I_{BQ} = 0.123\ \text{mA}$

$r_\pi = \dfrac{(80)(0.026)}{9.88} = 0.211\ \text{k}\Omega$

$R_{ib} = 0.211 + (81)(0.5\|0.5) \Rightarrow \underline{R_{ib} = 20.46\ \text{k}\Omega}$

$A_i = \dfrac{I_0}{I_S} = (1+\beta)\left(\dfrac{R_E}{R_E+R_L}\right)\left(\dfrac{R_1\|R_2}{R_1\|R_2 + R_{ib}}\right)$

$8 = (81)\left(\dfrac{1}{2}\right)\left(\dfrac{R_1\|R_2}{R_1\|R_2 + 20.46}\right)$

$0.1975[R_1\|R_2 + 20.46] = R_1\|R_2$

$R_1\|R_2 \Rightarrow 5.04\ \text{k}\Omega$

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

$\dfrac{1}{R_1}(5.04)(10) = (0.123)(5.04) + 0.7 + (10)(0.5)$

$\Rightarrow \underline{R_1 = 7.97\ \text{k}\Omega}$

$\dfrac{7.97R_2}{7.97+R_2} = 5.04 \Rightarrow \underline{R_2 = 13.7\ \text{k}\Omega}$

(b) $R_{ib} = 0.211 + (81)(0.5\|2) = 32.6\ k\Omega$

$$A_i = (81)\left(\frac{0.5}{0.5+2}\right)\left(\frac{5.04}{5.04+32.6}\right) = (81)(0.2)(0.134)$$

$\underline{A_i = 2.17}$

4.35

$R_i = R_{TH}\|R_{ib}$ where $R_{ib} = r_\pi + (1+\beta)R_E$

$V_{CEQ} = 3.5,\quad I_{CQ} = \dfrac{5-3.5}{2} = 0.75\ mA$

$$r_\pi = \frac{(120)(0.026)}{0.75} = 4.16\ k\Omega$$

$R_{ib} = 4.16 + (121)(2) = 246\ k\Omega$

Then $R_i = 120 = R_{TH}\|245 \Rightarrow R_{TH} = 235\ k\Omega$

$$I_{BQ} = \frac{0.75}{120} = 0.00625\ mA$$

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

$$\frac{1}{R_1}\cdot R_{TH}\cdot V_{CC} = \frac{1}{R_1}(235)(5) = (0.00625)(235)$$
$$+0.7 + (121)(0.00625)(2)$$

which yields $\underline{R_1 = 319\ k\Omega}$ and $\underline{R_2 = 892\ k\Omega}$

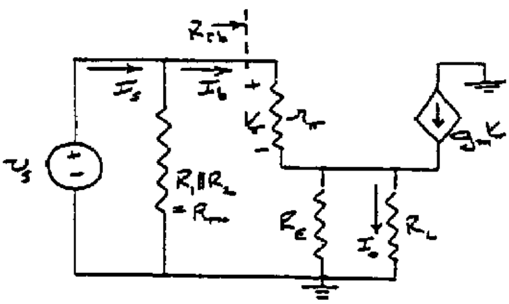
4.36

a. Let $R_E = 24\ \Omega$ and $V_{CEQ} = \frac{1}{2}V_{CC} = 12$ V

$$\Rightarrow I_{EQ} = \frac{12}{24} = 0.5 \text{ A}$$

$I_{CQ} = 0.493$ A, $I_{BQ} = 6.58$ mA

$$r_\pi = \frac{(75)(0.026)}{0.493} = 3.96\ \Omega$$



$$I_0 = (1+\beta)I_b\left(\frac{R_E}{R_E+R_L}\right)$$

$$I_b = I_S\left(\frac{R_{TH}}{R_{TH}+R_{ib}}\right)$$

$R_{ib} = r_\pi + (1+\beta)(R_E\|R_L)$

$= 3.96 + (76)(24\|8) \Rightarrow R_{ib} = 460\ \Omega$

$$A_i = \frac{I_0}{I_S} = (1+\beta)\left(\frac{R_E}{R_E+R_L}\right)\left(\frac{R_{TH}}{R_{TH}+R_{ib}}\right)$$

$$8 = (76)\left(\frac{24}{24+8}\right)\left(\frac{R_{TH}}{R_{TH}+460}\right)$$

$$0.140 = \frac{R_{TH}}{R_{TH}+460}$$

$\Rightarrow \underline{R_{TH} = 74.9\ \Omega}$ (Minimum value)

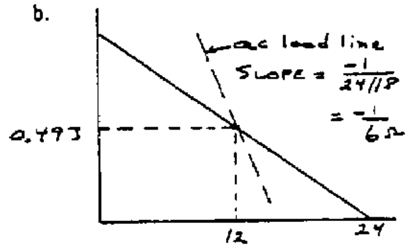
dc analysis:

$$V_{TH} = \frac{1}{R_1}\cdot R_{TH}\cdot V_{CC}$$
$$= I_{BQ}R_{TH} + V_{BE}(\text{on}) + I_{EQ}R_E$$

$$\frac{1}{R_1}(74.9)(24) = (0.00658)(74.9) + 0.70$$
$$+ (0.5)(24)$$
$$= 12.75$$

$\underline{R_1 = 136\ \Omega}$, $\dfrac{136R_2}{136+R_2} = 74.9 \Rightarrow \underline{R_2 = 167\ \Omega}$

b.



$$\Delta i_C = -\frac{1}{6}\Delta v_{ce}$$

For $\Delta i_C = 0.493$

$\Rightarrow |\Delta v_{ce}| = (0.493)(6)$

$\Rightarrow$ Max. swing in output voltage for this design

$= \underline{5.92 \text{ V peak-to-peak}}$

c. $R_0 = \dfrac{r_\pi}{1+\beta}\ \Big\|\ R_E = \dfrac{3.96}{76}\ \Big\|\ 24 = 0.0521\|24$

$\Rightarrow \underline{R_0 = 52\ m\Omega}$

4.37

a. $R_{TH} = R_1\|R_2 = 60\|40 = 24$ kΩ

$$V_{TH} = \left(\frac{R_2}{R_1+R_2}\right)V_{CC} = \left(\frac{40}{40+60}\right)(5) = 2 \text{ V}$$

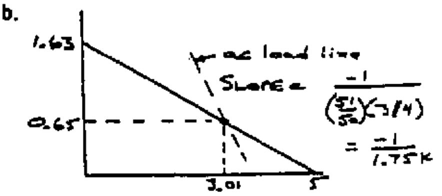
$$I_{BQ} = \frac{5-0.7-2}{24+(51)(3)} = 0.0130 \text{ mA}$$

$\underline{I_{CQ} = 0.650 \text{ mA}}$, $I_{EQ} = 0.663$ mA

$V_{ECQ} = 5 - I_{EQ}R_E = 5 - (0.663)(3)$

$\Rightarrow \underline{V_{CEQ} = 3.01 \text{ V}}$

b.



c. $r_\pi = \dfrac{(50)(0.026)}{0.650} = 2\ \text{k}\Omega,\ r_0 = \dfrac{80}{0.65} = 123\ \text{k}\Omega$

Define $R_L' = R_E \| R_L \| r_0 = 3\|4\|123 = 1.69\ \text{k}\Omega$

$$A_v = \frac{(1+\beta)R_L'}{r_\pi + (1+\beta)R_L'} = \frac{(51)(1.69)}{2+(51)(1.69)}$$

$\Rightarrow \underline{A_v = 0.977}$

$$A_i = (1+\beta)I_b\left(\frac{R_E\|r_0}{R_E\|r_0 + R_L}\right)$$

$$I_b = I_S\left(\frac{R_{TH}}{R_{TH}+R_{ib}}\right)$$

$R_{ib} = r_\pi + (1+\beta)R_L' = 2 + (51)(1.69) = 88.2$

$R_E\|r_0 = 3\|r_0 = 3\|123 = 2.93$

$$A_i = (51)\left(\frac{2.93}{2.93+4}\right)\left(\frac{24}{24+88.2}\right)$$

$\Rightarrow \underline{A_i = 4.61}$

d. $R_{ib} = r_\pi + (1+\beta)R_E\|R_L\|r_0 = 2 + (51)(1.69)$

$\Rightarrow \underline{R_{ib} = 88.2\ \text{k}\Omega}$

$R_0 = \dfrac{r_\pi}{1+3} \Big\| R_E = \left(\dfrac{2}{51}\right) \Big\| 3 = 0.0392\|3$

$R_0 = 38.7\ \Omega$

e. Assume variations in r_π and r_0 have negligible effects

$R_1 = 60 \pm 5\%$ —	$R_1 = 63$ kΩ,	$R_1 = 57$ kΩ
$R_2 = 40 \pm 5\%$	$R_2 = 42$ kΩ,	$R_2 = 38$ kΩ
$R_E = 3 \pm 5\%$	$R_E = 3.15$ kΩ,	$R_E = 2.85$ kΩ
$R_L = 4 \pm 5\%$	$R_L = 4.2$ kΩ,	$R_L = 3.8$ kΩ

$$A_i = (1+\beta)\left(\frac{R_E\|r_0}{R_E\|r_0 + R_L}\right)\left(\frac{R_{TH}}{R_{TH}+R_{ib}}\right)$$

$R_{ib} = r_\pi + (1+\beta)(R_E\|R_L\|r_0)$

$R_{TH}(\max) = 25.2\ \text{k}\Omega,\quad R_{TH}(\min) = 22.8\ \text{k}\Omega$

$R_{ib}(\max) = 92.5\ \text{k}\Omega,\quad R_{ib}(\min) = 84.0\ \text{k}\Omega$

$R_E(\max),\ R_L(\min),\ R_{ib} = 88.6\ \text{k}\Omega$

$R_E(\min),\ R_L(\max),\ R_{ib} = 87.4\ \text{k}\Omega$

$R_E(\max)\|r_0 = 3.07\ \text{k}\Omega$

$R_E(\min)\|r_0 = 2.79\ \text{k}\Omega$

For $R_E(\min),\ R_L(\max),\ R_{TH}(\min)$

$$A_i = (51)\left(\frac{2.79}{2.79+4.2}\right)\left(\frac{22.8}{22.8+87.4}\right)$$

$\Rightarrow \underline{A_i = 4.21}$

For $R_E(\max),\ R_L(\min),\ R_{TH}(\max)$

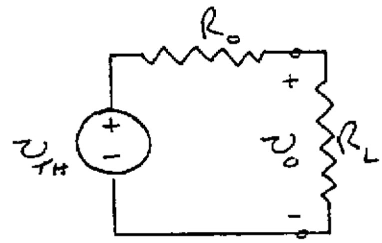
$$A_i = (51)\left(\frac{3.07}{3.07+3.8}\right)\left(\frac{25.2}{25.2+88.6}\right)$$

$\Rightarrow \underline{A_i = 5.05}$

4.38

The output of the emitter follower is

$$v_O = \left(\frac{R_L}{R_L+R_o}\right)\cdot v_{TH}$$



For v_O to be within 5% for a range of R_L, we have

$$\frac{R_L(\min)}{R_L(\min)+R_o} = (0.95)\frac{R_L(\max)}{R_L(\max)+R_o}$$

$\dfrac{4}{4+R_o} = (0.95)\dfrac{10}{10+R_o}$ which yields

$R_o = 0.364\ k\Omega$

We have $R_o = \left(\dfrac{r_\pi + R_1\|R_2\|R_S}{1+\beta}\right)\Big\|R_E\|r_o$

The first term dominates

Let $R_1\|R_2\|R_S \cong R_S$, then

$$R_o \cong \frac{r_\pi + R_S}{1+\beta} \Rightarrow 0.364 = \frac{r_\pi + 4}{1+\beta}$$

or

$$0.364 = \frac{r_\pi}{1+\beta} + \frac{4}{1+\beta} = \frac{\beta V_T}{I_{CQ}(1+\beta)} + \frac{4}{1+\beta}$$

$$0.364 \cong \frac{V_T}{I_{CQ}} + \frac{4}{1+\beta}$$

The factor $\dfrac{4}{1+\beta}$ is in the range of $\dfrac{4}{91} = 0.044$ to $\dfrac{4}{131} = 0.0305$. We can set $R_o \cong 0.32 = \dfrac{V_T}{I_{CQ}}$

Or $I_{CQ} = 0.08125\ mA$. To take into account other factors, set $I_{CQ} = 0.15\ mA$,

$$I_{BQ} = \frac{0.15}{110} = 0.00136\ mA$$

For $V_{CEQ} \cong 5V$, set $R_E = \dfrac{5}{0.15} = 33.3\ k\Omega$

Design a bias stable circuit.

$$V_{TH} = \left(\frac{R_2}{R_1+R_2}\right)(10) - 5 = \frac{1}{R_1}(R_{TH})(10) - 5$$

$$R_{TH} = (0.1)(1+\beta)R_E = (0.1)(111)(33.3) = 370\ k\Omega$$

$$V_{TH} = I_{BQ}R_{TH} + V_{BE}(on) + (1+\beta)I_{BQ}R_E - 5$$

So $\frac{1}{R_1}(370)(10) - 5 = (0.00136)(370) + 0.7$

$$+(111)(0.00136)(33.3) - 5$$

which yields $\underline{R_1 = 594\ k\Omega}$ and $\underline{R_2 = 981\ k\Omega}$

Now

$$A_v = \frac{(1+\beta)(R_E \| R_L)}{r_\pi + (1+\beta)(R_E \| R_L)} \cdot \left(\frac{R_{TH} \| R_{ib}}{R_{TH} \| R_{ib} + R_S}\right)$$

$R_{ib} = r_\pi + (1+\beta)(R_E \| R_L)$ and $r_\pi = \frac{\beta V_T}{I_{CQ}}$

For $\beta = 90$, $R_L = 4\ k\Omega$,

$r_\pi = 15.6\ k\Omega$, $R_{ib} = 340.6\ k\Omega$

$$A_v = \frac{(91)(33.3\|4)}{15.6 + (91)(33.3\|4)} \cdot \frac{370\|340.6}{370\|340.6 + 4} \Rightarrow$$

$A_v = 0.9332$

For $\beta = 90$, $R_L = 10\ k\Omega$

$R_{ib} = 715.4\ k\Omega$

$$A_v = \frac{(91)(33.3\|10)}{15.6 + (91)(33.3\|10)} \cdot \frac{370\|715.4}{370\|715.4 + 4} \Rightarrow$$

$A_v = 0.9625$

For $\beta = 130$, $R_L = 4\ k\Omega$

$r_\pi = 22.5\ k\Omega$, $R_{ib} = 490\ k\Omega$

$$A_v = \frac{(131)(33.3\|4)}{22.5 + (131)(33.3\|4)} \cdot \frac{370\|490}{370\|490 + 4} \Rightarrow$$

$A_v = 0.9360$

For $\beta = 130$, $R_L = 10\ k\Omega$

$R_{ib} = 1030\ k\Omega$

$$A_v = \frac{(131)(33.3\|10)}{22.5 + (131)(33.3\|10)} \cdot \frac{370\|1030}{370\|1030 + 4} \Rightarrow$$

$A_v = 0.9645$

Now $v_O(\min) = |A_v(\min)| \cdot v_S = 3.73 \sin \omega t$

$v_O(\max) = |A_v(\max)| \cdot v_S = 3.86 \sin \omega t$

$$\frac{\Delta v_O}{v_O} = 3.5\%$$

4.39

a. $R_{TH} = R_1 \| R_2 = 40\|60 = 24\ k\Omega$

$$V_{TH} = \left(\frac{60}{60+40}\right)(10) = 6\ \text{V}$$

$\beta = 75$

$$I_{BQ} = \frac{6 - 0.7}{24 + (76)(5)} = 0.0131\ \text{mA}$$

$I_{CQ} = 0.984$ mA

$\beta = 150$

$$I_{BQ} = \frac{6 - 0.7}{24 + (151)(5)} = 0.00680\ \text{mA}$$

$I_{CQ} = 1.02$ mA

$\beta = 75$

$$r_\pi = \frac{(75)(0.026)}{0.984} = \underline{1.98\ k\Omega}$$

$\beta = 150$

$\underline{r_\pi = 3.82\ k\Omega}$

$\beta = 75$

$R_{ib} = r_\pi + (1+\beta)(R_E \| R_L) = 65.3\ k\Omega$

$\beta = 150$

$R_{ib} = 130\ k\Omega$

$$A_v = \frac{(1+\beta)(R_E \| R_L)}{r_\pi + (1+\beta)(R_E \| R_L)} \cdot \frac{R_1 \| R_2 \| R_{ib}}{R_1 \| R_2 \| R_{ib} + R_S}$$

For $\beta = 75$, $R_1 \| R_2 \| R_{ib} = 40\|60\|65.3 = 17.5\ k\Omega$

$$A_v = \frac{(76)(0.833)}{1.98 + (76)(0.833)} \cdot \frac{17.5}{17.5 + 4} \Rightarrow$$

$\underline{A_v = 0.789}$

For $\beta = 150$, $R_1 \| R_2 \| R_{ib} = 40\|60\|130 = 20.3\ k\Omega$

$$A_v = \frac{(151)(0.833)}{3.82 + (151)(0.833)} \cdot \frac{20.3}{20.3 + 4} \Rightarrow$$

$\underline{A_v = 0.811}$

$$A_i = (1+\beta)\left(\frac{R_E}{R_E + R_L}\right)\left(\frac{R_{TH}}{R_{TH} + R_{ib}}\right)$$

$\beta = 75$

$$A_i = (76)\left(\frac{5}{5+1}\right)\left(\frac{24}{24 + 65.3}\right) \Rightarrow \underline{A_i = 17.0}$$

$\beta = 150$

$$A_i = (151)\left(\frac{5}{6}\right)\left(\frac{24}{24 + 130}\right) \Rightarrow \underline{A_i = 19.6}$$

$\underline{17.0 \le A_i \le 19.6}$

b. Current gain is the same as part (a)

(b)For $R_S = 5\ k\Omega$

$\beta = 75 \Rightarrow A_v = 0.754$

$\beta = 150 \Rightarrow A_v = 0.779$

4.40

(a) $I_{BQ} = \frac{0.5}{81} = 0.00617\ mA$

$V_B = I_{BQ}R_B = (0.00617)(10) \Rightarrow \underline{V_B = 0.0617\ V}$

$V_E = V_B + 0.7 \Rightarrow \underline{V_E = 0.7617\ V}$

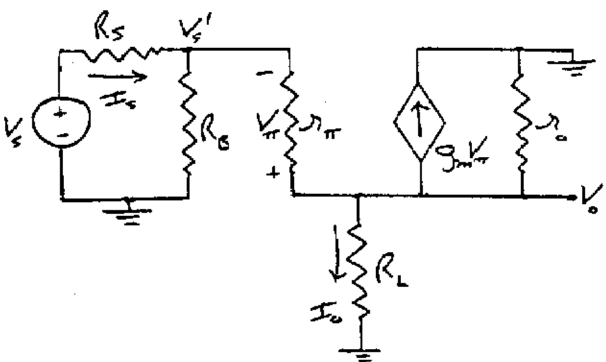
(b) $I_{CQ} = (0.5)\left(\frac{80}{81}\right) = 0.494\ mA$

$g_m = \frac{I_{CQ}}{V_T} = \frac{0.494}{0.026} \Rightarrow \underline{g_m = 19\ mA/V}$

$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{(80)(0.026)}{0.494} \Rightarrow \underline{r_\pi = 4.21\ k\Omega}$

$r_o = \frac{V_A}{I_{CQ}} = \frac{150}{0.494} \Rightarrow \underline{r_o = 304\ k\Omega}$

(c)



For $R_S = 0$

$$V_o = -\left(\frac{V_\pi}{r_\pi} + g_m V_\pi\right)(R_L \| r_o)$$

so that

$$V_\pi = \frac{-V_o}{\left(\frac{1+\beta}{r_\pi}\right)(R_L \| r_o)}$$

Now

$V_s + V_\pi = V_o$

or

$$V_s = V_o - V_\pi = V_o + \frac{V_o}{\left(\frac{1+\beta}{r_\pi}\right)(R_L \| r_o)}$$

We find

$$A_v = \frac{V_o}{V_s} = \frac{(1+\beta)(R_L \| r_o)}{r_\pi + (1+\beta)(R_L \| r_o)} = \frac{(81)(0.5 \| 304)}{4.21 + (81)(0.5 \| 304)}$$

$$\cong \frac{(81)(0.5)}{4.21 + (81)(0.5)} \Rightarrow \underline{A_v = 0.906}$$

$R_{ib} = r_\pi + (1+\beta)(R_L \| r_o) \cong 4.21 + (81)(0.5) = 44.7\ k\Omega$

$I_b = \left(\frac{R_B}{R_B + R_{ib}}\right) \cdot I_s$ and $I_o = \left(\frac{r_o}{r_o + R_L}\right)(1+\beta) I_b$

Then

$$A_i = \frac{I_o}{I_s} = (1+\beta)\left(\frac{R_B}{R_B + R_{ib}}\right)\left(\frac{r_o}{r_o + R_L}\right)$$

$$A_i \cong (81)\left(\frac{10}{10 + 44.7}\right)(1) \Rightarrow \underline{A_i = 14.8}$$

(d)

$$V_s' = \left(\frac{R_B \| R_{ib}}{R_B \| R_{ib} + R_S}\right) \cdot V_s = \left(\frac{10 \| 44.7}{10 \| 44.7 + 2}\right) \cdot V_s = (0.803) V_s$$

Then

$A_v = (0.803)(0.906) \Rightarrow \underline{A_v = 0.728}$

$\underline{A_i = 14.8}$ (Unchanged)

4.41

$V_o = (1+\beta) I_b R_L$

$$I_b = \frac{V_s}{r_\pi + (1+\beta) R_L}$$

so $A_v = \frac{(1+\beta) R_L}{r_\pi + (1+\beta) R_L}$

For $\beta = 100$, $R_L = 0.5\ k\Omega$

$r_\pi = \frac{(100)(0.026)}{0.5} = 5.2\ k\Omega$

Then $A_v(\min) = \frac{(101)(0.5)}{5.2 + (101)(0.5)} = 0.9066$

For $\beta = 180$, $R_L = 500\ k\Omega$

$r_\pi = \frac{(180)(0.026)}{0.5} = 9.36\ k\Omega$

Then $A_v(\max) = \frac{(181)(500)}{9.36 + (181)(500)} = 0.9999$

4.42

a. $I_{EQ} = 1$ mA, $V_{CEQ} = V_{CC} - I_{EQ} R_E$

$5 = 10 - (1)(R_E) \Rightarrow \underline{R_E = 5\ k\Omega}$

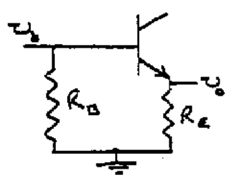
$I_{BQ} = \frac{1}{101} = 0.0099$

$10 = I_{BQ} R_B + V_{BE}(\text{on}) + I_{EQ} R_E$

$10 = (0.0099) R_B + 0.7 + (1)(5)$

$\Rightarrow \underline{R_B = 434\ k\Omega}$

b.

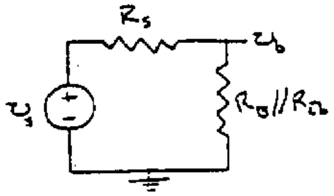


$r_\pi = \frac{(100)(0.026)}{0.99} = 2.63\ k\Omega$

$$\frac{v_0}{v_b} = \frac{(1+\beta) R_E}{r_\pi + (1+\beta) R_E} = \frac{(101)(5)}{2.63 + (101)(5)} = 0.995$$

$\Rightarrow v_b = \frac{v_0}{0.995} = \frac{4}{0.995}$

$\Rightarrow \underline{v_b = 4.02\ \text{V peak-to-peak at base}}$



$R_{ib} = r_\pi + (1+\beta)R_E = 508 \text{ k}\Omega$

$R_B \| R_{ib} = 434 \| 508 = 234 \text{ k}\Omega$

$\nu_b = \dfrac{R_B \| R_{ib}}{R_B \| R_{ib} + R_S} \cdot \nu_S = \dfrac{234\nu_S}{234 + 0.7} = \dfrac{234}{234.7}\nu_S$

$\nu_b = 0.997\nu_S$

$\Rightarrow \nu_S = \dfrac{4.02}{0.997} \Rightarrow \nu_S = 4.03$ V peak-to-peak

c. $R_{ib} = r_\pi + (1+\beta)(R_E \| R_L)$

$R_{ib} = 2.63 + (101)(5\|1) = 86.8 \text{ k}\Omega$

$R_B \| R_{ib} = 434 \| 86.8 = 72.3 \text{ k}\Omega$

$\nu_b = \left(\dfrac{72.3}{72.3 + 0.7}\right)\nu_S = 0.99\nu_S = (0.99)(4.03)$

$\nu_b = 3.99$ V peak-to-peak

$\nu_0 = \dfrac{(1+\beta)(R_E \| R_L)}{r_\pi + (1+\beta)(R_E \| R_L)} \cdot \nu_b$

$= \dfrac{(101)(0.833)}{2.63 + (101)(0.833)}(3.99)$

$\nu_0 = 3.87$ V peak-to-peak

4.43

$P_{AVG} = i_L^2(rms)R_L \Rightarrow 1 = i_L^2(rms)(12)$

so $i_L(rms) = 0.289\ A \Rightarrow i_L(peak) = \sqrt{2}(0.289)$

$i_L(peak) = 0.409\ A$

$v_L(peak) = i_L(peak) \cdot R_L = (0.409)(12) = 4.91\ V$

Need a gain of $\dfrac{4.91}{5} = 0.982$

With $R_S = 10\ k\Omega$, we will not be able to meet this voltage gain requirement. Need to insert a buffer or an op-amp voltage follower (see Chapter 9) between R_S and C_{C1}.

Set $I_{EQ} = 0.5\ A$, $V_{CEQ} = \dfrac{1}{3}(12 - (-12)) = 8\ V$

$24 = I_{EQ}R_E + V_{CEQ} = (0.5)R_E + 8 \Rightarrow \underline{R_E = 32\ \Omega}$

Let $\beta = 50$, $I_{CQ} = \dfrac{50}{51}(0.5) = 0.49\ A$

$r_\pi = \dfrac{\beta V_T}{I_{CQ}} = \dfrac{(50)(0.026)}{0.49} = 2.65\ \Omega$

$R_{ib} = r_\pi + (1+\beta)(R_E \| R_L) = 2.65 + (51)(32\|12)$

$R_{ib} = 448\ \Omega$

$I_{BQ} = \dfrac{0.49}{50} = 0.0098\ A = 9.8\ mA$

Let $I_R \cong \dfrac{24}{R_1 + R_2} \cong 10 I_B = 98\ mA$

So that $R_1 + R_2 = 245\ \Omega$

$V_{TH} = \dfrac{R_2}{R_1 + R_2}(24) - 12 = I_{BQ}R_{TH} + V_{BE}(on)$
$+ I_{EQ}R_E - 12$

$\left(\dfrac{R_2}{245}\right)(24) = \dfrac{(0.0098)R_1 R_2}{245} + 0.7 + (0.5)(32)$

Now $R_1 = 245 - R_2$

So we obtain

$4x10^{-5}R_2^2 + 0.0882R_2 - 16.7 = 0$

which yields $R_2 = 175\ \Omega$ and $R_1 = 70\ \Omega$

4.44

(a) $R_{TH} = R_1 \| R_2 = 25.6 \| 10.4 = 7.40\ k\Omega$

$V_{TH} = \left(\dfrac{R_2}{R_1 + R_2}\right)(V_{CC}) = \left(\dfrac{10.4}{10.4 + 25.6}\right)(18) = 5.2\ V$

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

$I_{BQ} = \dfrac{5.2 - 0.7}{7.40 + (126)(3)} = 0.0117\ mA$

Then $\underline{I_{CQ} = 1.46\ mA}$ and $I_{EQ} = 1.47\ mA$

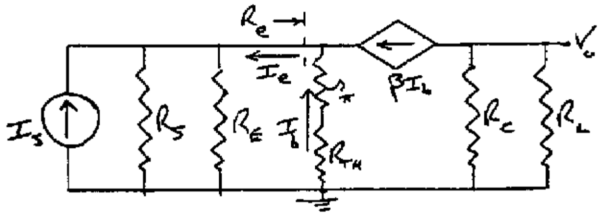
$V_{CEQ} = V_{CC} - I_{CQ}R_C - I_{EQ}R_E$

$V_{CEQ} = 18 - (1.46)(4) - (1.47)(3) \Rightarrow \underline{V_{CEQ} = 7.75\ V}$

(b)

$r_\pi = \dfrac{(125)(0.026)}{1.46} = 2.23\ k\Omega$

$g_m = \dfrac{1.46}{0.026} = 56.2\ mA/V$



$R_e = \dfrac{r_\pi + R_{TH}}{1+\beta} = \dfrac{2.23 + 7.40}{126} = 0.0764\ k\Omega$

$I_e = \dfrac{-(R_S \| R_E)}{(R_S \| R_E) + R_e} \cdot I_s = \dfrac{-(100\|3)}{(100\|3) + 0.0764} \cdot I_s$

or $I_e = -(0.974)I_s$

$V_o = -I_c(R_C \| R_L) = -\left(\dfrac{\beta}{1+\beta}\right)I_e(R_C \| R_L)$

Then

$$\frac{V_o}{I_s} = -\left(\frac{\beta}{1+\beta}\right)(-0.974)(R_C \| R_L) = \left(\frac{125}{126}\right)(0.974)(4\|4)$$

Then

$$R_m = \frac{V_o}{I_s} = 1.93\ k\Omega = 1.93\ V/mA$$

(c)

$$V_s = I_s(R_S \| R_E \| R_e) = I_s(100\|3\|0.0764) = I_s(0.0744)$$

or $I_s = \dfrac{V_s}{0.0744}$

which yields $\dfrac{V_o}{I_s} = \dfrac{V_o}{V_s}(0.0744) = 1.93$

or $A_v = \dfrac{V_o}{V_s} = 25.9$

4.45

(a) $A_v = \dfrac{\beta(R_C \| R_L)}{r_\pi + R_1 \| R_2}$, $R_L = 12\ k\Omega$, $\beta = 100$

Let $R_1 \| R_2 = 50\ k\Omega$, $I_{CQ} = 0.5\ mA$

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

$$I_{BQ} = \frac{0.5}{100} = 0.005\ mA, \quad r_\pi = \frac{(100)(0.026)}{0.5} = 5.2\ k\Omega$$

$$\frac{1}{R_1} \cdot R_{TH} \cdot V_{CC} = \frac{1}{R_1}(50)(12) = (0.005)(50) + 0.7 + (101)(0.005)(0.5)$$

which yields $R_1 = 500\ k\Omega$ and $R_2 = 55.6\ k\Omega$

$A_v = \dfrac{(100)(12\|12)}{5.2+50} = 10.7$, Design criterion is met.

(b)

$I_{CQ} = 0.5\ mA$, $I_{EQ} = 0.505\ mA$

$V_{CEQ} = 12 - (0.5)(12) - (0.505)(0.5) \Rightarrow$

$V_{CEQ} = 5.75\ V$

$A_v = g_m(R_C \| R_L)$, $g_m = \dfrac{0.5}{0.026} = 19.23\ mA/V$

$A_v = (19.23)(12\|12) \Rightarrow A_v = 115$

4.46

$i_s(peak) = 2.5\ \mu A$, $v_o(peak) = 5\ mV$

So we need $R_m = \dfrac{v_o}{i_s} = \dfrac{5x10^{-3}}{2.5x10^{-6}} = 2x10^3 = 2\ k\Omega$

From Problem 4.44

$$\frac{V_o}{I_s} = \left(\frac{\beta}{1+\beta}\right)(R_C \| R_L)\left(\frac{R_S \| R_E}{R_S \| R_E + R_e}\right)$$

Let $R_C = 4\ k\Omega$, $R_L = 5\ k\Omega$, $R_E = 2\ k\Omega$

Now $\beta = 120$, so we have

$$2 = \left(\frac{120}{121}\right)(4\|5)\left(\frac{R_S \| R_E}{R_S \| R_E + R_e}\right) = 2.20\left(\frac{R_S \| R_E}{R_S \| R_E + R_e}\right)$$

Then $\dfrac{R_S \| R_E}{R_S \| R_E + R_e} = 0.909$

$R_S \| R_E = 50\|2 = 1.92\ k\Omega$, so that $R_e = 0.192\ k\Omega$

Assume $V_{CEQ} = 6\ V$

$$V_{CC} \cong I_{CQ}(R_C + R_E) + V_{CEQ}$$

$$12 = I_{CQ}(4+2) + 6 \Rightarrow I_{CQ} = 1\ mA$$

$$r_\pi = \frac{(120)(0.026)}{1} = 3.12\ k\Omega$$

$$R_e = \frac{r_\pi + R_{TH}}{1+\beta} \Rightarrow 0.192 = \frac{3.12 + R_{TH}}{121}$$

which yields $R_{TH} = 20.1\ k\Omega$

Now $V_{TH} = I_{BQ}R_{TH} + V_{BE}(on) + I_{EQ}R_E$

$$I_{BQ} = \frac{1}{120} = 0.00833\ mA,\ I_{EQ} = \left(\frac{121}{120}\right)(1) = 1.008\ mA$$

$$V_{TH} = \frac{1}{R_1} \cdot R_{TH} \cdot V_{CC} = \frac{1}{R_1}(20.1)(5) = (0.00833)(20.1) + 0.7 + (1.008)(2)$$

which yields $R_1 = 34.9\ k\Omega$ and $R_2 = 47.4\ k\Omega$

4.47

a. Emitter current

$$I_{EQ} = I_{CC} = 0.5\ \text{mA}$$

$$I_{BQ} = \frac{0.5}{101} = 0.00495\ \text{mA}$$

$V_E = I_{EQ}R_E = (0.5)(1) \Rightarrow \underline{V_E = 0.5\ V}$

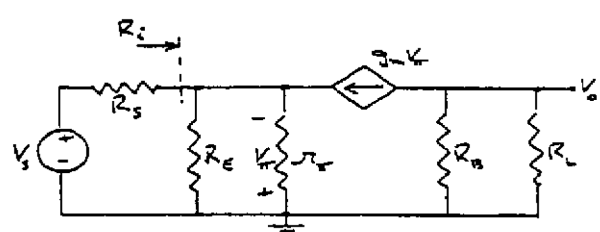
$V_B = V_E + V_{BE}(\text{on}) = 0.5 + 0.7 \Rightarrow \underline{V_B = 1.20\ V}$

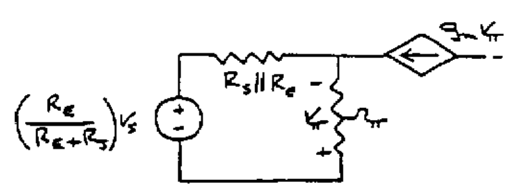
$V_C = V_B + I_{BQ}R_B = 1.20 + (0.00495)(100)$

$\Rightarrow \underline{V_C = 1.7\ V}$

b. $r_\pi = \dfrac{(100)(0.026)}{(100)(0.00495)} = 5.25\ k\Omega$

$$g_m = \frac{(100)(0.00495)}{0.026} = 19.0\ \text{mA/V}$$





$V_0 = -g_m V_\pi (R_B \| R_L)$

$$g_m V_\pi + \frac{V_\pi}{r_\pi} + \frac{\left(\frac{R_E}{R_E+R_S}\right)V_S - (-V_\pi)}{R_S \| R_E} = 0$$

$$V_\pi\left[g_m + \frac{1}{r_\pi} + \frac{1}{R_S\|R_E}\right] = \frac{-\left(\frac{R_E}{R_E+R_S}\right)V_S}{R_S\|R_E}$$

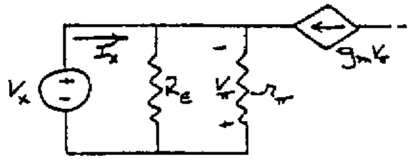
$$V_\pi\left[19.0 + \frac{1}{5.25} + \frac{1}{0.05\|1}\right] = \frac{-\left(\frac{1}{1+0.05}\right)V_S}{0.05\|1}$$

$V_\pi(40.19) = -20V_S \Rightarrow V_\pi = -(0.4976)V_S$

$V_0 = (19)(0.4976)V_S(100\|1)$

$\underline{A_V = 9.36}$

c.



$I_X = \frac{V_X}{R_E} + \frac{V_X}{r_\pi} - g_m V_\pi, \quad V_\pi = -V_X$

$\frac{I_X}{V_X} = \frac{1}{R_i} = \frac{1}{R_E} + \frac{1}{r_\pi} + g_m$

or $R_i = R_E \left\| r_\pi \right\| \frac{1}{g_m} = 1 \left\| 5.25 \right\| \frac{1}{19}$

$R_i = 0.84\|0.0526$

$\Rightarrow \underline{R_i = 49.5\ \Omega}$

4.48

a. $I_{EQ} = \frac{20-0.7}{10} = 1.93$ mA

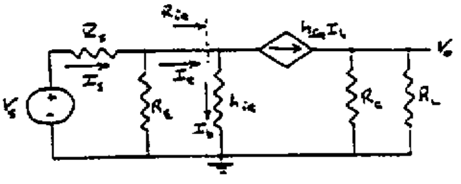
$\underline{I_{CQ} = 1.91\text{ mA}}$

$V_{ECQ} = V_{CC} + V_{EB}(\text{on}) - I_C R_C$

$= 25 + 0.7 - (1.91)(6.5)$

$\Rightarrow \underline{V_{ECQ} = 13.3\text{ V}}$

b.



Neglect effect of h_{oe}

From Problem 4-16, assume

$2.45 \le h_{ie} \le 3.7$ kΩ

$80 \le h_{fe} \le 120$

$V_0 = (h_{fe}I_b)(R_C\|R_L)$

$R_{ie} = \frac{h_{ie}}{1+h_{fe}}, \quad I_e = \left(\frac{R_E}{R_E+R_{ie}}\right)I_S$

$I_b = \left(\frac{I_e}{1+h_{fe}}\right), \quad I_S = \frac{V_S}{R_S + R_E\|R_{ie}}$

$$A_v = \left(\frac{h_{fe}}{1+h_{fe}}\right)(R_C\|R_L)\left(\frac{R_E}{R_E+R_{ie}}\right)\times \left(\frac{1}{R_S + R_E\|R_{ie}}\right)$$

High gain device: $h_{ie} = 3.7$ kΩ, $h_{fe} = 120$

$R_{ie} = \frac{3.7}{121} = 0.0306$ kΩ

$R_E\|R_{ie} = 10\|0.0306 = 0.0305$

$$A_v = \left(\frac{120}{121}\right)(6.5\|5)\left(\frac{10}{10+0.0306}\right)\left(\frac{1}{1+0.0305}\right)$$

$\Rightarrow A_v = 2.711$

Low gain device: $h_{ie} = 2.45$ kΩ, $h_{fe} = 80$

$R_{ie} = \frac{2.45}{81} = 0.03025$ kΩ

$R_E\|R_{ie} = 10\|0.03025 = 0.0302$

$$A_v = \left(\frac{80}{81}\right)(6.5\|5)\left(\frac{10}{10+0.03025}\right)\left(\frac{1}{1+0.0302}\right)$$

$\Rightarrow A_v = 2.70$ So $A_v \approx$ constant

$\underline{2.70 \le A_v \le 2.71}$

c. $R_i = R_E\|R_{ie}$

We found $\underline{0.0302 \le R_i \le 0.0305\text{ k}\Omega}$

Neglecting h_{oe}, $\underline{R_0 = R_C = 6.5\text{ k}\Omega}$

4.49

a. Small-signal voltage gain

$A_v = g_m(R_C\|R_L) \Rightarrow 25 = g_m(R_C\|1)$

For $V_{ECQ} = 3$ V

$\Rightarrow V_C = -V_{ECQ} + V_{EB}(\text{on}) = -3 + 0.7$

$\Rightarrow V_C = -2.3$

$V_{CC} - I_{CQ}R_C + V_C = 0$

$\Rightarrow I_{CQ} = \frac{5-2.3}{R_C} = \frac{2.7}{R_C} = I_{CQ}$

For $I_{CQ} = 1$ mA, $\underline{R_C = 2.7\text{ k}\Omega}$

$g_m = \frac{1}{0.026} = 38.5$ mA/V

$A_v = (38.5)(2.7\|1) = \underline{28.1}$

Design criterion satisfied and V_{ECQ} satisfied.

$I_E = \left(\frac{101}{100}\right)(1) = 1.01 \text{ mA}$

$V_{EE} = I_E R_E + V_{EB}(\text{on})$

$\Rightarrow R_E = \frac{5 - 0.7}{1.01} \Rightarrow \underline{R_E = 4.26 \text{ k}\Omega}$

b. $r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{(100)(0.026)}{1}$

$\Rightarrow \underline{r_\pi = 2.6 \text{ k}\Omega},\ \underline{g_m = 38.5 \text{ mA/V}},\ \underline{r_0 = \infty}$

4.50

a. $V_{TH1} = \left(\frac{R_2}{R_1 + R_2}\right)V_{CC} = \left(\frac{20}{20+80}\right)(10)$

$\Rightarrow V_{TH1} = 2.0 \text{ V}$

$R_{TH1} = R_1 \| R_2 = 20\|80 = 16 \text{ k}\Omega$

$I_{B1} = \frac{2 - 0.7}{16 + (101)(1)} = 0.0111 \text{ mA}$

$I_{C1} = 1.11 \text{ mA}$

$\Rightarrow g_{m1} = \frac{1.11}{0.026} \Rightarrow \underline{g_{m1} = 42.7 \text{ mA/V}}$

$r_{\pi 1} = \frac{(100)(0.026)}{1.11} \Rightarrow \underline{r_{\pi 1} = 2.34 \text{ k}\Omega}$

$r_{01} = \frac{\infty}{1.11} \Rightarrow \underline{r_{01} = \infty}$

$V_{TH2} = \left(\frac{R_4}{R_3 + R_4}\right)V_{CC} = \left(\frac{15}{15+85}\right)(10) = 1.50 \text{ V}$

$R_{TH2} = R_3 \| R_4 = 15\|85 = 12.75 \text{ k}\Omega$

$I_{B2} = \frac{1.50 - 0.70}{12.75 + (101)(0.5)} = 0.0126 \text{ mA}$

$I_{C2} = 1.26 \text{ mA}$

$\Rightarrow g_{m2} = \frac{1.26}{0.026} \Rightarrow \underline{g_{m2} = 48.5 \text{ mA/V}}$

$r_{\pi 2} = \frac{(100)(0.026)}{1.26} \Rightarrow \underline{r_{\pi 2} = 2.06 \text{ k}\Omega}$

$\underline{r_{02} = \infty}$

b. $A_{v1} = -g_{m1} R_{C1} = -(42.7)(2)$

$\Rightarrow \underline{A_{v1} = -85.4}$

$A_{v2} = -g_{m2}(R_{C2} \| R_L) = -(48.5)(4\|4)$

$\Rightarrow \underline{A_{v2} = -97}$

c. Input resistance of 2nd stage

$R_{i2} = R_3 \| R_4 \| r_{\pi 2} = 15\|85\|2.06$

$= 12.75\|2.06 \Rightarrow R_{i2} = 1.77 \text{ k}\Omega$

$A'_{v1} = -g_{m1}(R_{C1} \| R_{i2}) = -(42.7)(2\|1.77)$

$A'_{v1} = -40.1$

Overall gain: $A_v = (-40.1)(-97) \Rightarrow \underline{A_v = 3890}$

If we had $A_{v1} \cdot A_{v2} = (-85.4)(-97) = \underline{8284}$

Loading effect reduces overall gain

4.51

a. $V_{TH1} = \left(\frac{R_2}{R_1 + R_2}\right)V_{CC} = \left(\frac{12.7}{12.7+67.3}\right)(12)$

$\Rightarrow V_{TH1} = 1.905 \text{ V}$

$R_{TH1} = R_1 \| R_2 = 12.7\|67.3 = 10.68 \text{ k}\Omega$

$I_{B1} = \frac{1.905 - 0.70}{10.68 + (121)(2)} = 0.00477 \text{ mA}$

$I_{C1} = 0.572 \text{ mA}$

$g_{m1} = \frac{0.572}{0.026} \Rightarrow \underline{g_{m1} = 22 \text{ mA/V}}$

$r_{\pi 1} = \frac{(120)(0.026)}{0.572} \Rightarrow \underline{r_{\pi 1} = 5.45 \text{ k}\Omega}$

$r_{01} = \frac{\infty}{0.572} \Rightarrow \underline{r_{01} = \infty}$

$V_{TH2} = \left(\frac{R_4}{R_3 + R_4}\right)V_{CC} = \left(\frac{45}{45+15}\right)(12)$

$\Rightarrow V_{TH2} = 9.0 \text{ V}$

$R_{TH2} = R_3 \| R_4 = 15\|45 = 11.25 \text{ k}\Omega$

$I_{B2} = \frac{9.0 - 0.70}{11.25 + (121)(1.6)} = 0.0405 \text{ mA}$

$I_{C2} = 4.86 \text{ mA}$

$g_{m2} = \frac{4.86}{0.026} \Rightarrow \underline{g_{m2} = 187 \text{ mA/V}}$

$r_{\pi 2} = \frac{(120)(0.026)}{4.86} \Rightarrow \underline{r_{\pi 2} = 0.642 \text{ k}\Omega}$

$\underline{r_{02} = \infty}$

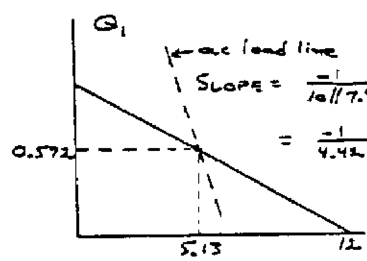
b. $I_{E1} = 0.577 \text{ mA}$

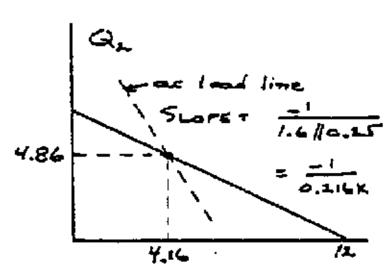
$V_{CEQ1} = 12 - (0.572)(10) - (0.577)(2)$

$\Rightarrow \underline{V_{CEQ1} = 5.13 \text{ V}}$

$I_{E2} = 4.90$

$V_{CEQ2} = 12 - (4.90)(1.6) \Rightarrow \underline{V_{CEQ2} = 4.16 \text{ V}}$





$R_{i2} = R_3 \| R_4 \| R_{ib}$

$R_{ib} = r_{\pi 2} + (1+\beta)(R_{E2} \| R_L)$

$= 0.642 + (121)(1.6 \| 0.25)$

$R_{ib} = 26.8$

$R_{i2} = 15 \| 45 \| 26.8$

$R_{i2} = 7.92 \text{ k}\Omega$

c. $A_{v1} = -g_{m1}(R_{C1} \| R_{i2}) = -(22)(10 \| 7.92)$

$\Rightarrow A_{v2} = -97.2$

$$A_{v2} = \frac{(1+\beta)(R_{E2} \| R_L)}{r_{\pi 2} + (1+\beta)(R_{E2} \| R_L)}$$

$$= \frac{(121)(0.216)}{0.642 + (121)(0.216)} = 0.976$$

Overall gain $= (-97.2)(0.976) = \underline{-94.9}$

d. $R_{iS} = R_1 \| R_2 \| r_{\pi 1} = 67.3 \| 12.7 \| 5.45$

$\Rightarrow \underline{R_{iS} = 3.61 \text{ k}\Omega}$

$R_0 = \dfrac{r_{\pi 2} + R_S}{1+\beta} \Big\| R_{E2}$ where

$R_S = R_3 \| R_4 \| R_{C1}$

$= 15 \| 45 \| 10 \Rightarrow R_s = 5.29 \text{ k}\Omega$

$R_0 = \dfrac{0.642 + 5.29}{121} \Big\| 1.6 \Rightarrow 0.049 \| 1.6$

$\Rightarrow \underline{R_0 = 47.5 \ \Omega}$

e. $\Delta i_C = \dfrac{-1}{0.216 \text{ k}\Omega} \cdot \Delta v_{ce}$. $\Delta i_C = 4.86$

$|\Delta v_{ce}| = (4.86)(0.216) = 1.05$ V

Max. output voltage swing

$= \underline{2.10 \text{ V peak-to-peak}}$

4.52

(a) $I_{R1} = \dfrac{5 - 2(0.7)}{0.050} = 72 \ mA$

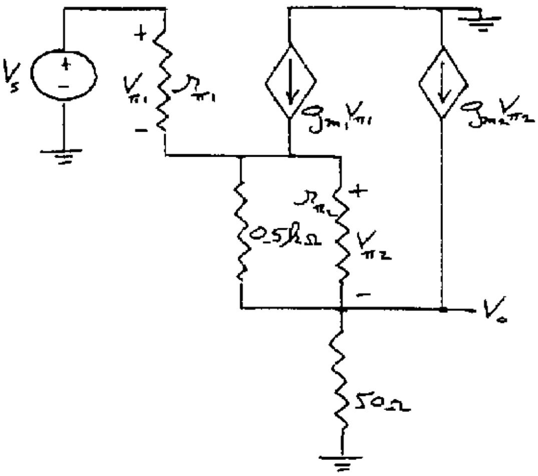
$I_{R2} = \dfrac{0.7}{0.5} = 1.4 \ mA$

$I_{C2} = \left(\dfrac{\beta}{1+\beta}\right)(72 - 1.4) \Rightarrow \quad \underline{I_{C2} = 69.9 \ mA}$

$I_{B2} = \dfrac{69.9}{100} = 0.699 \ mA$

$I_{C1} = \left(\dfrac{\beta}{1+\beta}\right)(1.4 + 0.699) \Rightarrow \quad \underline{I_{C1} = 2.08 \ mA}$

(b)



$V_s = V_{\pi 1} + V_{\pi 2} + V_o$

(1) $V_o = \left(\dfrac{V_{\pi 2}}{0.5} + \dfrac{V_{\pi 2}}{r_{\pi 2}} + g_{m2}V_{\pi 2}\right)(0.05)$

$r_{\pi 2} = \dfrac{(100)(0.026)}{69.9} = 0.0372 \ k\Omega$

$g_{m2} = \dfrac{69.9}{0.026} = 2688 \ mA/V$

$V_o = V_{\pi 2}\left(\dfrac{1}{0.05} + \dfrac{1}{0.0372} + 2688\right)(0.05)$

so that (1) $V_{\pi 2} = \dfrac{V_o}{136.7}$

(2) $\dfrac{V_{\pi 1}}{r_{\pi 1}} + g_{m1}V_{\pi 1} = \dfrac{V_{\pi 2}}{0.5} + \dfrac{V_{\pi 2}}{r_{\pi 2}}$

$r_{\pi 1} = \dfrac{(100)(0.026)}{2.08} = 1.25 \ k\Omega$

$g_{m1} = \dfrac{2.08}{0.026} = 80 \ mA/V$

$V_{\pi 1}\left(\dfrac{1}{1.25} + 80\right) = V_{\pi 2}\left(\dfrac{1}{0.5} + \dfrac{1}{0.0372}\right)$

$V_{\pi 1}(80.8) = V_{\pi 2}(28.88) = \left(\dfrac{V_o}{136.7}\right)(28.88)$

or (2) $V_{\pi 1} = V_o(0.00261)$

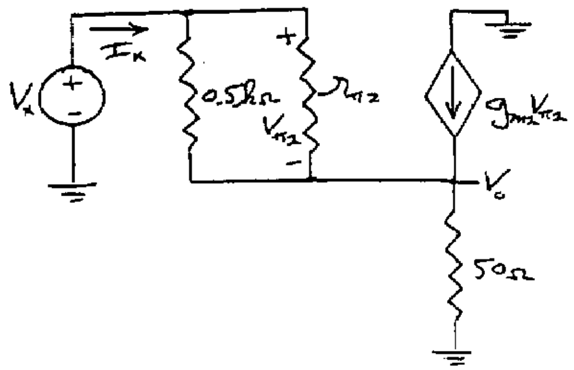
Then

$V_s = V_o(0.00261) + \dfrac{V_o}{136.7} + V_o = V_o(1.00993)$

or $\underline{A_v = \dfrac{V_o}{V_s} = 0.990}$

(c)

$R_{ib} = r_{\pi 1} + (1+\beta)[R_x]$



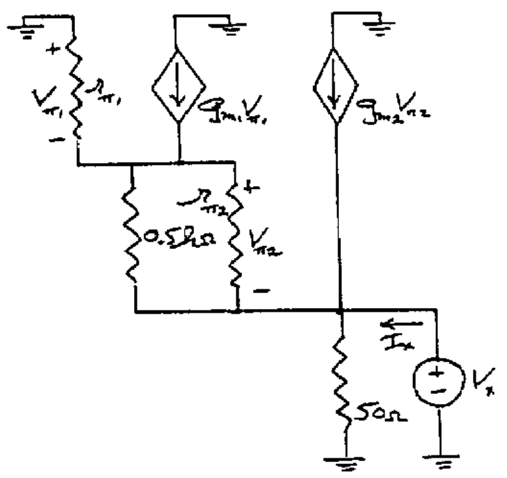
$$I_x = \frac{V_{\pi 2}}{0.5} + \frac{V_{\pi 2}}{r_{\pi 2}} = V_{\pi 2}\left(\frac{1}{0.5} + \frac{1}{r_{\pi 2}}\right)$$

$$\frac{V_o}{0.05} = \frac{V_x - V_{\pi 2}}{0.05} = I_x + g_{m2} V_{\pi 2}$$

$$\frac{V_x}{0.05} - I_x = V_{\pi 2}\left(\frac{1}{0.05} + g_{m2}\right) = \frac{I_x\left(\frac{1}{0.05} + g_{m2}\right)}{\left(\frac{1}{0.05} + \frac{1}{r_{\pi 2}}\right)}$$

We find $\frac{V_x}{I_x} = R_x = 2.89\ k\Omega$

Then $R_{ib} = 1.25 + (101)(2.89) \Rightarrow$ $\underline{R_{ib} = 293\ k\Omega}$



To find R_o:

(1) $I_x = \frac{V_x}{0.05} - g_{m2} V_{\pi 2} - \frac{V_{\pi 2}}{0.05 \| r_{\pi 2}}$

(2) $V_{\pi 2} = \left(\frac{V_{\pi 1}}{r_{\pi 1}} + g_{m1} V_{\pi 1}\right)(0.05 \| r_{\pi 2})$

$$= V_{\pi 1}\left(\frac{1}{1.25} + 80\right)(0.05 \| 0.0372)$$

or $V_{\pi 2} = (1.72) V_{\pi 1}$

(3) $V_{\pi 1} + V_{\pi 2} + V_x = 0 \Rightarrow V_{\pi 1} + (1.72) V_{\pi 1} + V_x = 0$

so that $V_{\pi 1} = -(0.368) V_x$

and $V_{\pi 2} = (1.72)[-(0.368) V_x] = -(0.633) V_x$

Now $I_x = \frac{V_x}{0.05} - V_{\pi 2}\left(g_{m2} + \frac{1}{0.05 \| r_{\pi 2}}\right)$

So that

$$I_x = \frac{V_x}{0.05} + (0.633) V_x \left[2688 + \frac{1}{0.05 \| 0.0372}\right]$$

which yields

$$\underline{R_o = \frac{V_x}{I_x} = 0.583\ \Omega}$$

4.53

a. $R_{TH} = R_1 \| R_2 = 335 \| 125 = 91.0\ k\Omega$

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

$$= \left(\frac{125}{125 + 335}\right)(10) = 2.717\ V$$

$V_{TH} = I_{B1} R_{TH} + V_{BE1} + V_{BE2} + I_{E2} R_{E2}$

$I_{E2} = (1+\beta) I_{E1} = (1+\beta)^2 I_{B1}$

$$I_{B1} = \frac{2.717 - 1.40}{91.0 + (101)^2(1)} \Rightarrow I_{B1} = 0.128\ \mu A$$

$\underline{I_{C1} = 12.8\ \mu A}$

$I_{C2} = \beta I_{E1} = \beta(1+\beta) I_{B1} = (100)(101)(0.128\ \mu A)$

$\underline{I_{C2} = 1.29\ mA}$, $I_{E2} = 1.31\ mA$

$I_{RC} = I_{C2} + I_{C1} = 1.29 + 0.0128 = 1.31\ mA$

$V_C = 10 - I_{RC} R_C = 10 - (1.31)(2.2) = 7.12\ V$

$V_E = I_{E2} R_{E2} = (1.31)(1) = 1.31\ V$

$V_{CE2} = 7.12 - 1.31 = 5.81\ V$

$V_{CE1} = V_{CE2} - V_{BE2} = 5.81 - 0.7$

$V_{CE1} = 5.11\ V$

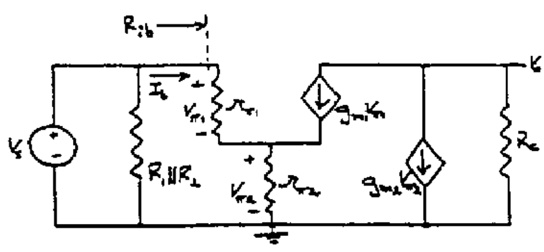
Summary:

$I_{C1} = 12.8\ \mu A$ $\quad I_{C2} = 1.29\ mA$

$V_{CE1} = 5.11\ V$ $\quad V_{CE2} = 5.81\ V$

b. $g_{m1} = \frac{0.0128}{0.026} = 0.492\ mA/V$

$g_{m2} = \frac{1.29}{0.026} = 49.6\ mA/V$



$$V_0 = -(g_{m1}V_{\pi 1} + g_{m2}V_{\pi 2})R_C$$
$$V_S = V_{\pi 1} + V_{\pi 2}, \quad V_{\pi 1} = V_S - V_{\pi 2}$$
$$V_{\pi 2} = \left(\frac{V_{\pi 1}}{r_{\pi 1}} + g_{m1}V_{\pi 1}\right)r_{\pi 2}$$
$$V_{\pi 2} = V_{\pi 1}\left(\frac{1+\beta}{r_{\pi 1}}\right)r_{\pi 2}$$
$$r_{\pi 1} = \frac{(100)(0.026)}{0.0128} = 203\ \text{k}\Omega$$
$$r_{\pi 2} = \frac{(100)(0.026)}{1.29} = 2.02\ \text{k}\Omega$$

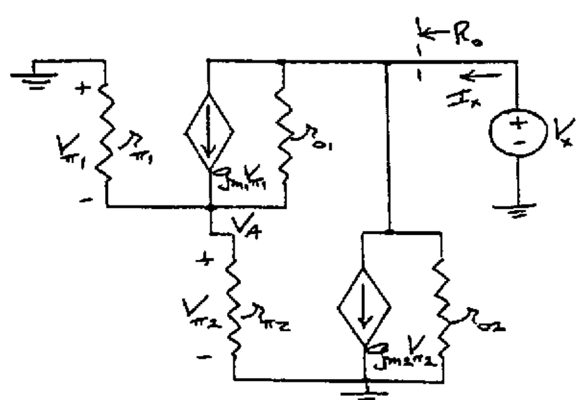
$$V_0 = -[g_{m1}(V_S - V_{\pi 2}) + g_{m2}V_{\pi 2}]R_C$$
$$V_0 = -[g_{m1}V_S + (g_{m2} - g_{m1})V_{\pi 2}]R_C$$
$$V_{\pi 2} = (V_S - V_{\pi 2})(1+\beta)\left(\frac{r_{\pi 2}}{r_{\pi 1}}\right)$$
$$V_{\pi 2}\left[1 + (1+\beta)\left(\frac{r_{\pi 2}}{r_{\pi 1}}\right)\right] = V_S(1+\beta)\left(\frac{r_{\pi 2}}{r_{\pi 1}}\right)$$
$$V_0 = -\left\{g_{m1}V_S + (g_{m2} - g_{m1})\cdot\frac{V_S(1+\beta)\left(\frac{r_{\pi 2}}{r_{\pi 1}}\right)}{1+(1+\beta)\left(\frac{r_{\pi 2}}{r_{\pi 1}}\right)}\right\}R_C$$

$$A_v = \frac{V_0}{V_S}$$
$$= -\left\{(0.492) + \frac{(49.6 - 0.492)(101)\left(\frac{2.02}{203}\right)}{1 + (101)\left(\frac{2.02}{203}\right)}\right\}2.2$$
$$A_v = -55.2$$

c. $R_{is} = R_1 \| R_2 \| R_{ib}$

$$R_{ib} = r_{\pi 1} + (1+\beta)r_{\pi 2}$$
$$= 203 + (101)(2.02) = 407\ \text{k}\Omega$$
$$R_{is} = 91\|407 = \underline{74.4\ \text{k}\Omega = R_{is}}$$
$$\underline{R_0 = R_C = 2.2\ \text{k}\Omega}$$

4.54



(1) $I_x = g_{m2}V_{\pi 2} + \frac{V_x}{r_{o2}} + \frac{V_x - V_A}{r_{o1}} + g_{m1}V_{\pi 1}$

(2) $\frac{V_x - V_A}{r_{o1}} + g_{m1}V_{\pi 1} = \frac{V_A}{r_{\pi 1}\|r_{\pi 2}}$

(3) $V_{\pi 2} = V_A = -V_{\pi 1}$

Then from (2)

$$\frac{V_x}{r_{o1}} = V_A\left(\frac{1}{r_{o1}} + g_{m1} + \frac{1}{r_{\pi 1}\|r_{\pi 2}}\right)$$

(1) $I_x = g_{m2}V_A + \frac{V_x}{r_{o2}} + \frac{V_x}{r_{o1}} - \frac{V_A}{r_{o1}} - g_{m1}V_A$

or $I_x = V_x\left(\frac{1}{r_{o1}} + \frac{1}{r_{o2}}\right) + V_A\left(g_{m2} - \frac{1}{r_{o1}} - g_{m1}\right)$

Solving for V_A from Equation (2) and substituting into Equation (1), we find

$$R_o = \frac{V_x}{I_x} = \frac{\frac{1}{r_{o1}} + g_{m1} + \frac{1}{r_{\pi 1}\|r_{\pi 2}}}{\frac{1}{r_{o2}}\left(\frac{1}{r_{o1}} + g_{m1} + \frac{1}{r_{\pi 1}\|r_{\pi 2}}\right) + \frac{1}{r_{o1}}\left(\frac{1}{r_{\pi 1}\|r_{\pi 2}} + g_{m2}\right)}$$

For $\beta = 100, V_A = 100\,V, I_{C1} = I_{Bias} = 1\,mA$

$$r_{o1} = r_{o2} = \frac{100}{1} = 100\ k\Omega$$
$$r_{\pi 1} = r_{\pi 2} = \frac{(100)(0.026)}{1} = 2.6\ k\Omega$$
$$g_{m1} = g_{m2} = \frac{1}{0.026} = 38.46\ mA/V$$

Then

$$R_o = \frac{\frac{1}{100} + 38.46 + \frac{1}{2.6\|2.6}}{\frac{1}{100}\left(\frac{1}{100} + 38.46 + \frac{1}{2.6\|2.6}\right) + \frac{1}{100}\left(\frac{1}{2.6\|2.6} + 38.46\right)}$$

or

$\underline{R_o = 50.0\ k\Omega}$

Now

$I_{C2} = 1\,mA, I_{Bias} = 0$

Replace I_{Bias} by $\frac{I_{C2}}{\beta}\cdot\frac{\beta}{1+\beta} = \frac{I_{C2}}{1+\beta}$, $I_{C1} \cong 0.01\,mA$

$$r_{o2} = \frac{100}{1} = 100\ k\Omega,\ r_{o1} = \frac{100}{0.01} = 10{,}000\ k\Omega$$
$$g_{m_2} = \frac{1}{0.026} = 38.46\ mA/V,\ g_{m1} = 0.3846\ mA/V$$
$$r_{\pi 2} = \frac{(100)(0.026)}{1} = 2.6\ k\Omega,\ r_{\pi 1} = 260\ k\Omega$$

Then

$\underline{R_o = 66.4\ k\Omega}$

4.55

a. $R_{TH} = R_1 \| R_2 = 93.7 \| 6.3 = 5.90 \text{ k}\Omega$

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

$$= \left(\frac{6.3}{6.3 + 93.7}\right)(12) = 0.756 \text{ V}$$

$$I_{BQ} = \frac{0.756 - 0.70}{5.90} = 0.00949 \text{ mA}$$

$I_{CQ} = 0.949 \text{ mA}$

$V_{CEQ} = 12 - (0.949)(6) \Rightarrow V_{CEQ} = 6.31 \text{ V}$

Transistor:

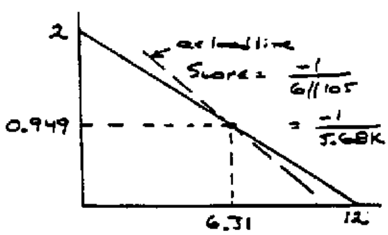
$P_Q \approx I_{CQ} V_{CEQ} = (0.949)(6.31)$

$\Rightarrow \underline{P_Q = 5.99 \text{ mW}}$

$R_C: \quad P_R = I_{CQ}^2 R_C = (0.949)^2 (6)$

$\Rightarrow \underline{P_R = 5.40 \text{ mW}}$

b.



$$r_0 = \frac{100}{0.949} = 105 \text{ k}\Omega$$

Peak signal current $= 0.949$ mA

$|V_0(\max)| = (5.68)(0.949) = 5.39 \text{ V}$

$$P_{RC} = \frac{1}{2} \cdot \frac{V_0^2(\max)}{R_C} = \frac{1}{2}\left[\frac{(5.39)^2}{6}\right]$$

$\Rightarrow P_{RC} = 2.42 \text{ mW}$

4.56

(a) $10 = I_{BQ} R_B + V_{BE}(on) + (1+\beta) I_{BQ} R_E$

$$I_{BQ} = \frac{10 - 0.7}{100 + (121)(20)} = 0.00369 \, mA$$

$I_{CQ} = 0.443 \, mA, \quad I_{EQ} = 0.447 \, mA$

For R_C: $P_{RC} = (0.443)^2 (10) \Rightarrow \underline{P_{RC} = 1.96 \, mW}$

For R_E: $P_{RE} = (0.447)^2 (20) \Rightarrow \underline{P_{RE} = 4.0 \, mW}$

(b)

$\Delta i_C = 0.443 \, mA, \quad \Delta v_{CE} = (0.443)(10) = 4.43 \, V$

Then

$$\overline{P}_{RC} = \frac{1}{2}(\Delta i_C)^2 R_C = \frac{1}{2}(0.443)^2 (10)$$

$\underline{\overline{P}_{RC} = 0.981 \, mW}$

4.57

a. $$I_{BQ} = \frac{10 - 0.7}{50 + (151)(10)} = 0.00596 \text{ mA}$$

$I_{CQ} = 0.894 \text{ mA}, \quad I_{EQ} = 0.90 \text{ mA}$

$V_{ECQ} = 20 - (0.894)(5) - (0.90)(10)$

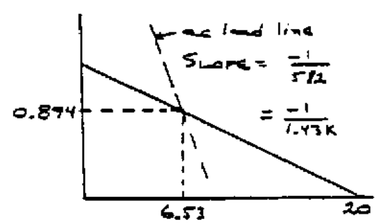
$\Rightarrow V_{ECQ} = 6.53 \text{ V}$

$P_Q \cong I_{CQ} V_{ECQ} = (0.894)(6.53) \Rightarrow \underline{P_Q = 5.84 \text{ mW}}$

$P_{RC} \cong I_{CQ}^2 R_C = (0.894)^2 (5) \Rightarrow \underline{P_{RC} = 4.0 \text{ mW}}$

$P_{RE} \cong I_{EQ}^2 R_C = (0.90)^2 (10) \Rightarrow \underline{P_{RE} = 8.1 \text{ mW}}$

b.



$$\Delta i_C = \frac{-1}{1.43 \text{ k}\Omega} \cdot \Delta v_{ec}$$

$\Delta i_C = 0.894 \Rightarrow |\Delta v_{ec}| = (0.894)(1.43) = 1.28 \text{ V}$

$$\Delta i_0 = \left(\frac{5}{5+2}\right) \Delta i_C = 0.639 \text{ mA}$$

$\overline{P_{RL}} = \frac{1}{2}(0.639)^2 (2) \Rightarrow \underline{\overline{P_{RL}} = 0.408 \text{ mW}}$

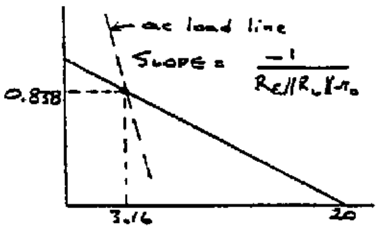
$\overline{P_{RC}} = \frac{1}{2} \cdot (0.894 - 0.639)^2 (5) \Rightarrow \underline{\overline{P_{RC}} = 0.163 \text{ mW}}$

$\underline{\overline{P_{RE}} = 0}$

$\overline{P_Q} = 5.84 - 0.408 - 0.163 \Rightarrow \underline{\overline{P_Q} = 5.27 \text{ mW}}$

4.58

$$I_{BQ} = \frac{10 - 0.70}{100 + (101)(10)} = 0.00838 \text{ mA}$$
$$I_{CQ} = 0.838 \text{ mA}, \quad I_{EQ} = 0.846 \text{ mA}$$
$$V_{CEQ} = 20 - (0.838)(10) - (0.846)(10)$$
$$\Rightarrow V_{CEQ} = 3.16 \text{ V}$$



$$r_o = \frac{100}{0.838} = 119 \text{ k}\Omega$$

Neglecting base currents:

a. $R_L = 1 \text{ k}\Omega$

$$\text{slope} = \frac{-1}{10\|1\|119} = \frac{-1}{0.902 \text{ k}\Omega}$$
$$\Delta i_C = \frac{-1}{0.902 \text{ k}\Omega} \cdot \Delta v_{ce}$$
$$\Delta i_C = 0.838 \Rightarrow |\Delta v_{ce}| = (0.902)(0.838)$$
$$= 0.756 \text{ V}$$
$$\overline{P_{RL}} = \frac{1}{2}\frac{(0.756)^2}{1} \Rightarrow \underline{\overline{P_{RL}} = 0.286 \text{ mW}}$$

b. $R_L = 10 \text{ k}\Omega$

$$\text{slope} = \frac{-1}{10\|10\|119} = \frac{-1}{4.80}$$

For

$$\Delta i_C = 0.838 \Rightarrow |\Delta v_{ce}| = (0.838)(4.80) = 4.02$$

Max. swing determined by voltage

$$\overline{P_{RL}} = \frac{1}{2}\frac{(3.16)^2}{10} \Rightarrow \underline{\overline{P_{RL}} = 0.499 \text{ mW}}$$

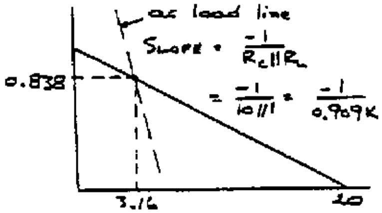
4.59

a. $$I_{BQ} = \frac{10 - 0.7}{100 + (101)(10)} = 0.00838 \text{ mA}$$

$$I_{CQ} = 0.838 \text{ mA}, \quad I_{EQ} = 0.846 \text{ mA}$$
$$V_{CEQ} = 20 - (0.838)(10) - (0.846)(10)$$
$$\Rightarrow V_{CEQ} = 3.16 \text{ V}$$

$$P_Q \cong I_{CQ}V_{CEQ} = (0.838)(3.16) \Rightarrow \underline{P_Q = 2.65 \text{ mW}}$$
$$P_{RC} \cong I_{CQ}^2 R_C = (0.838)^2(10) \Rightarrow \underline{P_{RC} = 7.02 \text{ mW}}$$

b.



$$\Delta i_C = \frac{-1}{0.909 \text{ k}\Omega} \cdot \Delta v_{ce}$$

For

$$\Delta i_C = 0.838 \Rightarrow |\Delta v_{ce}| = (0.909)(0.838) = 0.762 \text{ V}$$
$$\Delta i_0 = \left(\frac{R_C}{R_C + R_L}\right)\Delta i_C = \left(\frac{10}{10+1}\right)\Delta i_C = 0.762 \text{ mA}$$
$$\overline{P_{RL}} = \frac{1}{2}(0.762)^2(1) \Rightarrow \underline{\overline{P_{RL}} = 0.290 \text{ mW}}$$
$$\overline{P_{RC}} = \frac{1}{2} \cdot (0.838 - 0.762)^2(10) \Rightarrow \underline{\overline{P_{RC}} = 0.0289 \text{ mW}}$$
$$\overline{P_Q} = 2.65 - 0.290 - 0.0289 \Rightarrow \underline{\overline{P_Q} = 2.33 \text{ mW}}$$