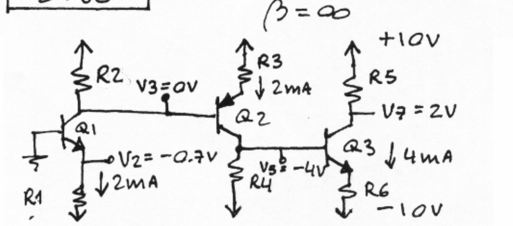
Solutions to Selected Problems (Problem Set 1)

<u>Chapter 5:</u> 5.85, 5.122, 5.136, 5.143
<u>Chapter 6:</u> *6.29, 6.30, 6.34*

Microelectronic Circuits – 5th Edition – Sedra/Smith

5.85

$\beta = \infty$



$R_1 = \frac{9.3}{2} = \underline{\underline{4.7\,k\Omega}}$

$R_2 = \frac{10}{2} = 5 \rightarrow \underline{\underline{5.1\,k\Omega}}$

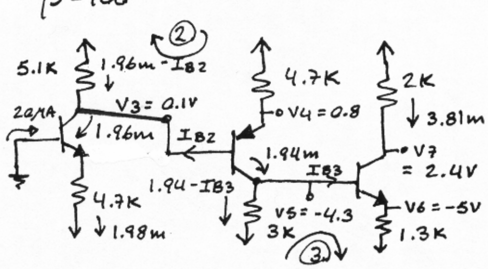
$R_3 = \frac{9.3}{2} = \underline{\underline{4.7\,k\Omega}}$

$R_4 = \frac{6}{2} = \underline{\underline{3\,k\Omega}}$

$R_5 = \frac{8}{4} = \underline{\underline{2\,k\Omega}}$

$R_6 = \frac{10-4.7}{4} = \underline{\underline{1.3\,k\Omega}}$

$\beta = 100$



② $(1.96 - I_{B2}) \times 5.1$
$= (\beta+1) I_{B2} \times 4.7 + 0.7$

$I_{B2} = 0.0194\,mA$

$I_{E2} = 1.96\,mA$

$V_3 = \underline{\underline{0.1V}} \quad V_4 = \underline{\underline{0.8V}}$

③ $(1.94 - I_{B3}) \times 3$
$= 0.7 + 1.3 \times (\beta+1) \cdot I_{B3}$

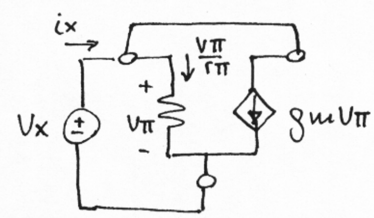
$I_{B3} = 0.038\,mA$

$I_{E3} = 3.85\,mA$

$V_5 = \underline{\underline{-4.3V}} \quad V_6 = \underline{\underline{-5V}}$

$V_7 = \underline{\underline{2.4V}}$

5.122



$$i_x = \frac{v_\pi}{r_\pi} + g_m v_\pi$$
$$= \frac{v_\pi}{r_\pi}(1 + g_m r_\pi)$$
$$= \frac{v_\pi}{r_\pi}(1 + \beta)$$

But $v_\pi = v_x$

$$\rightarrow R_{in} = \frac{v_x}{i_x} = \frac{v_\pi}{i_x} = \frac{r_\pi}{\beta+1}$$

$$R_{in} = \underline{\underline{r_e}}$$

5.130

Refer to Fig. P5.130

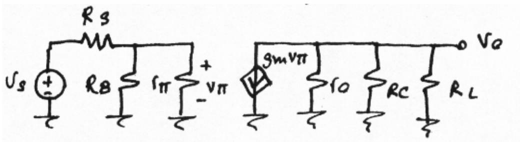
$$I_E = \frac{V_{BB} - V_{BE}}{R_E + R_B/(\beta+1)}$$

where, $V_{BB} = V_{CC} \cdot \frac{R_2}{R_1 + R_2}$

$$= 9 \cdot \frac{15}{27+15} = 3.21V$$

$$R_B = R_1 \| R_2 = 15 \| 27 = 9.64\,K\Omega$$

Thus, $I_E = \frac{3.21 - 0.7}{1.2 + \frac{9.64}{101}} = \underline{\underline{1.94\,mA}}$



$$g_m = \frac{I_C}{V_T} = \frac{0.99 \times 1.94}{0.025} = 76.8\,\frac{mA}{V}$$

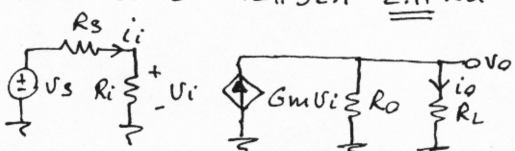
$$r_\pi = \frac{\beta}{g_m} = \frac{100}{76.8} = 1.3\,K\Omega$$

$$r_o = \frac{V_A}{I_C} = \frac{100}{0.99 \times 1.94} = 52.1\,K\Omega$$

$R_i = R_B \| r_\pi = 9.64 \| 1.3 = \underline{\underline{1.15\,K\Omega}}$

$G_m = -g_m = -\underline{\underline{76.8}}\,\frac{mA}{V}$

$R_o = R_C \| r_o = 2.2 \| 52.1 = \underline{\underline{2.11}}\,K\Omega$



Equivalent circuit

$$A_v = \frac{v_o}{v_s} = \frac{v_i}{v_s} \cdot \frac{v_o}{v_i}$$

$$= \frac{R_i}{R_s + R_i} \cdot \frac{G_m (R_o \| R_L) v_i}{v_i}$$

$$= \frac{-1.15}{10+1.15} \times 76.8 \times (2.11 \| 2)$$

$= -\underline{\underline{8.13}}\ V/V$

$$A_i = \frac{i_o}{i_i} = \frac{v_o \cdot R_L}{v_s/(R_s + R_i)}$$

$$\rightarrow A_i = \frac{v_o}{v_s} \cdot \frac{R_s + R_i}{R_L}$$

$$= -8.13 \times \frac{(10 + 1.15)}{2}$$

$= -\underline{\underline{45.3}}\ A/A$

5.136

Refer to the circuit in Fig. P5.136

$R_{in} = (\beta+1)(r_e + 250) \,//\, 1M$

$\beta = 100 \quad r_e = \dfrac{V_T}{I_e} = \dfrac{0.025}{0.1} = 250\Omega$

$R_{in} = 101 \times (250+250) \,//\, 1M$

$= \underline{\underline{50.5K\Omega}}$

$\dfrac{v_b}{v_s} = \dfrac{R_{in}}{R_s + R_{in}} = \dfrac{50.5}{20+50.5}$

$= 0.72 \, V/V$

$\dfrac{v_o}{v_b} = \dfrac{-\alpha\,(20//20)}{(r_e + R_E)}$

$= -\dfrac{0.99 \times 10}{0.250 + 0.250} = \underline{\underline{-19.8}} \, V/V$

Thus, $\dfrac{v_o}{v_s} = 0.72 \times -19.8 = \underline{\underline{-14.2}} \, V/V$

For $v_{be} = 5mV$, $v_e = 5mV$ also

(since $R_e = r_e = 250\Omega$)

Thus,

$v_b = 5 + 5 = 10mV$

$v_s = \dfrac{10m}{0.72} = \underline{\underline{13.88}} \, mV$

$v_o = 13.88 \times 14.2 = \underline{\underline{197.2}} \, mV$

5.143

Refer to Fig. P5.143

(a) $I_E = \dfrac{9 - 0.7}{1 + 100/(\beta+1)}$

for $\beta = 40$, $I_E = \dfrac{8.3}{1+\frac{100}{41}} = \underline{\underline{2.41}} \, mA$

$V_E = 1 \times 2.41 = \underline{\underline{2.41V}}$

$V_B = 2.41 + 0.7 = \underline{\underline{3.11V}}$

For $\beta = 200$, $I_E = \dfrac{8.3}{1+\frac{100}{201}} = \underline{\underline{5.54}} \, mA$

$V_E = +\underline{\underline{5.54V}}$

$V_B = +\underline{\underline{6.24V}}$

(b) $R_i = 100K\Omega \,//\, (\beta+1)[r_e + (1//1)]$

$= 100 \,//\, (\beta+1)[r_e + 0.5]$

For $\beta = 40$, $I_E = 2.41mA$

$\rightarrow r_e = 10.37\,\Omega$

thus $R_i = 100 \,//\, 41 \times (0.01037 + 0.5)$

$= 100 \,//\, 21$

$= \underline{\underline{17.30}}\,\Omega$

For $\beta = 200$, $I_E = 5.54mA$

$\rightarrow r_e = 4.51\,\Omega$

thus $R_i = 100 \,//\, 201(0.0045 + 0.5)$

$= 100 \,//\, 101.4$

$= \underline{\underline{50.3}} \, K\Omega$

(c) $\dfrac{v_o}{v_s} = \dfrac{v_b}{v_s} \cdot \dfrac{v_o}{v_b}$

$= \dfrac{R_i}{R_s + R_i} \cdot \dfrac{(1//1)}{(1//1) + r_e}$

For $\beta = 40$,

$\dfrac{v_o}{v_s} = \dfrac{17.3}{10 + 17.3} \times \dfrac{0.5}{0.5 + 0.01037}$

$= \underline{\underline{0.621}} \, V/V$

For $\beta = 200$,

$\dfrac{v_o}{v_s} = \dfrac{50.3}{10 + 50.3} \cdot \dfrac{0.5}{0.5 + 0.0045}$

$= \underline{\underline{0.827}} \, V/V$

6.29

$I_S = 10^{-15} A$

a) $I_{REF} = I_S \, e^{V_{BE}/V_T} \Rightarrow V_{BE} = V_T \ln \dfrac{I_{REF}}{I_S}$

$I_{REF} = 10\mu A \Rightarrow V_{BE} = 0.025 \ln \dfrac{10 \times 10^{-6}}{10^{-15}} = 0.576^V$

$I_{REF} = 10mA \Rightarrow V_{BE} = 0.025 \ln \dfrac{10 \times 10^{-3}}{10^{-15}} = 0.748^V$

Therefore:

$10\mu A \leq I_{REF} \leq 10mA \Rightarrow \overline{0.576^V \leq V_{BE} \leq 0.748^V}$

Since β is very high, I_B is negligible and hence

$I_o \simeq I_{REF}$: $\underline{10\mu A \leq I_o \leq 10 \, mA}$

b) $I_o = I_{REF} \dfrac{1}{1 + 2/\beta}$ (Eq. 6.21)

for $0.1^{mA} \leq I_C \leq 5^{mA}$, β remains constant at 100.

$I_{REF} = 10mA \Rightarrow I_o = \dfrac{10}{1 + \frac{2}{70}} = 9.72mA$

$I_{REF} = 0.1mA \Rightarrow I_o = \dfrac{0.1}{1 + 2/100} = 0.098mA$

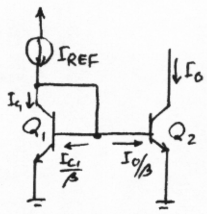
$I_{REF} = 1mA \Rightarrow I_o = \dfrac{1}{1 + 2/100} = 0.98mA$

$I_{REF} = 10\mu A \Rightarrow$

6.30

$I_{S2} = I_{S1} \times m \quad , \; I_{C1} = I_C$

$I_{REF} = I_C + \frac{I_C}{\beta} + \frac{I_O}{\beta}$ (1)



$V_{BE1} = V_{BE2} \Rightarrow$

$V_T \ln \frac{I_C}{I_{S1}} = V_T \ln \frac{I_O}{I_{S2}}$

$\Rightarrow \frac{I_O}{I_C} = \frac{I_{S2}}{I_{S1}} = m \Rightarrow I_C = I_O/m$

by substituting for I_C in (1):

$I_{REF} = \frac{I_O}{m} + \frac{I_O}{m\beta} + \frac{I_O}{\beta} \Rightarrow \frac{I_O}{I_{REF}} = \frac{m}{1 + \frac{1}{\beta} + \frac{m}{\beta}}$

$\frac{I_O}{I_{REF}} = \frac{m}{1 + \frac{1+m}{\beta}}$

This result is the same as Eq. 6.22.

For large β, $I_O/I_{REF} = m$, with finite β this ratio drops to $I_O/I_{REF} = \frac{m}{1 + \frac{1+m}{\beta}}$. To keep the introduced error within 5% : $0.95m = \frac{m}{1+\frac{1+m}{\beta}}$

$\beta_{min} = 80 \Rightarrow 0.95 = \frac{1}{1 + \frac{1+m}{80}} \Rightarrow \underline{m = 3.21}$

6.34

$I_{C1} = I_{C2} = I_{R1}$

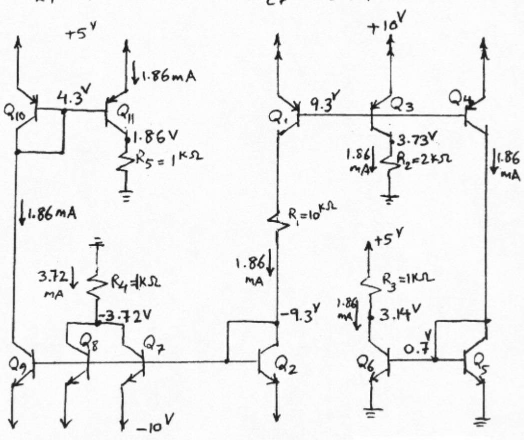
$V_{B1} = 10 - 0.7 = 9.3V \;,\; V_{B2} = -10 + 0.7 = -9.3^V, \; I_{R1} = \frac{9.3+9.3}{10}$

$\Rightarrow I_{R1} = 1.86\,mA = I_{C1} = I_{C2} = I_{C3} = I_{C4} = I_{C5} = I_{C6}$

$V_{C3} = 1.86^m \times 2^K = 3.72V \qquad , \; V_{C5} = 0.7^V$

$V_{C6} = 5 - 1.86 \times 1 = 3.14V \qquad , \; I_{C9} = I_{C8} = I_{C7} = I_{C2} = 1.86^{mA}$

$I_{R4} = 2 \times 1.86 = 3.72mA \Rightarrow V_{C7} = -3.72 \times 1 = -3.72V$



$I_{C10} = I_{C9} = 1.86mA$

$V_{C9} = V_{C10} = V_{B10} = 5 - 0.7 = 4.3^V$

$I_{C11} = I_{C10} = 1.86mA$

$V_{C11} = 1.86 \times 1 = 1.86V$