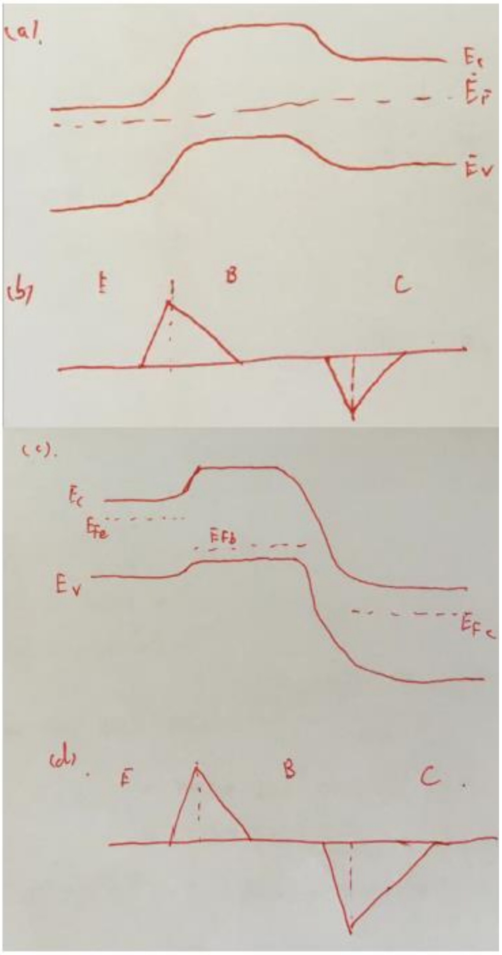
VE320 HW6 Solution

1.



2.

(a) $$p_{E0} = \frac{n_i^2}{N_E} = \frac{(1.5\times10^{10})^2}{8\times10^{17}}$$
$$= 2.8125\times10^2 \text{ cm}^{-3}$$
$$n_{B0} = \frac{n_i^2}{N_B} = \frac{(1.5\times10^{10})^2}{2\times10^{16}}$$
$$= 1.125\times10^4 \text{ cm}^{-3}$$
$$p_{C0} = \frac{n_i^2}{N_C} = \frac{(1.5\times10^{10})^2}{10^{15}}$$
$$= 2.25\times10^5 \text{ cm}^{-3}$$

(b) $$n_B(0) = n_{B0}\exp\left(\frac{V_{BE}}{V_t}\right)$$
$$= (1.125\times10^4)\exp\left(\frac{0.640}{0.0259}\right)$$
$$= 6.064\times10^{14} \text{ cm}^{-3}$$

$$p_E(0) = p_{E0}\exp\left(\frac{V_{BE}}{V_t}\right)$$
$$= (2.8125\times10^2)\exp\left(\frac{0.640}{0.0259}\right)$$
$$= 1.516\times10^{13} \text{ cm}^{-3}$$

3.

(a)

(i) $$\gamma = \frac{1}{1+\frac{I_{pE}}{I_{nE}}} = \frac{1}{1+\frac{0.0035}{0.50}} = 0.99305$$

(ii) $$\alpha_T = \frac{I_{nC}}{I_{nE}} = \frac{0.495}{0.50} = 0.990$$

(iii) $$\delta = \frac{I_{nE}+I_{pE}}{I_{nE}+I_R+I_{pE}}$$
$$= \frac{0.50+0.0035}{0.50+0.005+0.0035} = 0.990167$$

(iv) $$\alpha = \delta\alpha_T\delta = (0.99305)(0.990)(0.990167)$$
$$= 0.97345$$

(v) $$\beta = \frac{\alpha}{1-\alpha} = \frac{0.97345}{1-0.97345} = 36.7$$

(b) For $\beta = 120 \Rightarrow \alpha = \frac{\beta}{1+\beta} = \frac{120}{121}$

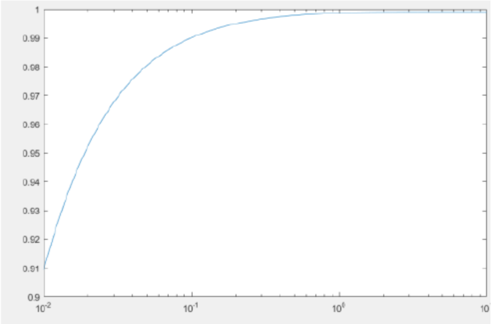
$$\alpha = 0.991736$$

Then $\gamma = \alpha_T = \delta = 0.997238$

$$\alpha_T = 0.997238 = \frac{I_{nC}}{I_{nE}} = \frac{I_{nC}}{0.50}$$
$$\Rightarrow I_{nC} = 0.4986 \text{ mA}$$

$$\gamma = 0.997238 = \frac{1}{1+\frac{I_{pE}}{I_{nE}}} = \frac{1}{1+\frac{I_{pE}}{0.50}}$$
$$\Rightarrow I_{pE} = 0.00138 \text{ mA} = 1.38\ \mu\text{A}$$
$$\delta = \frac{I_{nE}+I_{pE}}{I_{nE}+I_R+I_{pE}}$$
$$0.997238 = \frac{0.50+0.00138}{0.50+I_R+0.00138}$$
$$\Rightarrow I_R = 0.00139 \text{ mA} = 1.39\ \mu\text{A}$$

4.



When X_E/L_E increaase, the gain will increase rapidly.

5.

(a) $I_C = \frac{1}{r_o}(V_{CE} + V_A) \Rightarrow r_o = \frac{(V_{CE} + V_A)}{I_C}$

(i) $r_o = \frac{2+120}{1.2} = 101.67\,\text{k}\Omega$

(ii) $g_o = \frac{1}{r_o} = \frac{1}{101.67} = 0.00984\,(\text{k}\Omega)^{-1}$

$= 9.84 \times 10^{-6}\,(\Omega)^{-1}$

(iii) $I_C = \frac{4+120}{101.667} = 1.22\,\text{mA}$

(b)

(i) $r_o = \frac{V_{CE} + V_A}{I_C} = \frac{2+160}{0.25} = 648\,\text{k}\Omega$

(ii) $g_o = \frac{1}{r_o} = \frac{1}{648} = 0.00154\,(\text{k}\Omega)^{-1}$

$= 1.54 \times 10^{-6}\,(\Omega)^{-1}$

(iii) $I_C = \frac{4+160}{648} = 0.253\,\text{mA}$

6.

$$x_{dB} = \left\{ \frac{2\in_s (V_{bi} + V_{CB})}{e} \left[\frac{N_C}{N_B} \cdot \frac{1}{(N_B + N_C)} \right] \right\}^{1/2}$$

$$= \left\{ \frac{2(11.7)(8.85 \times 10^{-14})(V_{bi} + V_{CB})}{1.6 \times 10^{-19}} \times \left[\frac{2 \times 10^{15}}{2 \times 10^{16}} \cdot \frac{1}{(2 \times 10^{15} + 2 \times 10^{16})} \right] \right\}^{1/2}$$

$$= \{(5.8832 \times 10^{-11})(V_{bi} + V_{CB})\}^{1/2}$$

Now

$$V_{bi} = V_t \ln\left(\frac{N_B N_C}{n_i^2}\right)$$

$$= (0.0259) \ln\left[\frac{(2 \times 10^{15})(2 \times 10^{16})}{(1.5 \times 10^{10})^2}\right]$$

$$= 0.6709\ \text{V}$$

(i) For $V_{CB} = 4\,\text{V}$, $x_{dB} = 0.1658\,\mu\text{m}$

(ii) For $V_{CB} = 8\,\text{V}$, $x_{dB} = 0.2259\,\mu\text{m}$

(iii) For $V_{CB} = 12\,\text{V}$, $x_{dB} = 0.2730\,\mu\text{m}$

Neglecting the B-E space charge width,

(i) For $V_{CB} = 4\,\text{V}$,

$x_B = 0.85 - 0.1658 = 0.6842\,\mu\text{m}$

(ii) For $V_{CB} = 8\,\text{V}$,

$x_B = 0.85 - 0.2259 = 0.6241\,\mu\text{m}$

(iii) For $V_{CB} = 12\,\text{V}$,

$x_B = 0.85 - 0.2730 = 0.5770\,\mu\text{m}$

Now

$$J_C = \frac{eD_B n_{B0}}{x_B} \exp\left(\frac{V_{BE}}{V_t}\right)$$

where

$$n_{B0} = \frac{n_i^2}{N_B} = \frac{(1.5 \times 10^{10})^2}{2 \times 10^{16}}$$

$$= 1.125 \times 10^4\ \text{cm}^{-3}$$

so

$$J_C = \frac{(1.6 \times 10^{-19})(25)(1.125 \times 10^4)}{x_B} \exp\left(\frac{0.650}{0.0259}\right)$$

$$= \frac{3.5686 \times 10^{-3}}{x_B}\ \text{A/cm}^2$$

(i)For $V_{CB} = 4\,\text{V}$, $J_C = 52.16\ \text{A/cm}^2$

(ii)For $V_{CB} = 8\,\text{V}$, $J_C = 57.18\ \text{A/cm}^2$

(iii)For $V_{CB} = 12\,\text{V}$, $J_C = 61.85\ \text{A/cm}^2$

(b) $\frac{\Delta J_C}{\Delta V_{CE}} = \frac{J_C}{V_{CE} + V_A}$

$$\frac{61.85 - 52.16}{12 - 4} = \frac{52.16}{4 + 0.650 + V_A}$$

$\Rightarrow V_A = 38.4\ \text{V}$

7.

$$x_{dB} = \left\{ \frac{2 \in_s (V_{bi} + V_{BC})}{e} \left[\frac{N_C}{N_B} \cdot \frac{1}{(N_B + N_C)} \right] \right\}^{1/2}$$

$$= \left\{ \frac{2(11.7)(8.85\times10^{-14})(V_{bi} + V_{BC})}{1.6\times10^{-19}} \times \left[\frac{10^{15}}{10^{16}} \cdot \frac{1}{(10^{15}+10^{16})} \right] \right\}^{1/2}$$

$$= \left\{ (1.1766\times10^{-10})(V_{bi} + V_{BC}) \right\}^{1/2}$$

Now

$$V_{bi} = V_t \ln\left(\frac{N_B N_C}{n_i^2} \right)$$

$$= (0.0259)\ln\left[\frac{(10^{15})(10^{16})}{(1.5\times10^{10})^2} \right]$$

$$= 0.6350 \text{ V}$$

For $V_{BC} = 1\text{ V}$, $x_{dB} = 0.1387\ \mu\text{m}$

For $V_{BC} = 5\text{ V}$, $x_{dB} = 0.2575\ \mu\text{m}$

Then $\Delta x_{dB} = 0.2575 - 0.1387 = 0.1188\ \mu\text{m}$

(b) $I_C = \dfrac{eD_B p_{B0} A_{BE}}{x_B} \exp\left(\dfrac{V_{EB}}{V_t} \right)$

We find

$$p_{B0} = \frac{n_i^2}{N_B} = \frac{(1.5\times10^{10})^2}{10^{16}}$$

$$= 2.25\times10^4 \text{ cm}^{-3}$$

Then

$$I_C = \frac{(1.6\times10^{-19})(10)(2.25\times10^4)(10^{-4})}{x_B} \times \exp\left(\frac{0.625}{0.0259} \right)$$

$$= \frac{1.0874\times10^{-7}}{x_B} \text{ A}$$

For $V_{BC} = 1\text{ V}$, $I_C = \dfrac{1.0874\times10^{-7}}{(0.70 - 0.1387)\times10^{-4}}$

$$= 1.937\times10^{-3}\text{ A} = 1.937\text{ mA}$$

For $V_{BC} = 5\text{ V}$, $I_C = \dfrac{1.0874\times10^{-7}}{(0.70 - 0.2575)\times10^{-4}}$

$$= 2.456\times10^{-3}\text{ A} = 2.456\text{ mA}$$

Then

$$\Delta I_C = 2.456 - 1.937 = 0.519 \text{ mA}$$

(c) $\dfrac{\Delta I_C}{\Delta V_{BC}} = \dfrac{I_C}{V_{EC} + V_A}$

$$\frac{0.519\times10^{-3}}{5-1} = \frac{1.937\times10^{-3}}{1 + 0.625 + V_A}$$

$$V_A = 13.3 \text{ V}$$

(d) $r_o = \dfrac{V_{EC} + V_A}{I_C} = \dfrac{1.625 + 13.3}{1.937\times10^{-3}}$

$$= 7.705\times10^3\ \Omega = 7.705\text{ k}\Omega$$