Assignment 1

1.

(a) Acceptor impurity atoms should be added to achieve electron concentration.

(b) At room temperature ($T=300k$),

$$n_i = BT^{\frac{3}{2}} e^{\left(\frac{-E_g}{2kT}\right)} = (5.23\times10^{15})(300)^{\frac{3}{2}} e^{\left(\frac{-1.1}{2(86\times10^{-6})(300)}\right)} = 1.5\times10^{10}\ cm^{-3}$$

Since donor concentration $n_o >> n_i$,

$$p_o = \frac{n_i^2}{n_o} = \frac{(1.5\times10^{10})^2}{7\times10^{15}} \approx 3.21\times10^{4}\ cm^{-3}$$

(C) Since $p_o \le 10^6\ cm^{-3}$, $n_i = \sqrt{n_o p_o} \le \sqrt{7\times10^{15}\times10^{6}} \approx 8.37\times10^{10}\ cm^{-3}$

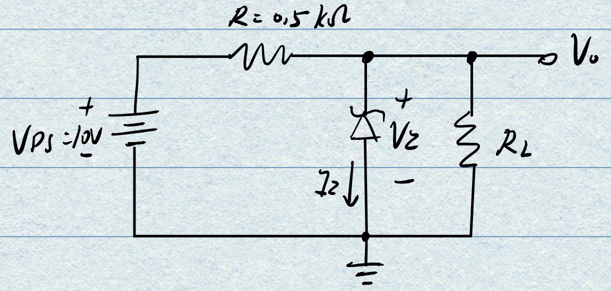
When n_i achieve $n_i max$, T achieve $T max$.

$$n_{i\,max} = BT_{max}^{\frac{3}{2}} e^{\left(\frac{-E_g}{2kT_{max}}\right)}$$

$$8.37\times10^{10} = (5.23\times10^{15})\, T_{max}^{\frac{3}{2}} e^{\left(\frac{-1.1}{2(86\times10^{-6})T_{max}}\right)}$$

$$T_{max} = 324\ K$$

2.



(a) When $R_L = \infty$, $V_o = V_{PS} - IR = V_o - \frac{V_{PS}-V_Z}{R+R_Z}\cdot R$

$$= 10 - \frac{10-5.6}{500+10}\times500 \approx 5.686\ V$$

(b) $V_Z' = V_Z - I_Z\times r_Z = 5.6V - 0.1mA\times10\Omega = 5.599\ V$

$$V_{o\,max} = \frac{V_{PS\,max} - V_Z'}{R+r_Z} r_Z + V_Z = \frac{11-5.599}{500+10}\times10 + 5.599 \approx 5.706\ V$$

$$V_{o\,min} = \frac{V_{PS\,min} - V_Z'}{R+r_Z} r_Z + V_Z = \frac{9-5.599}{500+10}\times10 + 5.599 \approx 5.667\ V$$

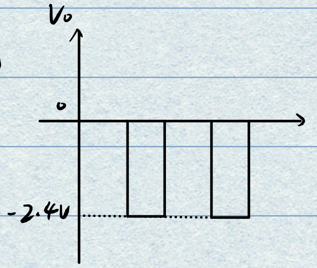
The output voltage change $\Delta V_o = V_{o\,max} - V_{o\,min} = 0.039\,V$

(c) $R_{TH} = R // r_z = \frac{500 \times 10}{500 + 10} \approx 9.8\,\Omega$

$V_{TH} = \frac{V_{PS} - V_Z}{R + r_z} r_z + V_Z = \frac{10 - 5.6}{500 + 10} \times 10 + 5.6 \approx 5.686\,V$

$V_o = \frac{V_{TH}}{R_{TH} + R_L} R_L = \frac{5.686}{9.8 + 2000} \times 2000 \approx 5.658\,V$

3. (a)

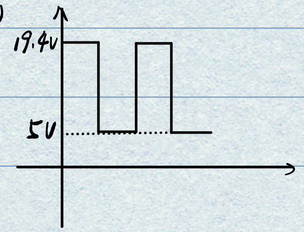


From the diagram, $-5V \le V_I \le 20V$

when $V_I = 20V$, diode is off, $V_o = 0$

when $V_I = -5V$, $V_o = V_I + V + V_\gamma = -2.4V$

(b)



when $V_I = 20V$, the diode is on.

$V_o = V_I - V_\gamma = 20 - 0.6 = 19.4V$

When the diode is off, $V_o = 5V$

4. (a) When $V_1 = V_2 = 10V$,

diode D_1 and D_2 are off

$I_{D_1} = I_{D_2} = 0$.

$V_o = 10V$.

(b) When $V_1 = 10V$, $V_2 = 0$,

D_1 is off and D_2 is on.

$I_{D_1} = 0$, $I_{D_2} = \frac{10 - V_\gamma - V_2}{0.5 + 9.5} = 0.94\,mA$

$V_o = 10 - I_D R = 10 - 0.94\,mA \times 9.5\,k\Omega = 1.07\,V$

(c) When $V_1 = 10V$, $V_2 = 5V$,

D_1 is off and D_2 is on.

$I_{D_1} = 0, \quad I_{D_2} = \frac{10 - V_\gamma - V_2}{0.5 + 9.5} = 0.44\ mA$

$V_0 = 10 - I_{D_2}R = 10 - 0.44 \times 9.5 = 5.82\ V$

(d) When $V_1 = 0, V_2 = 0$,

D_1 and D_2 are on.

Therefore $\frac{I}{2} = \frac{10 - V_\gamma - 9.5I}{0.5}$

$I = \frac{9.4}{9.75} \approx 0.964\ mA$

$I_{D_1} = I_{D_2} = 0.482\ mA$

$V_0 = 10 - IR = 10 - 0.964 \times 9.5 = 0.842\ V$

5. (a) $V_{DS(sat)} = V_{GS} - V_{TN}$

$= 2.2 - 0.4 = 1.8\ V$

$V_{DS} = 2.2V > V_{DS(sat)}$

Thus the transistor is in saturation region.

(b) $V_{DS(sat)} = V_{GS} - V_{TH}$

$= 1 - 0.4 = 0.6\ V$

$V_{DS} = -0.6V < V_{DS(sat)}$

Thus in nonsaturation region.

(c) $V_{DS(sat)} = V_{GS} - V_{TH}$

$= 0 - 0.4 = -0.4\ V < 0$

Thus in cut-off region.

6. $V_{SD(sat)} = V_{SG} + V_{TP} = 2 - 0.5 = 1.5\ V$

Thus in (a)(b), $V_{SD} < V_{SD(sat)}$

nonsaturation region.

in (c),(d), $V_{SD} > V_{SD(sat)}$

saturation region.

$$K_p = \frac{k_p'}{2} \cdot \frac{W}{L} = \frac{50}{2} \cdot \frac{12}{0.8} = 375\ \mu A/V^2 = 0.375\ mA/V^2$$

Since (a)(b) in nonsaturation region.

(a) $i_D = K_p [\, 2(V_{SG} + V_{TP}) V_{SD} - V_{SD}^2 \,]$

$= 0.375 \times [\, 2(2-0.5) \times 0.2 - 0.2^2 \,]$

$= 0.21\ mA$

(b) $i_D = K_p [\, 2(V_{SG} + V_{TP}) V_{SD} - V_{SD}^2 \,]$

$= 0.66\ mA$

Since (c)(d) in saturation region.

(c) $i_D = K_p (V_{SG} + V_{TP})^2$

$= 0.375 \times (2-0.5)^2$

$\approx 0.844\ mA$

(d) $i_D = K_p (V_{SG} + V_{TP})^2 \approx 0.844\ mA$

7. (a) $I_B = \frac{I_E}{(1+\beta)} = \frac{1.2}{1+80} \approx 0.0148\ mA = 14.8\ \mu A$

$I_C = (\frac{\beta}{1+\beta}) I_E = \frac{80}{1+80} \times 1.2 \approx 1.185\ mA$

$\alpha = \frac{\beta}{1+\beta} \approx 0.9877$

$V_C = 5 - I_C \cdot R_C = 2.63\ V$

(b) $I_B = \frac{I_E}{(1+\beta)} = \frac{0.8}{1+80} \approx 0.009877\ mA = 9.88\ \mu A$

$I_C = (\frac{\beta}{1+\beta}) I_E = \frac{80}{1+80} \times 0.8 \approx 0.790\ mA$

$\alpha = \frac{\beta}{1+\beta} \approx 0.9877$

$V_C = 5 - I_C \cdot R_C = 3.42\ V$

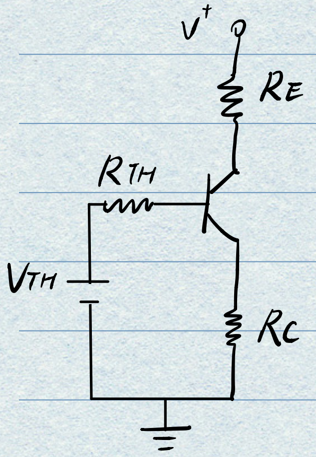
(c) $I_B = \frac{I_E}{(1+\beta)} = \frac{1.2}{1+120} \approx 9.92\ \mu A$

$I_C = \left(\frac{\beta}{1+\beta}\right) I_E = \frac{120}{1+120} \times 1.2 \approx 1.190\ mA$

$\alpha = \frac{\beta}{1+\beta} \approx 0.9917$

$V_C = 5 - I_C \cdot R_C = 2.62\ V$

8. Redraw the diagram.



(a) $R_{TH} = R_1 // R_2 = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{40 \times 40}{40+40} = 20\Omega$

$V_{TH} = V^+ \cdot \frac{R_2}{R_1+R_2} = 1.25\ V$

$I_{BQ} = \frac{V_{TH} - V_{BE(on)}}{R_{TH} + (1+\beta) R_E} = \frac{1.25 - 0.7}{20 + (1+90) \times 0.7}$

$\approx 6.57\ mA$

$I_{CQ} = \beta I_{BQ} \approx 0.591\ mA$

$V_{ECQ} = V^+ - V_{EB(on)} - V_C$

$= 2.5 - 0.7 - 0.591 \times 1.6$

$= 1.135\ V$

(b) $I_{CQ}' = \beta I_{BQ} = \beta \frac{V_{TH} - V_{BE(on)}}{R_{TH} + (1+\beta) R_E} = 120 \times \frac{1.25 - 0.7}{20 + (1+120) \times 0.7} \approx 0.657\ mA$

$\frac{\Delta I_{CQ}}{I_{CQ}} \times 100\% = \frac{0.657 - 0.591}{0.591} \times 100\% \approx 11.2\%$

$V_{ECQ}' = V^+ - V_{EB(on)} - V_C'$

$= 2.5 - 0.7 - 0.657 \times 1.6$

$= 0.986\ V$

$\frac{\Delta V_{ECQ}}{V_{ECQ}} \times 100\% = \frac{1.135 - 0.986}{1.135} \times 100\% \approx 13.1\%$

Thus the percent change in I_{CQ} is 11.2%

in V_{ECQ} is 13.1%