2)

a) $I_S = I_{E_S} = I_{C_S} = \frac{e A D_P p_B}{L_P} \cdot \coth\left(\frac{l}{L_P}\right) + \frac{e A D_{nE} n_E}{L_{nE}}$

$\alpha_N = \alpha_I = \frac{e A D_P p_B}{I_S L_P} \operatorname{csch}\left(\frac{l}{L_P}\right)$

$I_{E_B} = I_{C_B} = (1 - \alpha_N \alpha_I) I_{E_S} = (1 - \alpha^2) I_{E_S}$

b) $V_{BE} = V_{BC} = V \quad I_E = I/2$

$I_E = I_S\left(e^{\frac{eV_E}{K_B T}} - 1\right) - \alpha I_S\left(e^{\frac{eV}{K_B T}} - 1\right) = \left(e^{\frac{eV}{K_B T}} - 1\right)(1-\alpha) I_S \Rightarrow$

$\boxed{I = \alpha I_S (1-\alpha)\left(e^{\frac{eV}{K_B T}} - 1\right)}$

c) $I = I_E \quad I_C = 0$

$I_C = 0 \Rightarrow \alpha I_S\left(e^{\frac{eV_{EB}}{K_B T}} - 1\right) - I_S\left(e^{\frac{eV_{CB}}{K_B T}} - 1\right) = 0 \Rightarrow \alpha\left(e^{\frac{eV_{EB}}{K_B T}} - 1\right) = \left(e^{\frac{eV_{CB}}{K_B T}} - 1\right)$

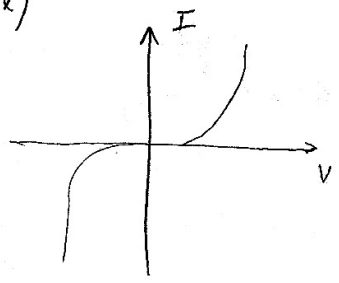
$I = I_E = I_S\left(e^{\frac{eV_{EB}}{K_B T}} - 1\right) - \alpha I_S\left(e^{\frac{eV_{CB}}{K_B T}} - 1\right) =$

$= I_S\left(e^{\frac{eV_{EB}}{K_B T}} - 1\right) - \alpha I_S \alpha\left(e^{\frac{eV_{EB}}{K_B T}} - 1\right) \Rightarrow \boxed{I = I_S (1-\alpha^2)\left(e^{\frac{eV_{EB}}{K_B T}} - 1\right)}$

d) $V_{CB} = 0 \quad V_{EB} = V \quad I = I_E$

$I = I_S\left(e^{\frac{eV}{K_B T}} - 1\right) - \alpha I_S\left(e^{\frac{eV_{CB}}{K_B T}} - 1\right)^{0} \Rightarrow \boxed{I = I_S\left(e^{\frac{eV}{K_B T}} - 1\right)}$

e)



3)

$l = 10^{-6}\ m \qquad N_a = 10^{17}\ cm^{-3} = 10^{23}\ m^{-3} \qquad \tau_p = 0,5 \cdot 10^{-6}\ s \qquad \tau_n = 0,1 \cdot 10^{-6}\ s$

$L_p = \sqrt{D_p \tau_p} = \sqrt{12,5 \cdot 10^{-4} \cdot 0,5 \cdot 10^{-6}} = 2,5 \cdot 10^{-5}\ m$

$L_n = \sqrt{D_n \tau_n} = \sqrt{35 \cdot 10^{-4} \cdot 0,1 \cdot 10^{-6}} = 1,87 \cdot 10^{-5}\ m$

$0,01 = \cosh\left(\frac{10^{-6}}{2,5 \cdot 10^{-5}}\right) + \left[\frac{35 \cdot 10^{-4} \cdot N_d \cdot 2,5 \cdot 10^{-5}}{12,5 \cdot 10^{-4} \cdot 10^{23} \cdot 1,87 \cdot 10^{-5}} \operatorname{senh}\left(\frac{10^{-6}}{2,5 \cdot 10^{-5}}\right)\right] - 1 \Rightarrow$

$\frac{0,01}{0,25} = 1 + \frac{87,5\, N_d}{23,375} \cdot 0,04 \cdot 10^{-23} - 1 \Rightarrow 0,25 = 3,74 \cdot 10^{-23} \cdot N_d \Rightarrow N_d = 0,0668 \cdot 10^{23} = 6,68 \cdot 10^{21}\ m^{-3}$

$\boxed{N_d = 6,68 \cdot 10^{15}\ cm^{-3}}$

b)

$\beta = \frac{\alpha}{1-\alpha} \Rightarrow 100 = \frac{\alpha}{1-\alpha} \Rightarrow 100 - 100\alpha = \alpha \Rightarrow \alpha = \frac{100}{101} = 0,99$

4)

$N_a = 10^{18}\ cm^{-3} \qquad N_d = 10^{16}\ cm^{-3} \qquad a = 0,5\mu s \qquad L = 30\mu m \qquad D = 1mm$

a) $V_c = \frac{e N_d a^2}{2 \varepsilon \varepsilon_0} = \frac{1,6 \cdot 10^{-19} \cdot 10^{22} \cdot 0,25 \cdot 10^{-12}}{2 \cdot 11,8 \cdot 8,85 \cdot 10^{-12}} \Rightarrow V_c = \frac{0,4 \cdot 10^{3}}{208,86} \Rightarrow \boxed{V_c = 1,91\ V}$

b) $G_0 = \frac{2 e N_d \mu_n D \cdot a}{L} = \frac{2 \cdot 1,6 \cdot 10^{-19} \cdot 10^{22} \cdot 0,135 \cdot 10^{-2} \cdot 0,5 \cdot 10^{-6}}{30 \cdot 10^{-6}} \Rightarrow G_0 = \frac{0,216}{30} \Rightarrow \boxed{G_0 = 7,2 \cdot 10^{-3}\ \Omega^{-1}}$

c) $V_D = V_c + V_p \Rightarrow V_D = 1,91 + (-1) \Rightarrow \boxed{V_D = 0,91\ V}$

$I_D = G_0 V_c \left[\frac{V_D}{V_c} + \frac{2}{3}\left(\frac{-V_p}{V_c}\right)^{3/2} - \frac{2}{3}\left(\frac{V_D - V_p}{V_c}\right)^{3/2}\right] =$

$= 7,2 \cdot 10^{-3} \cdot 1,91 \left[\frac{0,91}{1,91} + \frac{2}{3}\left(\frac{1}{1,91}\right)^{3/2} - \frac{2}{3}\left(\frac{0,91 - (-1)}{1,91}\right)\right] = 13,752 \cdot 10^{-3} \underbrace{\left[0,476 + 0,25 - 0,66\right]}_{0,062}$

$\Rightarrow I_D = 13752 \cdot 10^{-3} \cdot 0,062 \Rightarrow \boxed{I_D = 0,85\ mA}$

d) A corrente máxima é $I_{SAT} = 0,85mA$, quando $V = V_d$, então para tensões maiores que V_D, $I = I_{SAT}$.

5) $N_a = 5\times10^{17}\,cm^{-3} = 5.10^{23}\,m^{-3}$ $d = 10\,nm$ $\frac{Q_{ox}}{A} = 10^{-8}\,C/cm^2$ $L = 10\mu m$ $D = 300\mu m$ $\epsilon_i = 3,9\epsilon_0$ $\epsilon_s = 11,8\epsilon_0$ $\phi_{ms} = -1,1\,V$

a)

$$2\phi_F = 2\,\frac{K_B T}{e}\ln\left(\frac{N_a}{n_i}\right) = 0,026.2.\ln\left(\frac{5.10^{17}}{1,5.10^{10}}\right) \Rightarrow \boxed{2\phi_F = 0,9V}$$

$$Q_d = 2\left(\epsilon_s e N_a \phi_F\right)^{1/2} A = 2\left(11,8.8,85.10^{-12}.1,6.10^{-19}.5.10^{23}.0,45\right)^{1/2} A = 3,88.10^{-3}\,A\,C$$

$$C_i = \frac{\epsilon_i . A}{d} = \frac{3,9.8,85.10^{-12}.A}{10^{-8}} = 3,4515.10^{-3}\,A$$

$$V_c = \frac{Q_d - Q_{ox}}{C_i} + 2\phi_F + \phi_{ms} = \frac{3,88.10^{-3}\,A - 10^{-8}\,A}{3,4515.10^{-3}\,A} + 0,9 + (-1,1) = 1,1 - 0,2 = 0,9V$$

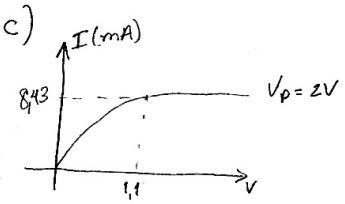
b)

$$V_{DS} = V_p - V_c = 2 - 0,9 = 1,1V$$

$$I_{DSAT} = \frac{\mu_n C_i V_{DS}^2}{2L^2} = \frac{0,135.3,4515\,A.(1,1)^2}{2.L^2} = \frac{0,135.3,4515.D.1,21}{2.L^2} = 0,281\,D.10^{+5}$$

$$I_{DSAT} = 0,281.200.10^{-1} \Rightarrow I_{D_{SAT}} = 8,43$$

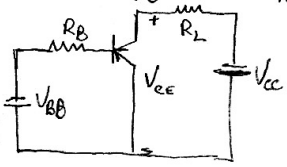
c)



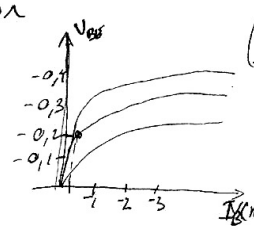
d) $C = \frac{A}{\frac{d}{\epsilon_i} + \frac{l}{\epsilon_s}} = \frac{D.L}{\frac{d}{\epsilon_i} + \frac{l}{\epsilon_s}} = \frac{300.10^{-6}.10.10^{-6}}{\frac{10^{-8}}{3,9.8,85.10^{-12}} + \frac{10.10^{-6}}{11,8.8,85.10^{-12}}} = 0,31\,pF$

4)

$V_{BB} = V_{CC} = 10V$ $R_L = 500\Omega$

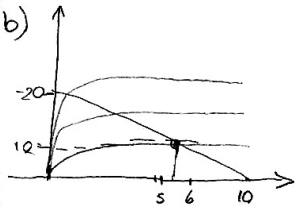


a)



$\boxed{V_{BE} = 0,2V}$ $R_B = \frac{V_{BB} - V_{BE}}{I_B} = \frac{10 - 0,2}{50.10^{-6}} \Rightarrow \boxed{R_B = 196K\Omega}$

b)



$V_{CE} = 5,2V$

$I_C = -9mA$

c) $\beta = \frac{I_C}{I_B} = \frac{9.10^{-3}}{50.10^{-6}} = 180$

d) Corte: $I_B \cong 0$

$0 = \frac{V_{BB} - V_{BE}}{R_B} \Rightarrow V_{BB} = V_{BE}$

$\boxed{V_{BB} = 0,2V}$

Saturação $I_C \cong 20mA$

$I_B = 0,15mA$

$0,15.10^{-3} = \frac{V_{BB} - 0,2}{196.10^3}$

$\boxed{V_{BB} = 29,6V}$

e) $V_{CC} = -1,4V$ $I_B = 0,25$

$0,25.10^{-3} = \frac{9,8}{R_B} \Rightarrow$

$\boxed{R_B = 39,2K\Omega}$

$R_L = \frac{V_{CC} - V_{CE}}{I_C} = \frac{10 - 1,4}{35.10^{-3}}$

$\boxed{R_L = 245,7\Omega}$