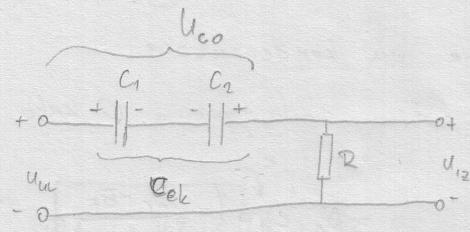


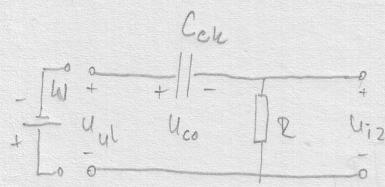
$$\textcircled{1} \quad U_{UL} = U_{C1} + U_{i_2} - U_{C2} = \\ = U_{C1} - U_{C2} + U_{i_2}$$



$$U_{c0} = U_{c10} - U_{c20}$$

$$C_{ek} = \left[\frac{1}{C_1} + \frac{1}{C_2} \right]^{-1} = \left\{ C_1 = C_2 = C \right\} = \left[\frac{1}{C} + \frac{1}{C} \right]^{-1} = \frac{C}{2} = \frac{2}{2} = 1 \mu F$$

$$\tau = C_{ek} \cdot R = 10^{-6} \cdot 5,6 \cdot 10^3 = 5,6 \cdot 10^{-3} s = 5,6 ms$$



$$U_{c0} = U_{c10} - U_{c20} = 1,5 - 1,5 = 0$$

$$t = 0^- \Rightarrow U_{i2}(0^-) = 0$$

$$t = 0^+ \Rightarrow U_{i2}(0^+) = -4V$$

$$U_{c0} = U_{c1} = 0$$

$$U_{ek} = -4V$$

$$U_{i2}(t) = U_R(t) = U_R(0^+) \exp \frac{-t}{\tau}$$

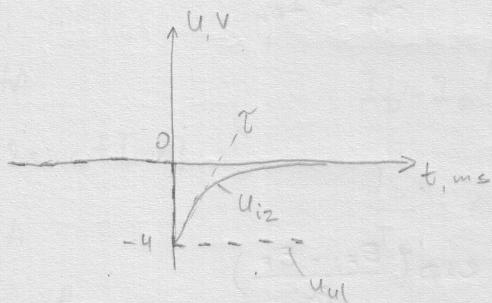
$$\text{b)} \quad U_{i2}(0^-) = 0$$

$$U_{i2}(0^+) = -4V$$

$$U_{i2}(t=5ms)$$

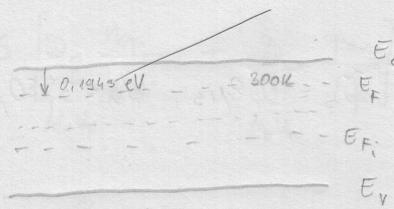
$$U_{i2} = -4 \exp \frac{-5 \cdot 10^{-3}}{5,6 \cdot 10^{-3}} = -1,64 V$$

c)



$$\textcircled{2} \quad N_D = 2 \cdot 10^{16} \text{ cm}^{-3}$$

a) $T = 300K$
 $E_F = ?$



b) $T = 400K$

$$\text{a)} \quad n_{on} = N_c \cdot \exp \frac{E_F - E_C}{E_T} \Rightarrow E_F = E_C + E_T \ln \frac{n_{on}}{N_c}$$

$$N_D = 2 \cdot 10^{16} \text{ cm}^{-3} \quad n_i = 1,45 \cdot 10^{10} \text{ cm}^{-3} \Rightarrow N_D \gg n_i \Rightarrow \text{EKSTRINZIČAN}$$

$$n_{on} = N_D = 2 \cdot 10^{16} \text{ cm}^{-3}$$

$$N_c = C \cdot T^{\frac{3}{2}} = 7,07 \cdot 10^{15} \cdot (300)^{\frac{3}{2}} = 3,67 \cdot 10^{19} \text{ cm}^{-3}$$

$$E_F = E_C + E_T \ln \frac{n_{on}}{N_c} = E_C + \frac{300}{11600} \ln \frac{2 \cdot 10^{16}}{3,67 \cdot 10^{19}} = E_C - 0,1943 \text{ eV}$$

b) $T \uparrow \Rightarrow E_F \Rightarrow E_{F_i}, \quad E_F \uparrow \Rightarrow N_D \uparrow$

$$N_{Duk} = N_{D1} + N_{D2}$$

$$T = 400K$$

$$N_c = C \cdot T^{\frac{3}{2}} = 7,07 \cdot 10^{15} \cdot 400^{\frac{3}{2}} = 5,66 \cdot 10^{19} \text{ cm}^{-3}$$

$$n_i(400K) = C \cdot T^{\frac{3}{2}} \exp \frac{-E_G}{2kT} = 7,22 \cdot 10^{12} \text{ cm}^{-3}$$

$$E_C - E_F = 0,1943 \text{ eV} \Rightarrow E_F - E_C = -0,1943 \text{ eV}$$

$$n_{on2} = N_c \exp \frac{E_F - E_C}{E_T} = 5,66 \cdot 10^{19} \exp \frac{-0,1943 \text{ eV}}{\frac{400}{11600}} = 1,02 \cdot 10^{17} \text{ cm}^{-3}$$

$$n_{on2} \gg n_i \Rightarrow \text{EKSTRINZIČAN}$$

$$n_{on2} \approx N_{Duk} = N_{D1} + N_{D2} \Rightarrow N_{D2} = n_{on2} - N_{D1}$$

$$N_{D2} = 1,82 \cdot 10^{17} \text{ cm}^{-3}$$

3) I_Sn-strana

$$N_D = 4 \cdot 10^{15} \text{ cm}^{-3}, \quad M_p = 300 \text{ cm}^2/\text{Vs}, \quad \tau_p = 0,8 \mu\text{s}, \quad W_n = 3,50 \mu\text{m} = 350 \cdot 10^{-4} \text{ cm}$$

p-strana

$$N_A = 2 \cdot 10^{17} \text{ cm}^{-3}, \quad M_n = 800 \text{ cm}^2/\text{Vs}, \quad \tau_n = 0,5 \mu\text{s}, \quad W_p = 0,8 \mu\text{m} = 0,8 \cdot 10^{-4} \text{ cm}$$

$$S = 1 \text{ mm}^2 = 10^{-2} \text{ cm}^2$$

a) RAVNOTEŽNE KONC.

$$p_{n0} = \frac{n_i^2}{N_{n0}} = \frac{n_i^2}{N_D} = \frac{(1,45 \cdot 10^{10})^2}{4 \cdot 10^{15}} = 5,26 \cdot 10^4 \text{ cm}^{-3}$$

$$n_{p0} = \frac{n_i^2}{p_{n0}} = \frac{n_i^2}{N_A} = \dots = 1,05 \cdot 10^3 \text{ cm}^{-3}$$

RUBNE KONC.

$$p_{n0} = p_{n0} \exp \frac{U_0}{m U_T} = 5,26 \cdot 10^4 \exp \frac{0,55 \cdot 11600}{1 \cdot 300} = 9,06 \cdot 10^{13} \text{ cm}^{-3}$$

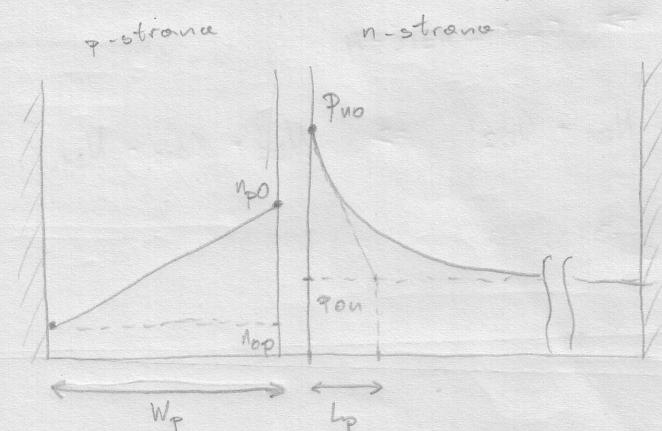
$$n_{p0} = n_{p0} \exp \frac{U_0}{m U_T} = \dots = 1,81 \cdot 10^{12} \text{ cm}^{-3}$$

$$L_n = \sqrt{D_n \tau_n} = \sqrt{M_n U_T \tau_n} = \sqrt{800 \cdot \frac{300}{11600} \cdot 0,5 \cdot 10^{-6}} = 32,2 \mu\text{m} = 32,2 \cdot 10^{-4} \text{ cm}$$

$$L_p = \sqrt{D_p \tau_p} = \sqrt{M_p U_T \tau_p} = \dots = 24,9 \mu\text{m} = 24,9 \cdot 10^{-4} \text{ cm}$$

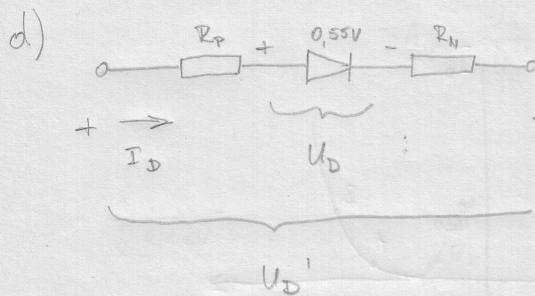
$W_p \ll L_n \Rightarrow$ USKA P-STRANA

$W_n \gg L_p \Rightarrow$ ŠIROKA N-STRANA



$$\begin{aligned}
 b) I_S &= I_{SN} + I_{SP} = qS \left[\underbrace{D_n}_{M_n U_T} \frac{V_{OP}}{W_P} + \underbrace{D_P}_{M_P U_T} \frac{I_{on}}{L_P} \right] = qS U_T \left[M_n \frac{V_{OP}}{W_P} + M_P \frac{I_{on}}{L_P} \right] = \\
 &= 1,6 \cdot 10^{-19} \cdot 10^{-2} \frac{300}{11600} \left[800 \frac{1,05 \cdot 10^3}{0,8 \cdot 10^{-4}} + 300 \frac{5,26 \cdot 10^4}{24,9 \cdot 10^{-4}} \right] = \\
 &= 0,7 \cdot 10^{-12} A = 0,7 \mu A
 \end{aligned}$$

$$c) I_D = I_S \left[\exp\left(\frac{U_D}{mU_T}\right) - 1 \right] = 0,7 \cdot 10^{-12} \left[\exp\left(\frac{0,55 \cdot 11600}{1 \cdot 300}\right) - 1 \right] = 1,2 \text{ mA}$$



$$U_D' = U_P + I_D (R_P + R_N) = 0,55 + 1,2 \cdot 10^3 (5 + 7)$$

$$U_D' = 0,564 \text{ V}$$

$$4. \text{ a) } U_{GS} \text{ pozitivan} \Rightarrow I_D \uparrow \Rightarrow \text{NMOS}$$

- moramo znati U_{GSO}

$$\text{b) A: } I_{DA} = 1 \text{ mA} \quad \text{B: } I_{DB} = 9 \text{ mA}$$

$$U_{GSA} = 2 \text{ V}$$

$$U_{GSB} = 4 \text{ V}$$

A i B u zasicanju

$$I_{DA} = \frac{k}{2} (U_{GSA} - U_{GSO})^2 \quad I_{DB} = \frac{k}{2} (U_{GSB} - U_{GSO})^2$$

$$\frac{I_{DB}}{I_{DA}} = \frac{(U_{GSB} - U_{GSO})^2}{(U_{GSA} - U_{GSO})^2}$$

$$\pm \sqrt{\frac{I_{DB}}{I_{DA}}} = \frac{U_{GSB} - U_{GSO}}{U_{GSA} - U_{GSO}}$$

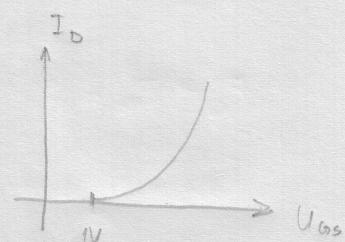
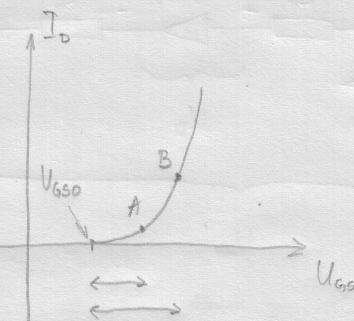
$$3 = \frac{U_{GSB} - U_{GSO}}{U_{GSA} - U_{GSO}}$$

$(U_{GSB} - U_{GSO})$ i $(U_{GSA} - U_{GSO})$ imaju isti produkt.
(i u A, i u B imamo kanal)

$$3(U_{GSA} - U_{GSO}) = U_{GSB} - U_{GSO} \Rightarrow U_{GSO} = \frac{3U_{GSA} - U_{GSB}}{2} = \frac{3 \cdot 2 - 4}{2} = 1 \text{ V}$$

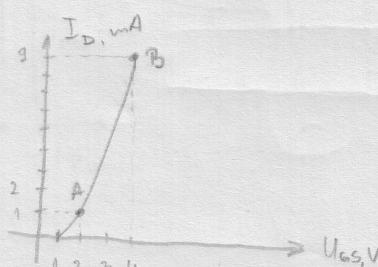
$$k = \frac{2 I_{D0}}{(U_{GSA} - U_{GSO})} = \dots = 2 \text{ mA V}^{-2}$$

u $U_{GS} = 0 \text{ V} \Rightarrow I_D = 0 \Rightarrow \text{OBOGACENI SLOJ}$



$$K = \mu_n C_{ox} \cdot \frac{W}{L} = \mu_n \frac{\epsilon_0 \epsilon_{r,ox}}{t_{ox}} \cdot \frac{W}{L} \Rightarrow t_{ox} = \frac{\mu_n \epsilon_0 \epsilon_{r,ox}}{K} \cdot \frac{W}{L}$$

$$t_{ox} = \frac{350 \cdot 8,854 \cdot 10^{-14} \cdot 3,9}{2 \cdot 10^{-3}} \cdot 20 = 1,21 \cdot 10^{-6} \text{ cm} = 12,1 \text{ nm}$$



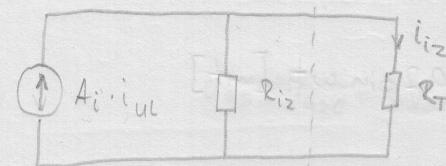
PITANJA

1) $A_i = 150$

$$R_{ul} = 1k\Omega$$

$$R_{iz} = 4k\Omega$$

$$A_I = \frac{i_{iz}}{i_{ul}} = 100$$

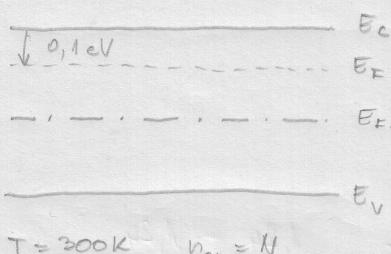


$$A_I = \frac{i_{iz}}{i_{ul}} = \frac{A_i \cdot i_{ul} \frac{R_{iz}}{R_{iz} + R_T}}{i_{ul}} \Rightarrow \frac{A_i}{A_I} = \frac{R_{iz} + R_T}{R_{iz}}$$

$$R_T = R_{iz} \left[\frac{A_i}{A_I} - 1 \right] = 4 \left[\frac{150}{100} - 1 \right] = 2k\Omega$$

$$A_v = \frac{U_{iz}}{U_{ul}} = \frac{i_{iz} R_T}{i_{ul} R_{ul}} = A_I \frac{R_T}{R_{ul}} = 100 \cdot \frac{2}{1} = 200$$

2)



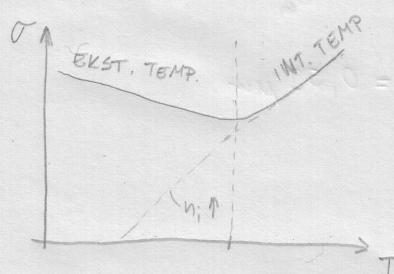
$$E_F > E_{F_i} \Rightarrow n\text{-tip} \quad N = N_D$$

$$T = 400K$$

$$N \gg n_i \Rightarrow n_{on} = N$$

$$T = T_N = q M_n \cdot n_{on} \xrightarrow{\text{KONST.}}$$

$$T \uparrow \Rightarrow M_n \downarrow \Rightarrow T \downarrow$$

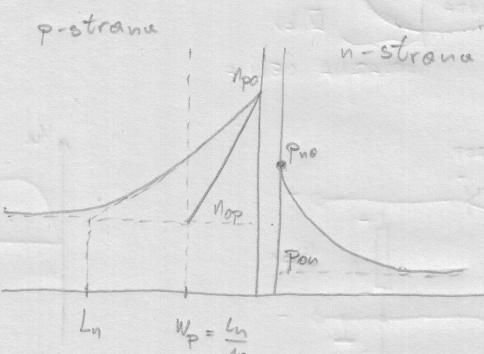


3) $N_D = 1000 N_A$

$$\rho_{on} = \frac{n_i^2}{N_D} \ll \rho_{op} = \frac{n_i^2}{N_A}$$

n-strana

p-strana



1) ŠIROKA

$$I_{D1} = I_{DP} = q S D_n \frac{dn}{dx} = q S D_n \frac{n_{po}}{L_n}$$

$$2) I_{D2} = I_{PP} = q S D_n \frac{n_{po}}{W_p}$$

$$\frac{I_{D2}}{I_{D1}} = \frac{L_n}{W_p} = \frac{L_n}{\frac{L_n}{10}} = 10$$

STRUJNA RASTE

$$④ I_s = 10 \text{ fA} = 10 \cdot 10^{-15} \text{ A}$$

$$i_d = I_D + I_{dm} \cdot \sin \omega t = 1 + 0,2 \sin \omega t [\text{mA}]$$

$$I_D = 1 \text{ mA}$$

$$I_{dm} = 0,2 \text{ mA}$$

$$I_D = I_s \exp \frac{U_D}{U_T} \Rightarrow U_D = U_T \ln \frac{I_D}{I_s} = 25 \cdot \ln \frac{10^3}{10 \cdot 10^{-15}} = 633 \text{ mV} \approx 630 \text{ mV}$$

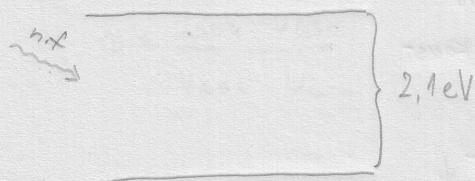
- Mali signal vidi dinamički otpor

$$r_d = \frac{U_T}{I_D} = \frac{25}{1} = 25 \Omega$$

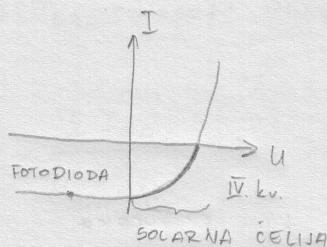
$$U_{dm} = r_d I_{dm} = 25 \cdot 0,2 \cdot 10^{-3} = 5 \cdot 10^{-3} \text{ V} = 5 \text{ mV}$$

$$U_D = U_D = U_D + U_{dm} \sin \omega t = 630 + 5 \sin \omega t [\text{mV}]$$

⑤

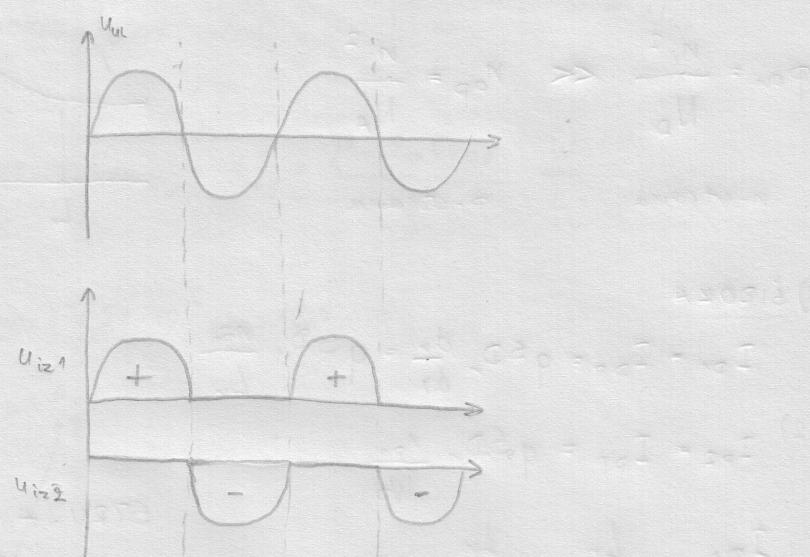
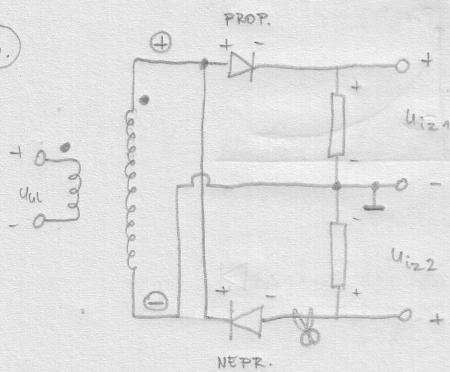


$$\left. \begin{aligned} h \cdot f &> E_g \\ h \cdot \frac{c}{\lambda} &\geq E_g \end{aligned} \right\} \lambda = \frac{hc}{E_g} = \frac{1,24}{E_g} = \frac{1,24}{2,1} \quad \lambda = 0,59 \mu\text{m}$$

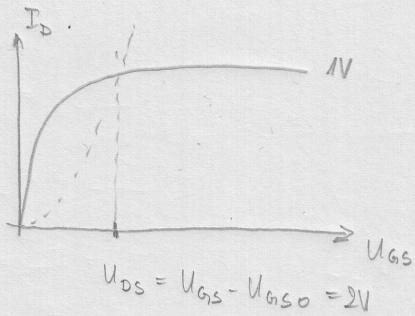


REVERZNO POL.

⑥



7) $U_{DS} > 0 \Rightarrow NMOS$



$$U_{GS} - U_{GSO} = 2V$$

$$U_{GSO} = U_{GS} - 2 = 1 - 2 = -1V$$

NMOS
 $U_{GSO} < 0 \} OSIROMAŠENO$

$$U_2: U_{GSO} = 0 \Rightarrow |I_D| > 0 \quad OSIROMAŠENO$$

