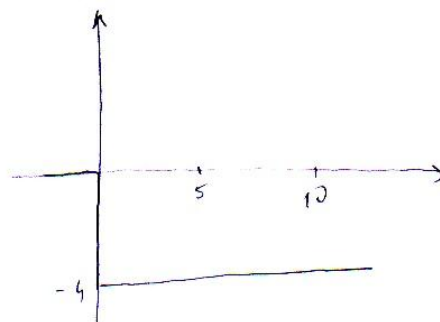
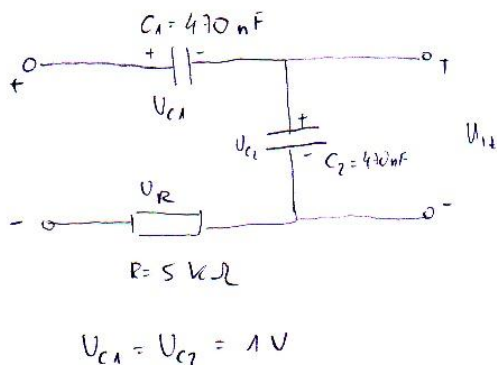


Z. 1.

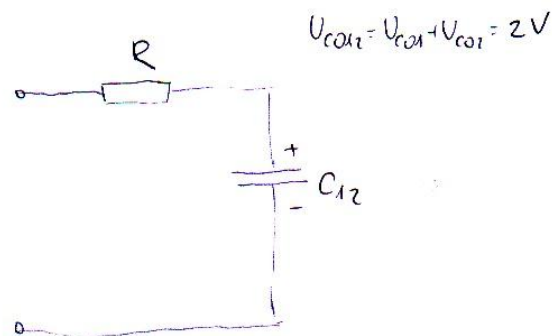
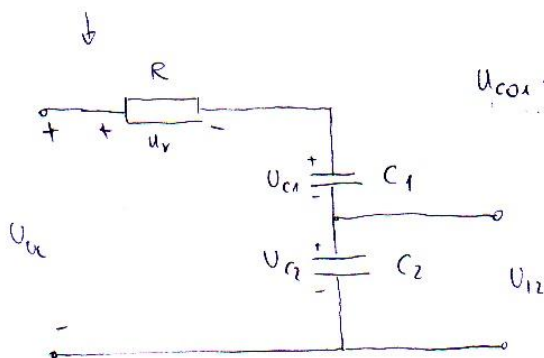
RC



- KAPACITIVNO DJELOVANJE
- RACUNAMO NA ZAJEDNIČKOM KAPACITETU PA PRE RAZDIOBI ODREĐIMO U_{C2}

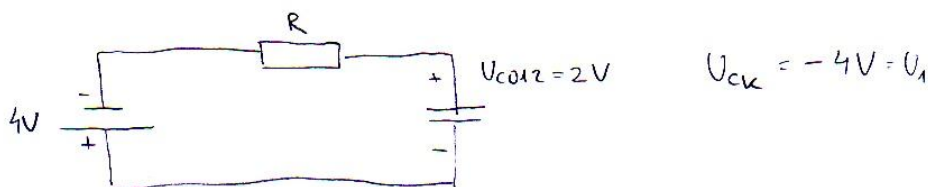
$$U_{uk} = U_{C1} + U_{C2} + U_R$$

$$= U_R + U_{C1} + U_{C2}$$



$$C_{12} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2}} = \frac{C_1 \cdot C_2}{C_1 + C_2} = \dots =$$

$$\tau = R \cdot C_{12} = R \cdot \frac{C_1 \cdot C_2}{C_1 + C_2} = 1.175 \text{ ms}$$



$$U_{C12}(t) = U_{C\infty} + [U_{Cuk} - U_{C\infty}] \left(1 - e^{-\frac{t}{\tau}}\right)$$

$$= U_{C12} + [U_1 - U_{C12}] \left(1 - e^{-\frac{t}{\tau}}\right)$$

ELE 2 19.11.12

$$U_{12}(t) = \frac{\frac{1}{C_2}}{\frac{1}{C_2} + \frac{1}{C_1}} U_{C12}(t) = \frac{C_1}{C_1 + C_2} \cdot U_{C12}(t) = 0,5 \cdot U_{C12}(t)$$

NAPONSVO DJELO

$$= 0,5 \left[U_{C012} + (U_1 - U_{C012}) \left(1 - \exp^{-\frac{t}{\tau}} \right) \right] \quad t > 0$$

OKRENUTI SHEMO, THEVENIN PO POTREBI. -)

b) IZRAČUN

$$U_{C12}(0) = U_{C012} = 2V$$

$$U_{12}(0) = 0,5 \cdot U_{C012} = 1V$$

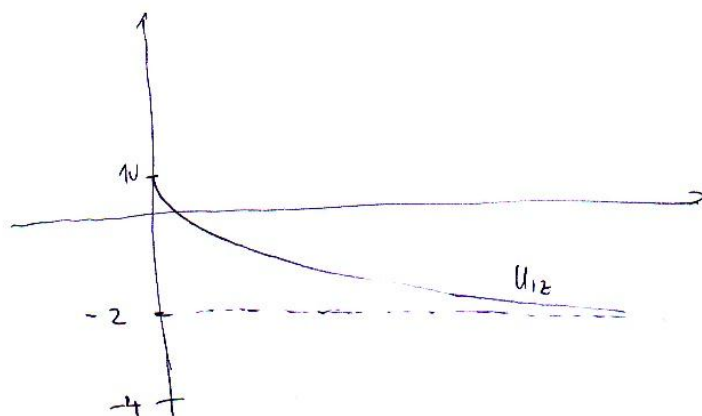
$$U_{C12}(1) = -1,438V$$

$$U_{12}(1) = 0,5 \cdot U_{C012}(1) = -0,719V$$

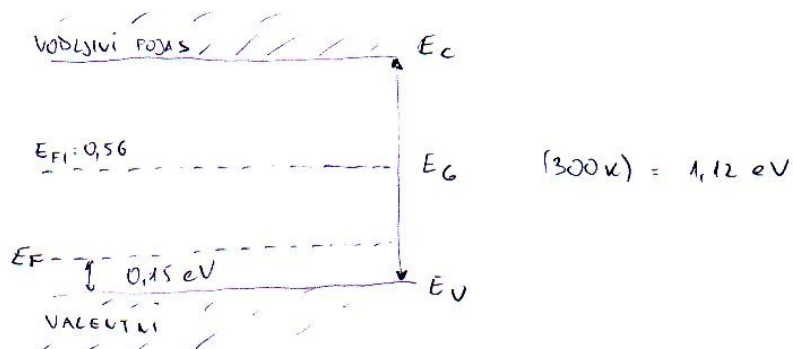
$$U_{C12}(\infty) = \dots \text{KONDENZATOR SE NABJE NA } -4V$$

$$U_{12}(\infty) = 0,5 \cdot U_{C12} = \underline{\underline{-2V}}$$

c)



2. ELEKTRIČNA SVOJSTVA POLUVODIČA



P-tip — jer je E_F ispod sredine zabranjenog pojasa.

$$E_F < \frac{E_G}{2}$$

Većinski nosioci:

$$p_0 = N_V \cdot \exp\left(\frac{E_V - E_F}{E_T}\right) = C \cdot T^{3/2} \cdot \exp\left(\frac{E_V - E_F}{\frac{T}{11600}}\right)$$

$$E_F - E_V = 0,15$$

$$E_V - E_F = -0,15 \quad = 7,07 \cdot 10^{15} \cdot 300^{3/2} \cdot \exp\left(\frac{-0,15}{\frac{300}{11600}}\right) = 1,11 \cdot 10^{17} \text{ cm}^{-3} \text{ (Na)}$$

$$n_i(300\text{K}) = 1,45 \cdot 10^{10} \text{ cm}^{-3}$$

$p_0 > n_i \Rightarrow$ P-TIP \Rightarrow OČEKIVANO, DOBRO ZA PROJEKT

$$n_0 = \frac{n_i^2}{p_0} = \frac{(1,45 \cdot 10^{10})^2}{1,11 \cdot 10^{17}} = 1,89 \cdot 10^3 \text{ cm}^{-3}$$

2b) VODLJIVOST SE SMANJILA 27%.

→ DODAJEMO SUPROTNI TIP PRIMJESE

$\sigma \downarrow \quad \rho \uparrow = \text{DODAJEMO SUPROTNI TIP}$

- U ovom slučaju DODAJEMO N_D

→ AKO JE $N_D < N_A \rightarrow$ ne mijenja se tip vodljivosti

→ $N_D > N_A \rightarrow$ mijenja se tip vodljivosti

- U ZADATKU KAVEDEMO DA JE PROMJENJEN TIP VODLJIVOSTI ($N_D > N_A$)

$n > p \rightarrow$ prelazi u n-TIP

$$\sigma = q(n \cdot \mu_n + p \cdot \mu_p)$$

PRJE: $p_0 \gg n_0 \rightarrow \sigma_0 \approx q \cdot p_0 \cdot \mu_p$

POSLEJE KAKO U DOPIRANJE S N_D : $\sigma = (1 - 0.27) \cdot \sigma_0 = 0.73 \sigma_0$

\rightarrow možemo zaključiti DA CE BITI U ISTOM REDU VELIČINE $N_D \cdot 10^{17} \text{ cm}^{-3}$

$\sigma = q \cdot \mu_n \cdot n_1 = n_1 \rightarrow$ koncentracija elektrona nakon 2. DOPIRANJA

$0.73 \cdot q \cdot p_0 \cdot \mu_p = q \cdot \mu_n \cdot n_1$

$n_1 = 0.73 \cdot p_0 \cdot \frac{\mu_p}{\mu_n} = 0.73 \cdot 1,11 \cdot 10^{17} \cdot \frac{350}{1100} = 2,58 \cdot 10^{16} \text{ cm}^{-3}$

PROJEKTA PRETPOSTAVKA

$n_1 \gg n_i = 1,45 \cdot 10^{10}$

$\Rightarrow \sigma_1 = q \cdot \mu_n \cdot n_1$ ✓

N_A, N_D

$n_1 = 2,58 \cdot 10^{16} \text{ cm}^{-3}$

$p_1 = \frac{n_i^2}{n_1} \ll n_1$

$$p + N_D^+ = n + N_A^-$$

ZAKON ELEKTRIČKE NEUTRALNOSTI

$$p_1 + N_D = n_1 + N_A$$

$$N_D = n_1 - p_1 + N_A \approx n_1 + N_A = 2,58 \cdot 10^{16} + 1,11 \cdot 10^{17} = \underline{1,368 \cdot 10^{17} \text{ cm}^{-3}}$$

→ PISATI JEDINICE OBVEZNO, PAZITI NA "OSNOVNE" JEDINICE

3. PN DIODA

- KROMIJEVO DOPIRANA

$$W_n = 2 \mu\text{m} \ll L_p \rightarrow \text{USKA n STRANA} = 2 \cdot 10^{-4} \text{ cm}$$

$$W_p = 3 \mu\text{m} \ll L_n \rightarrow \text{USKA P STRANA} = 3 \cdot 10^{-4} \text{ cm}$$

$$S = 0,5 \text{ mm}^2 = 0,5 \cdot 10^{-2} \text{ cm}^2$$

$$M_n = 1000 \text{ cm}^2/\text{Vs}$$

$$M_p = 200 \text{ cm}^2/\text{Vs}$$

$$N_D = 10^{16} \text{ cm}^{-3} \quad N_A = 8 \cdot 10^{15} \text{ cm}^{-3}$$

$$\tau_n = 0,8 \mu\text{s} \quad \tau_p = 0,5 \mu\text{s} \rightarrow \text{"VIŠAK" JEER IMA MO USKE STRANI}$$

PA KEMA REKOMBINACIJE

b) n STRANA

$$N_D = 10^{16} \text{ cm}^{-3}$$

!! → ZAKIMAJU KA MANJE SU NOSIOCI
KOJI ODREĐUJU STRUJU KROZ PN-DIOD !!

$$\text{većinski: } n_{0n} = 10^{16} \text{ cm}^{-3}$$

$$\text{manjinski: } p_{0n} = \frac{n_i^2}{n_{0n}} = \frac{1,45 \cdot 10^{10}}{10^{16}} = 2,1 \cdot 10^4 \text{ cm}^{-3} \rightarrow \text{RAVNOTEŽNA KONCENTRACIJA MANJ. NOSIOCA}$$

P-STRANA

$$N_A = 8 \cdot 10^{15} \text{ cm}^{-3}$$

$$\text{većinski } p_{0p} = 8 \cdot 10^{15}$$

$$\text{manjinski } n_{0p} = \frac{n_i^2}{p_{0p}} = \frac{1,45 \cdot 10^{10}}{8 \cdot 10^{15}} = 2,63 \cdot 10^4 \text{ cm}^{-3} \rightarrow \text{RAVNOTEŽNA KONCENTRACIJA MANJ. NOSIOCA}$$

$$V_D = 0,5 \rightarrow \text{napon PROPOSLE POLARIZACIJE}$$

RUBLJE KONCENTRACIJE → BOLTZMANOVE UVJETE

$$p_{n0} = p_{0n} \cdot \exp \frac{V_D}{V_T} = 2,1 \cdot 10^4 \cdot \exp \left(\frac{0,5}{\frac{300}{11600}} \right) = 52 \cdot 10^{12} \text{ cm}^{-3}$$

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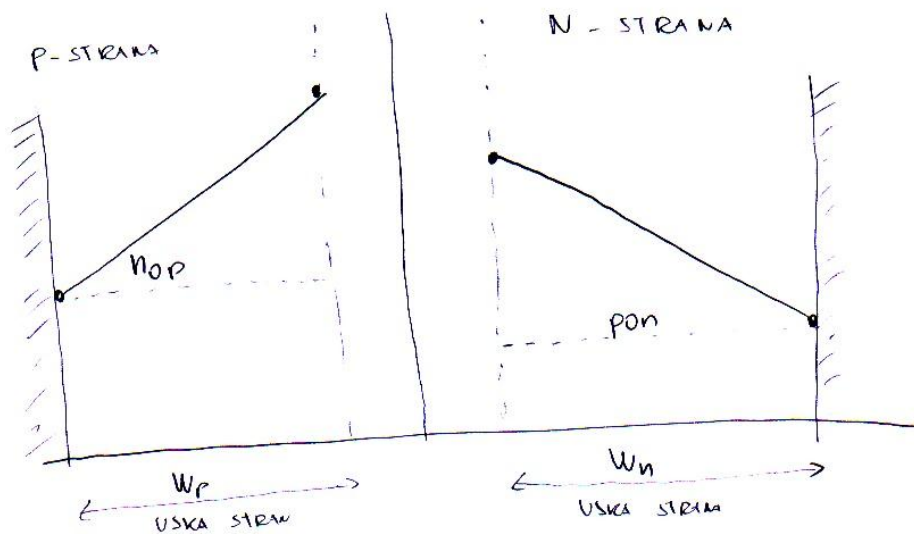
$$3. \quad n_{p0} = n_{0p} \exp \frac{U_D}{U_T} = \dots = 6,5 \cdot 10^{12} \text{ cm}^{-3}$$

ZA SKICU

$$N_D > N_A$$

$$n_{0n} > p_{0p}$$

$$p_{0n} < n_{0p}$$



- USKA STRANA → LINEARNA RASPODJELE

$$I_s = I_{hs} + I_{sp} \quad \dots \text{ gledamo manjinske nosioce}$$

$$= q \cdot S \left[D_n \frac{n_{0p}}{W_p} + D_p \frac{p_{0n}}{W_n} \right]$$

\downarrow \downarrow
 $\frac{L_n}{\text{SROVA}}$ $\frac{L_p}{\text{SROVA}}$

→ AKO BI BILE ŠIROKE STRANE

$$= 1,6 \cdot 10^{-19} \cdot 0,5 \cdot 10^{-2} \left[1000 \frac{300}{11600} \cdot \frac{2,63 \cdot 10^4}{3 \cdot 10^{-4}} + 200 \cdot \frac{300}{11600} \cdot \frac{21 \cdot 10^4}{2 \cdot 10^{-4}} \right]$$

$$= 2,75 \cdot 10^{-11} \text{ A} = \underline{\underline{2,25 \text{ pA}}}$$

$$I_D = I_s \left[\exp \left(\frac{U_D}{U_T} \right) - 1 \right] = 2,25 \cdot 10^{-11} \left[\exp \left(\frac{0,5}{\frac{300}{11600}} \right) - 1 \right] = \underline{\underline{0,6 \text{ mA}}}$$

3 DYNAMICKI OTPOR

ELEKTROSTATIKA

$$r_d = \frac{dU_D}{dI_D} = \frac{1}{\frac{dI_D}{dU_D}} = \frac{1}{\frac{d}{dU_D} \left[I_S \left(\exp \frac{U_D}{U_T} - 1 \right) \right]} = \frac{1}{I_S \exp \frac{U_D}{U_T} \cdot \frac{1}{U_T}} = \frac{U_T}{I_S \exp \frac{U_D}{U_T}}$$

$$= \frac{U_T}{I_S \exp \frac{U_D}{U_T} - I_S + I_S} = \frac{U_T}{I_D + I_S}$$

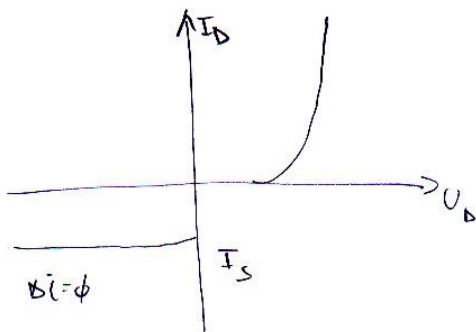
$$U_D = 0,5 \text{ V} \rightarrow \text{PROPUŠNA} \quad U_D \gg 3U_T$$

$$r_d = \frac{U_T}{I_D + I_S} \approx \frac{U_T}{I_D} = \frac{300}{\frac{11600}{0,6 \cdot 10^{-3}}} = \underline{\underline{46,2 \, \Omega}}$$

$\left. \begin{array}{l} \text{DYNAMICKI OTPOR} \\ \text{PROPUŠNO POLARIZIRAN} \\ \text{PN SPOLJA JE MALI} \end{array} \right\}$

$$U_D = -0,5 \text{ V} \rightarrow \text{ZAPORNA POLARIZACIJA} \quad |U| \ll |3U_T| \quad I_D \approx -I_S$$

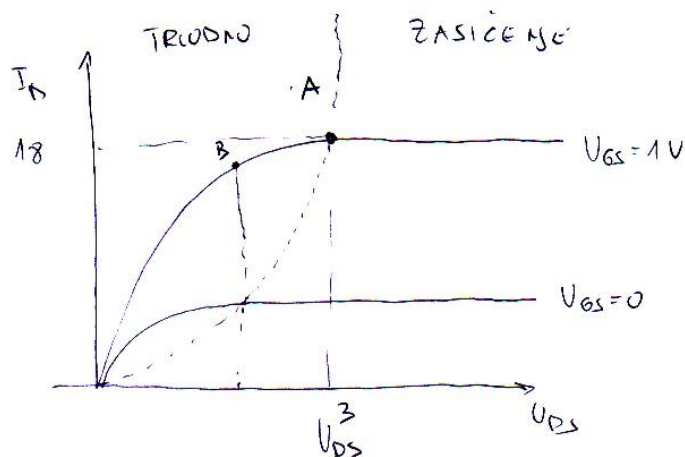
$$r_d = \frac{U_T}{I_D + I_S} = \frac{U_T}{-I_S + I_S} = \frac{U_T}{0} \approx \left\{ \begin{array}{l} \text{DYNAMICKI OTPOR} \\ \text{ZAPORNO } \infty \end{array} \right.$$



4. MOSFET

→ nema računanja DYNAMIČKI PARAMETARA JER NJE
OBRAĐELO : SAMO STATIKA

IZLAZNA KARAKTERISTIKA



- $V_{GS} \rightarrow$ POZITIVNIJU \rightarrow STRUJO I_D PRAKOSU RASTE \rightarrow N kanalni

- UZ $V_{GS} = 0$ I_D praktično > 0 \rightarrow OSIROMASENI

- TOČKA A : - na granici TRIODNO - ZASIĆENJE

$$V_{DSA} = 3V$$

$$V_{GSA} = 1V$$

$$I_{DA} = 18mA$$

$$\rightarrow V_{GS} \quad V_{DS} = V_{GS} - V_{GS0}$$

$$V_{DSA} = V_{GSA} - V_{GS0}$$

$$\rightarrow V_{GS0} = V_{GSA} - V_{DSA} = 1 - 3 = -2V$$

- UPRAVDE FORMULE ZA ZASIĆENJE

$$I_{DA} = \frac{K}{2} (V_{GSA} - V_{GS0})^2$$

$$K = \frac{2 I_{DA}}{(V_{GSA} - V_{GS0})^2} = \frac{2 \cdot 18 \cdot 10^{-3}}{(1 - (-2))^2} = 4 \frac{mA}{V^2} \rightarrow \text{konstanta MOSFETa}$$

4.

TOČKA B

$$U_{GSB} = U_{GSA} = \underline{1V}$$

$$U_{DSB} = 0,5 U_{DSA} = 0,5 \cdot 3 = \underline{1,5V}$$

$$|U_{DSB}| = 1,5V < |U_{GSB} - U_{GSD}| = 1 + 2 = 3V$$

↳ TRIODNO PODRUČJE

$$I_{DB} = K \left[(U_{GSB} - U_{GSD}) U_{DSB} - \frac{U_{DSB}^2}{2} \right] \rightarrow \text{TRIODNO PODRUČJE}$$

$$= 4 \left[(1 + 2) 1,5 - \frac{1,5^2}{2} \right] = \underline{\underline{13,5 \text{ mA}}}$$

DINAMIKA

$$g_m = \left. \frac{di_D}{dU_{GS}} \right|_B = \frac{di_{DB}}{dU_{GS}} = K \cdot U_{DSB} = 4 \cdot 1,5 = 6 \text{ mA/V}$$

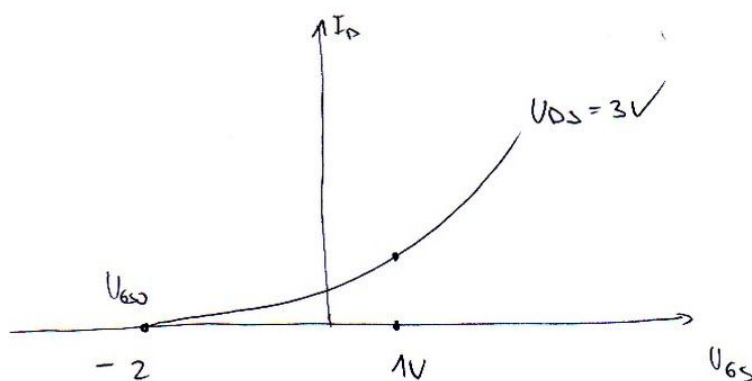
$$g_d = \left. \frac{di_D}{dU_{DS}} \right|_B = \frac{di_{DB}}{dU_{DS}} = K [U_{GSB} - U_{GSD} - U_{DSB}] = 4[1 + 2 - 1,5] = 6 \text{ mS}$$

$$r_d = \frac{1}{g_d} = 166,7 \Omega$$

$$\mu = g_m \cdot r_d = 1$$

(4)

ELE - 11 11.11, 12

PEREKOSNA KARAKTERISTIKA

n-kanalni MOSFET