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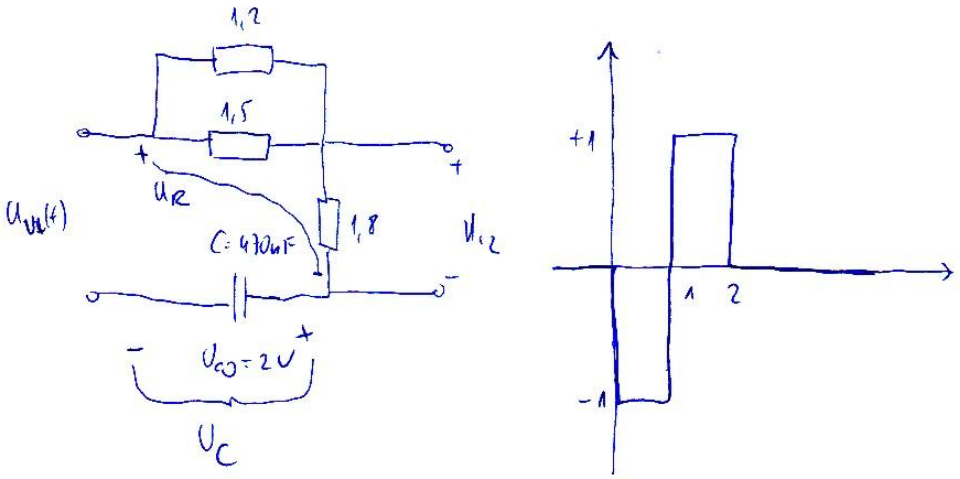
ZA SKLOP NA SLICI a) PRIKLJUČEN JE ULAZNI NAPON

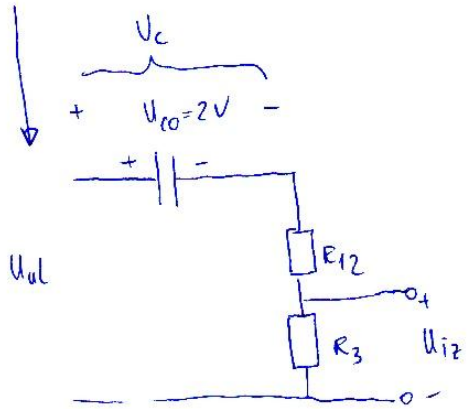
$U_{ul}(t)$



$t=0 \quad U_{C0}=2V$

$U_{ul} = U_R + U_C = U_C + U_R$

$R_{12} = R_1 \| R_2 = 0{,}667\ k\Omega$



⇒ slično kao i kad im uvučene otpornike

a) ODREDI VREMENSKU KONSTANTU

$\tau = C \cdot (R_{12} + R_3) = 470 \cdot 10^{-9} \cdot (667 + 1800) = 1{,}16\ ms$

b) NAPIŠI IZRAZE ZA IZLAZNI NAPON, TE IZ R

$0 < t < 1\ ms$

$1 < t < 2\ ms$

$2 < t$

te izvući članove U_{iz} $t=0$, $t=1$, $t=2$ $t=3\ ms$

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$u_c(t) = u_{c0} + (u_{ul} - u_{c0})\left[1 - \exp\frac{-(t-t_i)}{\tau}\right]$ → RASTUĆA EKSPONENCIJALA

↑ KONAČNI

$u_R(t) = u_{ul} - u_c = u_{ul} - u_{c0}\left[\exp\frac{-(t-t_i)}{\tau}\right]$

$u_{1z} = k \cdot u_{uR} = \frac{R_3}{R_{12}+R_3} \cdot u_{ul} = k(u_{ul} - u_c)$

$k = \frac{R_3}{R_n + R_3} = 0{,}73$

$t = 0$

$u_{ul} = 0 \qquad u_{c0} = u_c = 2V$

PRIJE SKOKA

$t = 0^-$

$u_{12}(0^-) = k(u_u - u_{c0}) = 0{,}73 \cdot (0-2) = -1.46V$

NAKON SKOKA

$t = 0^+$

$u_{1z}(0^+) = u_{12}^- + k\,\Delta u_{ul} = -1{,}46 + 0.73 \cdot (-1) = -2{,}19\,V$ (Δu_{ul})

$0 < t < 1$

$u_{1z}(t) = u_{12}0^+ \cdot \exp\frac{-(t-0)}{\tau} =$

PRIJE SKOKA (1)

$t = 1^-$

$u_{1z}(1^-) = u_{12}0^+ \cdot \exp\frac{-(1-0)}{\tau} = -2{,}19 \cdot \exp\frac{-1}{1{,}16} = -0{,}925\,V$

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Poslije skoka (1)

$t = 1^+$

$\Delta U_{ul} = -1 \to 1 = +2\,V$

$U_{12\,1^+} = U_{12\,1^-} + K\,\Delta U_{ul} = -0{,}925 + 0{,}73 \cdot 2 = \underline{0{,}535\,V}$

$1 < t < 2$

$U_{12}(t) = U_{12\,1^+} \cdot \exp\left(\frac{-t - t_1}{\tau}\right) =$

$t = 2^-$ prije skoka

$U_{12\,2^-} = U_{12\,1^+} \cdot \exp\left(\frac{-t_2 - t_1}{\tau}\right) = 0{,}535 \cdot \exp\frac{-2-1}{1{,}16} = \underline{0{,}226\,V}$

$t\ 2^+$ poslije skoka

$\Delta U_{ul} = 1 \to 0 = \underline{-1}$

$U_{12\,2^+} = U_{12\,2^-} + K \cdot \Delta U_{ul} = 0{,}226\,V + 0{,}73 \cdot (-1) = \underline{-0{,}504\,V}$

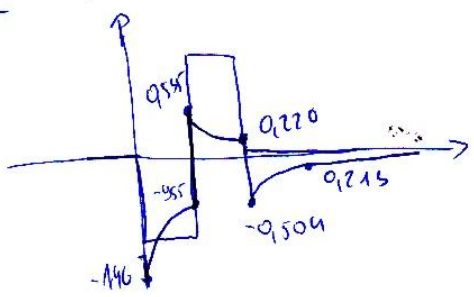
$t > 2$

$U_{12}(t) = U_{12\,2^+} \cdot \exp\left(\frac{-t - t_2}{\tau}\right)$

$t = t_3 = 3\,ms$

$U_{12\,3} = U_{12\,2} \cdot \exp\left(\frac{t_3 - t_2}{\tau}\right) = -0{,}504 \cdot \exp\frac{-(3-2)}{1{,}16} = \underline{0{,}213\,V}$

Skica



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2. SVOJSTVA POLUVODIČA

SILICIJ P TIPA HOMOGENO JE DOPIRAN $10^{16}\ cm^{-3}$

p - tip akceptori

DODAVANJEM U Si DRUGA PRIMJESA FERMIJEVA ENERGIJA ĆE SE POMAKNUTI ZA 0,15 eV, A SPECIFIČNA VODLJIVOST ĆE SE SMANJITI

POKRETLJIVOST U T. SLOBODNIH $820\ cm^2/Vs$ (e) $400\ cm^2/Vs$ (šupljine) $T = 300\ K$

a) TIP I IZNOS DRUGE PRIMJESE

Šupljji $N_A = 10^{16}\ cm^{-3}$, $n_i(300) = 1{,}45 \cdot 10^{10}\ cm^{-3}$

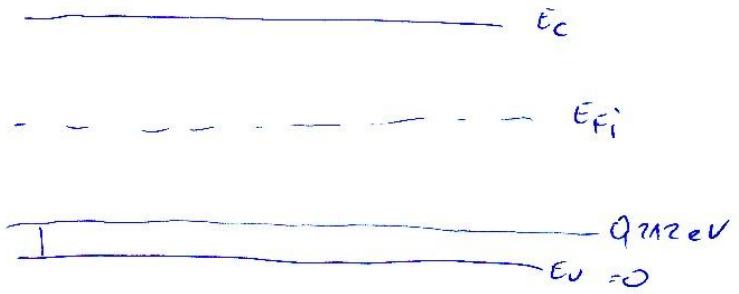
$\Rightarrow$ $N_A >> n_i$ $\quad p_1 = N_A = 10^{16}\ cm^{-3}$

$p_1 = n_i \cdot \exp\left(\frac{E_{Fi} - E_F}{\frac{E_T}{U_T}}\right)$ $\rightarrow$ RAČUNAM $\quad E_{Fi}$ - položaj u intrinzičnom

$E_{Fi} = \frac{E_G}{2}$

$$E_F = E_{Fi} - kT \cdot \ln\frac{p_1}{n_i} = 0{,}56\,eV - \frac{300}{11600} \cdot \ln\left(\frac{10^{16}}{1{,}45 \cdot 10^{10}}\right) = 0{,}212\ eV$$

P-TIP E_F ispod sredine ZA BRANJENOG POJASA



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a) TIP i UTJ DRUGE PRIMJESE

$\Delta E_F = 0{,}15\,eV$

→ SPEC. VODLJIVOS SE SMANJUJE $\sigma \downarrow$

GDJE KOD ZAUKSI E_{F_i} MOĆE SE PROMJENI VODLJIVOST JER I DAL. $\angle E_{F_i}$

$\sigma_i = q\,\mu_p\,p_1$ → AKO $\sigma \downarrow$ $p_1 > p_2$

$\sigma_2\ q\,\mu_p\,p_2$

→ pomice se prema gore

→ postaje slabiji P-TIP

E_F SE UDALJUJE OD VALENTNO POJASA

→ DRUGI TIP PRIMJESE JE DONORI JER DOBIJAM SLABIJI P-TIP

$p_2 = n_i \exp \frac{E_{Fi} - E_{F2}}{E_T}$ $E_{F2} = E_{F1} + 0{,}15\,eV = E_{F1} + \Delta E_F = 0{,}711 + 0{,}15 = \underline{0{,}362}\,eV$

$= 1{,}45 \cdot 10^{10} \exp \frac{0{,}56 - 0{,}362}{\frac{300}{11600}} = 3{,}06 \cdot 10^{13}$ $p_2 \gg n_i$

↳ $p_2 \sim N_A - N_D = N_A\text{netto}$ = $N_D = N_A - p = 10^{16} - p_2 = 10^{16} - 3{,}06 \cdot 10^{13} = 9{,}97 \cdot 10^{15}\,cm^{-3}$

→ KADA DODAJEM DONORE $E_F \uparrow$, KADA DODAJE AKCEPTOR $E_F \downarrow$

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b) KONCENTRACIJA MANJINSKIH NOSIOCA NAKON 2. DOPIRANJA (MANJINSKIH NOSIOCA)

manjini

$$n_2 = n_1^2 / p_2 = \frac{(1{,}45 \cdot 10^{10})^2}{3{,}06 \cdot 10^{13}} = 6{,}87 \cdot 10^6 \ cm^{-3}$$

c) SPECIFIČNI OTPOR Si NAKON 1. i 2. DOPIRANJA

$$\rho_1 = \frac{1}{\sigma_1} = \frac{1}{q \cdot \mu_p \cdot p_1} = \frac{1}{1{,}6 \cdot 10^{-19} \cdot 400 \cdot 10^{16}} = 1{,}56 \ \Omega cm$$

$$\rho_2 = \frac{1}{\sigma_2} = \frac{1}{q \cdot \mu_p \cdot p_2} = \frac{1}{1{,}6 \cdot 400 \cdot} = 511 \ \Omega cm$$

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(3) DIODA

Si pn diodu ima homogeno dopiran str

koncentracij prim $N_D = 2 \cdot 10^{17}\ cm^{-3}$ $N_A = 8 \cdot 10^{15}\ cm^{-3}$

Efektivn širin $W_n = 1\ \mu m$ $W_p = 200\ \mu m$ površina pn $S = 0{,}1\ mm^2 = 91 \cdot 10^{-2}\ cm^2$

pokretljivost manjinski nosioc $\mu_n = 1000\ cm^2/Vs$ $\mu_p = 200\ cm^2/Vs$

A vremena života $\tau_n = 91\ \mu s$ $\tau_p = 0{,}5\ \mu s$ $T = 300\ K$

a) odredi iznos struje kroz diodu ako se na nju spoji napon propusne polarizacije $U_D = 0{,}55\ V$

Dioda je uska, i široka Ali to moramo izreč.

Pro matpram manjinske nosioce

p strana -> manjinski su elektroni (difuzijska duljina)

$$L_n = \sqrt{D_n \tau_n} = \sqrt{\mu_n U_T \tau_n} = \sqrt{1000 \frac{300}{11600} 91 \cdot 10^{-6}} = 16{,}08 \cdot 10^{-4}\ cm$$

$= 16{,}08\ \mu m$ W_p (200 μm) $L_n << W_p$ široka p strana

(for molu N_{op}/L_n !

n- strana -> manjinski su šupljine

$$L_p = \sqrt{D \tau_p} = \sqrt{\mu_p U_T \tau_p} = \sqrt{200 \cdot \frac{3000}{11600} \cdot 0{,}5 \cdot 10^{-6}} = 16{,}08\ \mu m$$

W_n (1 μm) $W_n << L_p$ Uska N strana!

Istrati P_{on}/W_n form

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$$I_S = I_{Sn} + I_{Sp}$$

$$= \mathcal{S} \cdot S \left[D_n \frac{n_{on}}{L_p} + D_p \frac{p_{on}}{W_n} \right] =$$

elektr šupljine

$D_n = \mu_n U_T \qquad D_p = \mu_p U_T$

$$N_{OP} = N_i^2 / p_{OP} = \frac{n_i^2}{N_A} \qquad p_{ON} = \frac{n_i^2}{N_{ON}} = \frac{n_i^2}{N_D}$$

$$= \mathcal{S} \cdot S U_T \cdot n_i^2 \left[\frac{\mu_n}{N_A \cdot L_p} + \frac{\mu_p}{N_D \cdot W_n} \right] \qquad \left(\text{sve pretvoriti u cm} \right)$$

$$= 1{,}6 \cdot 10^{-19} \cdot 0{,}1 \cdot 10^{-2} \frac{300}{11600} \left(1{,}45 \cdot 10^{10}\right)^2 \left[\frac{1000}{3 \cdot 10^{15} \cdot 16{,}08 \cdot 10^{-4}} + \frac{200}{2 \cdot 10^{17} \cdot 1 \cdot 10^{-4}} \right]$$

$$= \ldots = \underline{7{,}63 \cdot 10^{-14} A}$$

$$I_D = I_S \cdot \left(\exp\left(\frac{U_D}{U_T} \right) - 1 \right) = \ldots = 0{,}131 \text{ mA}$$

b) NACRTAJ RASPODJELU MANJINSKIH NOSIOCA, IZRAČUNAJ I OZNAČI RUBNE TE RAVNOTEŽNE KONCENTRACIJE ZA TADAM PRIKLJUČENI NAPON

$$p_{on} = \frac{n_i^2}{n_{on}} = \frac{n_i^2}{N_D} = \frac{(1{,}45 \cdot 10^{10})^2}{2 \cdot 10^{17}} = 1{,}05 \cdot 10^3 \text{ cm}^{-3}$$

$$n_{op} = \frac{n_i^2}{p_{OP}} = \frac{n_i^2}{N_A} = \ldots = 2{,}63 \cdot 10^4 \text{ cm}^{-3}$$

} RAVNOTEŽNE KONCENTRACIJE I TAKOĐER TO RAVNOTEŽNE

RUBNE KONCENTRACIJE – BOLTZMANN

$$p_{nO} = p_{on} \exp \frac{U_D}{U_T} = 1{,}05 \cdot 10^3 \cdot \exp \frac{0{,}55}{\frac{300}{11600}} = 1{,}91 \cdot 10^{12} \text{ cm}^{-3}$$

$$n_{pO} = n_{op} \exp \frac{U_D}{U_T} = 4{,}53 \cdot 10^{13} \text{ cm}^{-3}$$

– USKA N, ŠIROKA P STRANA

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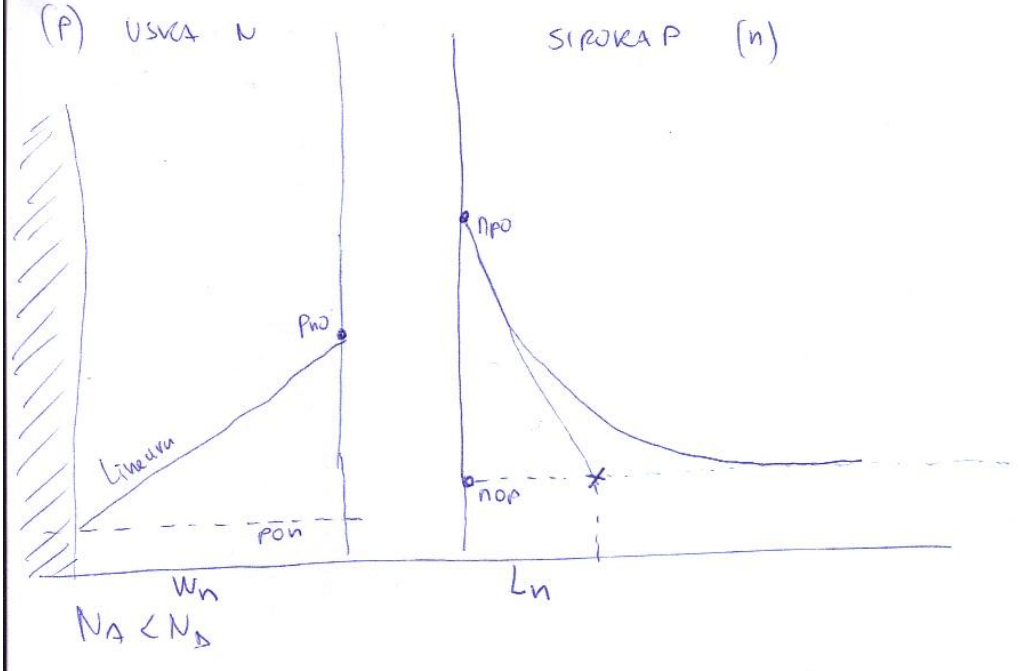

$N_A < N_D$

USKA -> LINEARA

SIROKA -> EKSPONENCIJA

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(4)

IDEALAN N-KANALNI MOSFET (Si) S PARAM MODULACIJE DUŽINE KANALA

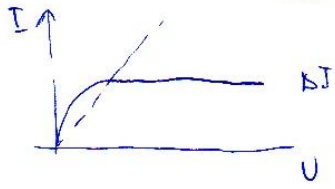
↳ $\lambda = 0$ IMA U RADNOJ TOČKI A IZLAZNI DINAMIČKI OTPOR

$r_{dA} = 333\ \Omega$ i FAKTOR MAPOJ $\mu_A = 2$

STRUJNI KOEF $K = 3\ mA/V^2$

a) U KOJEM PODRUČJU RADI SE KANALI A

→ IDEALNI MOSFET $\lambda = 0$ → U ZASIĆENJU $r_d = \infty$ $\mu = \infty$



$r_d = \frac{\Delta U}{\Delta I} = \infty$

⇒ TOČKA A = $r_{dA} = 333\ \Omega$ $\mu_A = 2$ $r_d \ll \infty$ $\mu_a \ll \infty$ → NIJE U ZASIĆENJU

→ U TRIODNOM PODRUČJU

b) ODREDI KAKO PRI U_{GSO} i U_{GSA} i U_{DSA} U TOČKI A

AKO JE U TOČKI B, UZ U_{GSB} KOJI JE 7A 50% > U_{GSA} i

NEPRO MIJENJIL NAPON $U_{DSB} = U_{DSA}$, STRUJA MOSFETA $I_{DB} = 24\ mA$

⇒ $U_{GSB} = 1{,}5\, U_{GSA}$ $U_{DSD} = U_{DSA}$

A ⇒ TRIODNO PODRUČJE

$$I_D = K \cdot \left[(U_{GS} - U_{GSO}) U_{DS} - \frac{U_{DS}^2}{2} \right]$$

$$g_m = \frac{\partial I_D}{\partial U_{GS}}\Big|_A = \ldots = K \cdot U_{DSA}$$

$r_{dA} = 333$ $\mu_A = 2$ $\mu_A = g_{mA} r_{dA}$ $g_{mA} = \frac{\mu_A}{r_{dA}} = 6\ mA/V$ STRMINA

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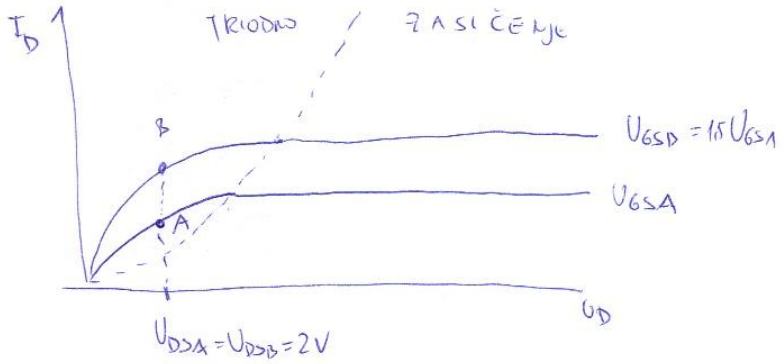
$$U_{DSA} = g_{mA}/K = \frac{6\ mA/V}{3\ mA/V^2} = \underline{2V}$$

$$g_d = \frac{1}{r_d}\left.\frac{\partial I_D}{\partial U_{DS}}\right|_A = K\cdot[(U_{GSA}-U_{GSO})\cdot 1 - U_{DSA}]$$

$$\Rightarrow \quad U_{GSO} = U_{GSA} - 3 \qquad (1)$$

$U_{GSB} = 1{,}5\,U_{GSA}$ $\qquad U_{DSB} = U_{DSA}$



→ B je isto u TRIODNOM

$U_{DSA} < |$ $\qquad |$

$U_{DSB} < |U_{GS}$

PODRUČJE RA

$$\underline{I_{DB}} = K\cdot\left[(U_{GB}-U_{GSO})\cdot U_{DSB} - \frac{U_{DSB}^2}{2}\right]$$

(2A)

$$= K\cdot\left[(1{,}5\cdot U_{GSA} - (U_{GSA}-3)\,U_{DSB} - \frac{U_{DSB}^2}{2}\right]$$

($U_{DSB} \downarrow 2V$)

$$\text{----} = 24 = 3\cdot[(1{,}5\,U_{GSA}+3)\,2 - 2]$$

$$\underline{U_{GSA} = 4V} \rightarrow \underline{U_{GSB} = 6V} \qquad \underline{U_{GSO} = 1V}$$

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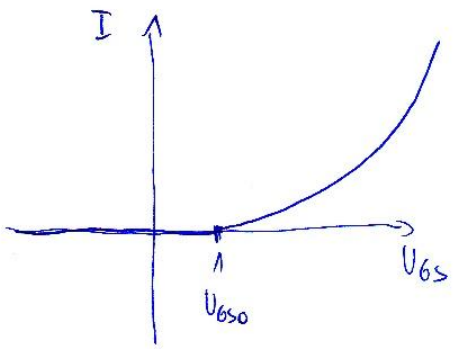
b) ODREDI TIP MOSFETA



N MOSFET U_{GS} pozit. STRUJA n

UZ $U_{GSO} = 0$ $I_D = 0$ → OBOGAĆENI

b) ODRED. MAX STRUJA OD. ODA MOSFETA UZ U_{GSA} IZ TOČ. A

$I_{D\,max}(U_{GSA}) = I_{D\,FASIĆ}(U_{GSA})$

$= \frac{K}{2}(U_{GSA} - U_{GSO})^2 = \ldots = 13{,}5\ mA$

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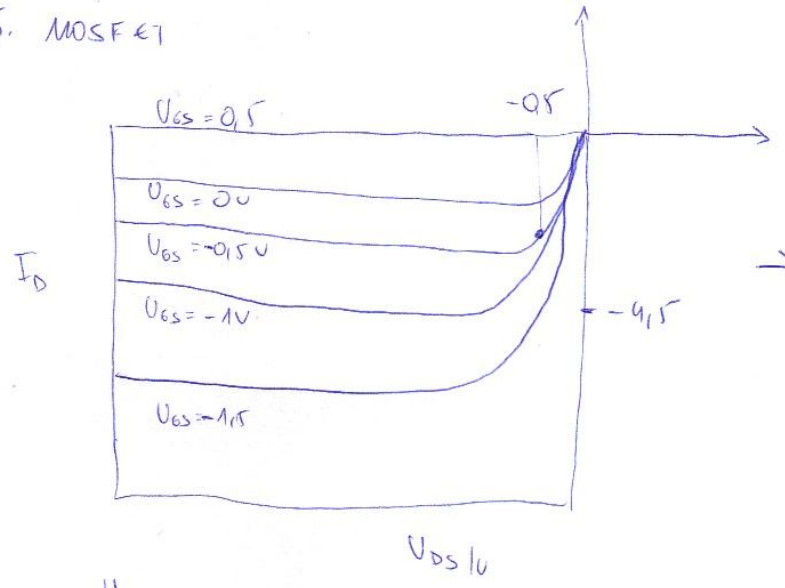
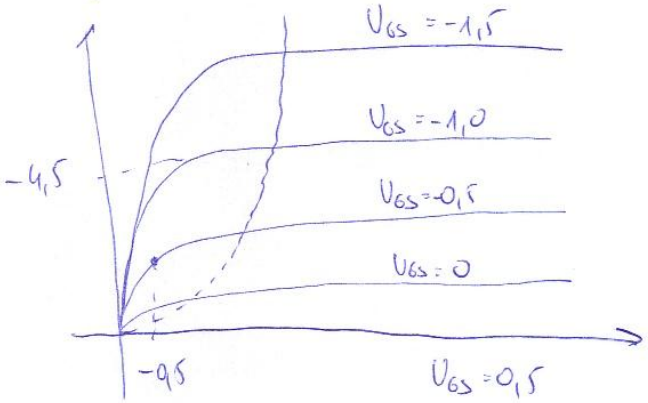
5. MOSFET



→ 3 KVADR

→ P KANAL MOSFET



U_{GS} POSTAJE NEGATIVAN STRUJA I_D POČINJE TEĆI

P-MOS

$U_{GSO} = 0,5\,V$ $I = 0$ → napon praga

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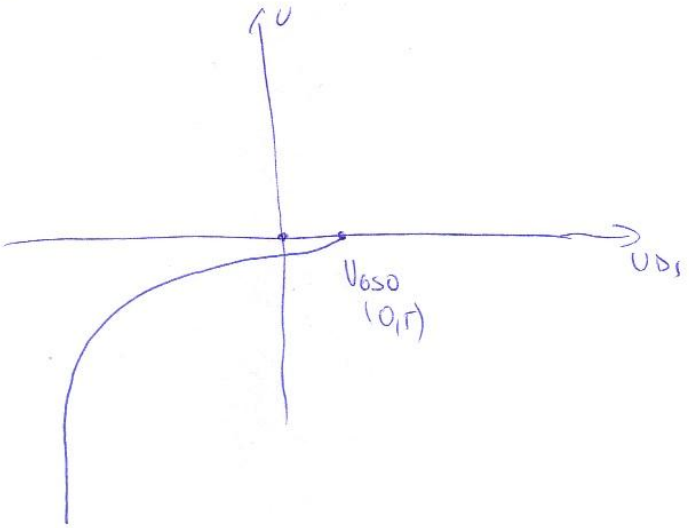


P-MOS

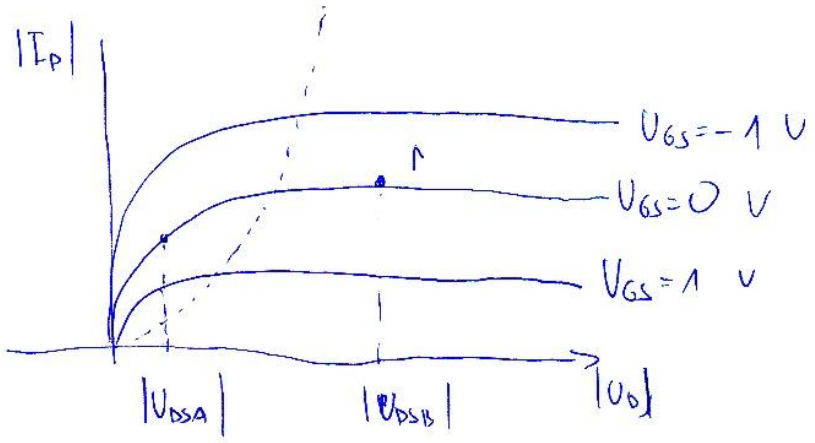
$U_{GS} = 0V \rightarrow (I_D) > 0$

KANAL POR → O SIROMAŠENJU

ELE ZA 14/11/11

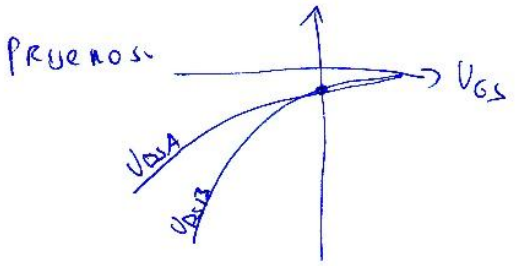
NA SLICI IZLAZ MOSFOI

g_{mA} i g_{mB} i koji tip



→ KAKO U_{GS} negativan $|I_D|$ raste (po modu) P-mos

$U_{GS} > 0$



$U_{GS} = 0 \Rightarrow |I_D| > 0$

→ OSIROMAŠENI

točka A → TRIODNO točka B → ZASIĆENJE

$$g_m = \frac{\partial I_D}{\partial U_{GS}} = k \cdot U_{GS} \qquad g_m = \frac{\partial I_D}{\partial U_{GS}} = k \cdot (U_{GS} - U_{GSO})$$

U TRIODNO $|U_{DS}| < |U_{GS} - U_{GSO}|$

$$k \cdot U_{DS} < k|U_{GS} - U_{GSO}|$$

$$g_{mA} < g_{mB}$$