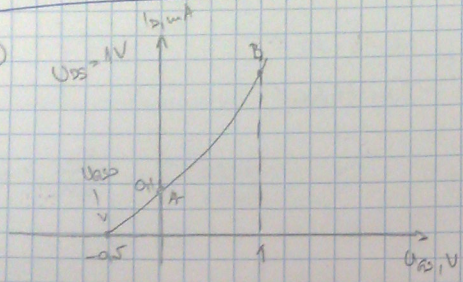
(2) n - tip jer strelica gleda u strukturu

VJ17



uz $U_{GSO} = 0 \Rightarrow |I_D| > 0 \Rightarrow$ obiranavajući

U_{DS} postaje pozitivniji, $|I_D|$ raste $\Rightarrow$ n - tip

Točka A

$U_{GSA} = 0$ $\quad U_{DS} = 1V$

$I_{DA} = 91\,\mu A$

$U_{GSO} = -0,3V$

Koje je područje A

$$|U_{GSA} - U_{GSO}| = |0 - (-0,5)| = 0,5 < |U_{DS}| = 1 \Rightarrow \text{zasićenje}$$

$$I_{DA} = \frac{K}{2}(U_{GSA} - U_{GSO})^2 \underbrace{(1 + \lambda U_{DS})}_{\text{Modulacija}}$$

$$K = \frac{2\, I_{DA}}{(U_{GSA} - U_{GSO})^2 (1 + \lambda U_{DS})} = \frac{2 \cdot 0,1}{(0 - (-0,5))^2 (1 + 0,05 \cdot 1)} = \dots = 0,736\ \mu A/V^2$$

Točka B

$U_{GSB} = 1V$ $\quad$ područje $|U_{GSB} - U_{GSO}| = |1 - (-0,5)| = 1,5 > |U_{DS}| = 1 \Rightarrow$ triodno

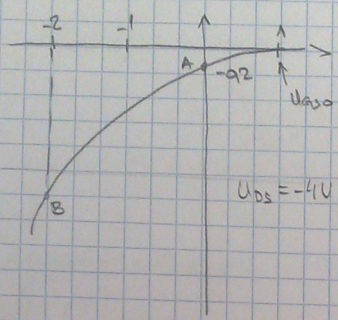
$$I_{DB} = K\left[(U_{GSB} - U_{GSO})U_{DS} - \frac{U_{DS}^2}{2}\right] = \dots = 0,736\ \mu A$$

$$g_m = \left.\frac{\partial I_D}{\partial U_{GS}}\right|_Q = K \cdot U_{DS} = 0,736 \cdot 1 = 0,736\,\mu A/V$$

$$r_d = \left.\frac{1}{\frac{\partial I_D}{\partial U_{DS}}}\right|_Q = \frac{1}{K[(U_{GSB} - U_{GSO}) - U_{DS}]} = \frac{1}{0,736 \cdot 10^{-3}[1 + (-0,5) - 1]}$$

$r_{DS} = 2,51\ k\Omega$ $\quad A_B = g_{mB} \cdot r_{DS} = 2$

VJ 18



$U_{GSO} = 1V$

$\lambda = +5 \cdot 10^{-3}$

a) ut $U_{GS} = 0$ $|I_D| > 0$ -> osiromašen

tako U_{GS} postaje negativniji $|I_D| \downarrow$ -> pmos

b) Točka A

$U_{GSA} = 0$

$I_{DA} = -0,2 mA$

$|U_{GSA} - U_{GSO}| = |0-1| = 1 < |U_{DS}| = 4$ => zasićenje

$$I_{DA} = \ominus \frac{k}{2} (U_{GSA} - U_{GSO})^2 (1 + \lambda U_{DS})$$

$$k = \frac{-2 I_{DA}}{(U_{GSA} - U_{GSO})^2 (1 + \lambda U_{DS})}$$

$$k = 0,392 \frac{mA}{V^2}$$

Točka B

$U_{GSB} = -2V$

$|U_{GSB} - U_{GSO}| = |-2-1| = 3 < |U_{DS}| = 4$ => zasićenje

$I_{DB} = -\frac{k}{2} (U_{GSB} - U_{GSO})^2 (1 + \lambda U_{DS}) = \dots = -1,8 mA$

$g_{mB} = \frac{\partial I_D}{\partial U_{GS}} \Big|_B = -k (U_{GSB} - U_{GSO}) (1 + \lambda U_{DS}) = \dots = 1,2 mA/V$

$-3 \qquad -0,4$

$$r_{dB} = \frac{1}{\frac{\partial I_D}{\partial U_{DS}} \Big|_B} = \frac{1}{-\frac{k}{2} (U_{GSB} - U_{GSO})^2 \cdot \lambda} \cdot \frac{1 + \lambda U_{DS}}{1 + \lambda U_{DS}} = \frac{1 + \lambda U_{DS}}{I_{DB} \cdot \lambda}$$

$$= \frac{1 + (-5 \cdot 10^{-3})(-4)}{-1,8 \cdot 10^{-3} \cdot (-5 \cdot 10^{-3})} = \dots = 113,3 k\Omega$$

$$A_B = g_{mB} \cdot r_{dB} = 1,2 \cdot 10^{-3} \cdot 113,3 \cdot 10^3 = 136$$

Zad 25

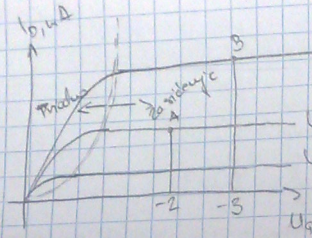


Tabela A

$U_{GSA} = -1,5V$
$U_{GSO} = -0,5V$
$U_{DSA} = -2V$

$|U_{GSA} - U_{GSO}| = 1V < |U_{DS}| = 2V \Rightarrow$ nasycenie

$$I_{DA} = (-)\frac{k}{2}(U_{GSA} - U_{GSO})^2(1 + \lambda U_{DS})$$

$$g_{mA} = \frac{\partial I_D}{\partial U_{GS}}\Big|_A = -k(U_{GSA} - U_{GSO})(1 + \lambda U_{DS})$$

$$k = \frac{-g_m}{(U_{GSA} - U_{GSO})(1 + \lambda U_{DS})} = \frac{-0,5 \cdot 10^{-3}}{(-1,5 + 0,5)[1 + (-5 \cdot 10^{-3})(-2)]} = 0,495 \ mA/V^2$$

Tabela B

$U_{GSB} = -2V$
$U_{GSO} = -0,5V$
$k = 0,495 \ mA/V^2$

$|U_{GSB} - U_{GSO}| = 1,5 < |U_{DS}| = 3 \Rightarrow$ nasycenie

$$I_{DB} = -\frac{k}{2}(U_{GSB} - U_{GSO})^2(1 + \lambda U_{DS}) = \ldots = -0,565 \ mA$$

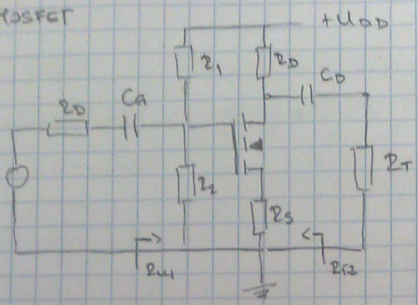
$$g_{mB} = \frac{\partial I_D}{\partial U_{GS}}\Big|_B = -k(U_{GSB} - U_{GSO})(1 + \lambda U_{DS}) = \ldots = 0,754 \ mA/V$$

$$r_{dB} = \frac{1}{\frac{\partial I_D}{\partial U_{DS}}\Big|_B} = \frac{1}{-\frac{k}{2}(U_{GSB} - U_{GSO})^2 \cdot \lambda} = \ldots = 359,3 \ k\Omega$$

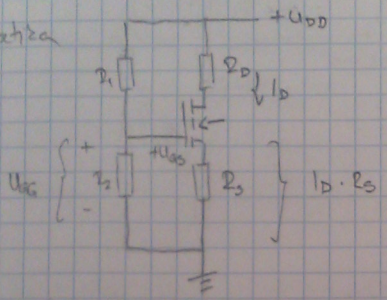
$$\mu_B = g_{mB} \cdot r_{dB} = \ldots = 271$$

Stopnje s MOSFET

VJ3



statična



1) $U_{GSQ} = U_{AG} - I_{DQ} R_S$

2) $I_{DQ} = \frac{k}{2} (U_{GSQ} - U_{GSO})^2$

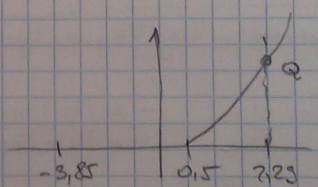
(2) → (1)

$$U_{GSQ} = U_{AG} - \frac{k \cdot R_S}{2} \left[U_{GSQ}^2 - 2 U_{GSO} \cdot U_{GSQ} + U_{GSO}^2 \right]$$

$$U_{GSQ}^2 + \left[\frac{2}{k \cdot R_S} - 2 U_{GSO} \right] \cdot U_{GSQ} + U_{GSO}^2 - \frac{2}{k \cdot R_S} \cdot U_{AG} = 0$$

$$U_{GSQ}^2 + 1{,}564\, U_{GSQ} - 28 = 0$$

$$U_{GSQ\,1,2} = \{ -3{,}85\ V,\ 2{,}29 \}$$



$$U_{AG} = \frac{R_2}{R_1 + R_2} U_{DD} = 3{,}53\ V$$

$$I_{DQ} = \frac{U_{AG} - U_{GSQ}}{R} \quad (1)$$

$$U_{DSQ} = U_{DD} - I_{DQ} (R_D + R_S) = \ldots 3{,}25\ V$$

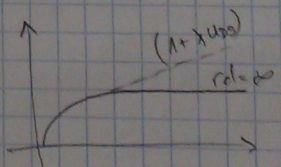
$$g_m = \frac{\partial I_D}{\partial U_{GS}} = k (U_{GSQ} - U_{GSO}) (1 + \lambda U_{DSQ}) = 3{,}65\ mA/V$$

$$r_d = \left. \frac{1}{\frac{\partial I_D}{\partial U_{DS}}} \right|_Q = \ldots = \frac{1}{\lambda \cdot I_{DQ}} = 68{,}72\ k\Omega$$

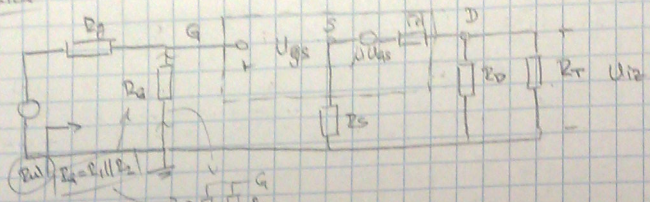
$$\mu = g_m \cdot r_d = 233$$

U statični jdbi se idealen MOSFET

U dinamični jdbi pa

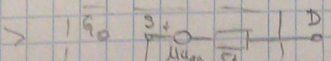


Dinamika

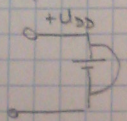


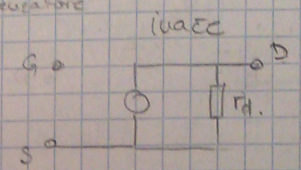
Ako S i D nisu direkt spojeni na masu

tranzistor po Theveninu ⟹



- zgodno spojiti istosmjerne naponske izvore





$$U_{iz} = -i_d \cdot (R_D \parallel R_T) \quad (1)$$

$$i_d \left[(R_D \parallel R_T) + r_d + R_S \right] - \mu U_{gs} = 0 \quad (2)$$

$$U_{gs} = U_{ul} - i_d \cdot R_S \quad (3)$$

Izrazimo U_{iz}, U_{ul}, i_d, U_{gs}

$$A_v = \frac{U_{iz}}{U_{ul}} = \frac{-\mu (R_D \parallel R_T)}{(1+\mu) R_S + r_d + (R_D \parallel R_T)} = \dots = -2{,}121$$

Uzdužna degeneracija

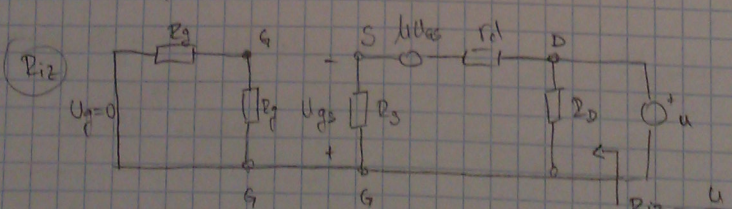
SZS

$A_v < 0$

U_{iz} i U_{ul} su u protufazi

INVERTIRA

$$R_{ul} = \frac{U_{ul}}{I_{ul}} = R_g = 1\text{M}\Omega$$



$$R_{iz} = \frac{u}{i}$$

- izlaz jeva (D)
- otpor iz strujnog (S) se vidi u (D) $(1+\lambda)$ puta veći

$$i = \frac{u}{R_D} + i_D$$

$$R_{iz} = R_D \parallel \left[r_d + (1+\mu) R_S \right]$$

$i_d \cdot r_d - (1+\mu) U_{gs} = u$

$-U_{gs}$

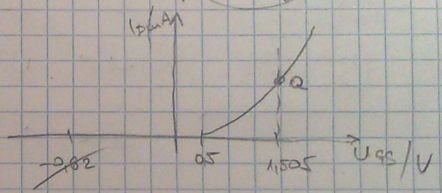
Ulaz -> Gate	Ulaz -> Uvod (S)	Ulaz -> Gate
Izlaz -> Drain (odvod)	Izlaz -> odvodu (D)	Izlaz -> Source (Uvod)
zajed. -> Source (uvod)	Zajed -> Gate	Zajed. -> Drain (odvod)

(VJ5) $U_{GG} = \frac{R_2}{R_1 + R_2} \cdot U_{DD} = 10V$

$U_{GSQ} = U_{GG} - I_{DQ} \cdot R_S$ (1)

$I_{DQ} = \frac{k}{2}\left[U_{GSQ} - U_{GS0}\right]^2$ (2)

$U_{GSQ}^2 - 0,88 U_{GSQ} - 0,94 = 0 \rightarrow U_{GSQ\,1,2} = \{-0,62\,V \,|\, 1,505\,V\}$



$I_{DQ} = \frac{U_{GG} - U_{GSQ}}{R_S} = \ldots = 1,517\,mA$

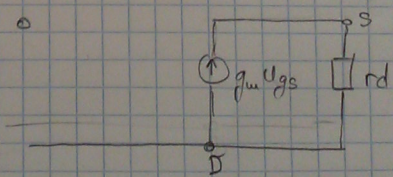
$U_{DSQ} = U_{DD} - I_{DQ} \cdot R_S = \ldots = 11,505\,V$

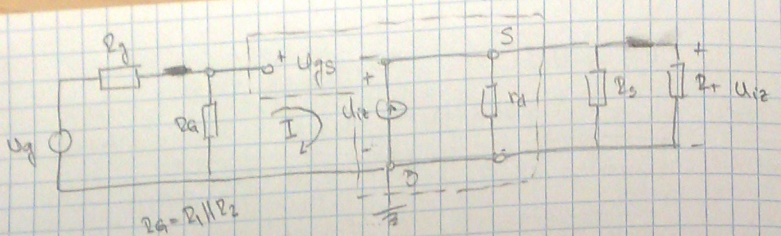
$g_m = \frac{\partial I_D}{\partial U_{GS}} = k\,(U_{GSQ} - U_{GS0})(1 + \lambda U_{DSQ}) = \ldots = 3,171\ mA/V$

$r_d = \left.\frac{1}{\frac{\partial I_D}{\partial U_{DS}}}\right|_Q = \frac{1}{\lambda \cdot I_{DQ}} = \ldots = 146,5\ k\Omega$

$\mu = g_m \cdot r_d = 465$

(D) je u dinamici spojen direktno na masu -> NADOMJESTITI PO NORTONU

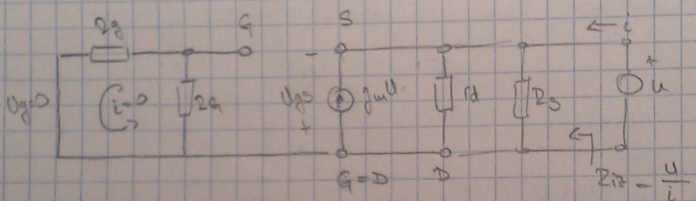




$$U_{iz} = g_m U_{gs} \left[r_d \| R_S \| R_T \right]$$

(I) $\quad U_{ul} = U_{gs} + U_{iz}$

$$A_v = \frac{U_{iz}}{U_{ul}} = \frac{g_m U_{gs} \left[r_d \| R_S \| R_T \right]}{U_{gs} + g_m U_{gs} \left[r_d \| R_S \| R_T \right]} = \frac{g_m \left[r_d \| R_S \| R_T \right]}{1 + g_m \left[r_d \| R_S \| R_T \right]}$$



SZD

$A_v < 1$

$A_v > 0$

$\Rightarrow$ pozitivan $\Rightarrow U_{ul}$ i U_{iz} su u fazi

NE INVERTIRA

- izlaz je na (S)
- otpor iz (D) se u (S) transformiše $(1+\mu)$ puta manji
- r_d je u krugu (D)

$$R_{iz} = R_S \| \frac{r_d}{1+\mu} = 298\ \Omega$$

Bipolarni tranz.

(VJ 2)

(npn) tranz

$N_{DE} = 1{,}5 \cdot 10^{18}$

$N_{AB} = 2{,}5 \cdot 10^{16}$

$W_B = 1\ \mu m$

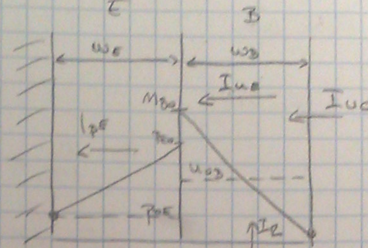
$W_E = 2\ \mu m$

$S = 1\ mm^2$

$\mu_{pE} = 280\ cm^2/Vs$

$\mu_{nB} = 520\ cm^2/Vs$

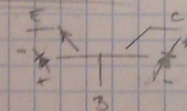
$\tau_{nB} = 945\ \mu s$



$n_{0E} = N_{DE} = 1{,}5 \cdot 10^{18}\ cm^{-3} \to p_{0E} = \frac{n_i^2}{N_{DE}} = \frac{(1{,}45 \cdot 10^{10})^2}{1{,}5 \cdot 10^{18}} = 1{,}4 \cdot 10^2\ cm^{-3}$

$p_{0B} = N_{AB} = 2{,}5 \cdot 10^{16}\ cm^{-3} \to n_{0B} = \frac{n_i^2}{N_{AB}} = \frac{(1{,}45 \cdot 10^{10})^2}{2{,}5 \cdot 10^{16}} = 8{,}41 \cdot 10^3\ cm^{-3}$

$U_{BE} = 0{,}575\ V \to$ propusno
$U_{CB} = 5\ V \to$ zaporno
} NAP



Rješenje:

$$n_{B0} = n_{0B} \cdot \exp\left(\frac{U_{BE}}{U_T}\right) = \ldots = 1{,}11 \cdot 10^{13}\ cm^{-3}$$

$$p_{E0} = p_{0E} \exp\left(\frac{U_{BE}}{U_T}\right) = \ldots = 1{,}85 \cdot 10^{11}\ cm^{3}$$

$$I_{nE} = q \cdot S \cdot D_{nB} \cdot \frac{n_{B0}}{W_B} = q \cdot S \cdot \mu_{nB} \cdot U_T \cdot \frac{n_{B0}}{W_B}$$

$$= 1{,}6 \cdot 10^{-19} \cdot 10^{-2} \cdot 520 \cdot 25 \cdot 10^{-3} \cdot \frac{1{,}11 \cdot 10^{13}}{10^{-4}} = 2{,}3088\ mA$$

$$I_{pE} = q \cdot S \cdot \underbrace{D_{pE}}_{\mu_p \cdot U_T} \cdot \frac{p_{E0}}{W_E} = \ldots = 10{,}36\ \mu A$$

$$\gamma = \frac{I_{nE}}{I_{nE} + I_{pE}} = \frac{1}{1 + \frac{I_{pE}}{I_{nE}}} = 0{,}9955$$

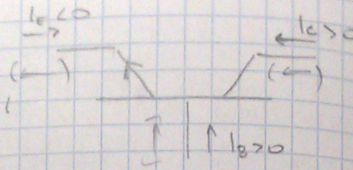
$$\beta^* = 1 - \frac{1}{2} \cdot \left(\frac{W_B^2}{D_{nB} \cdot \tau_{nB}}\right) = 1 - \frac{1}{2} \frac{W_B^2}{\mu_{nB} \cdot U_T \cdot \tau_{nB}}$$

$$\beta^* = \frac{I_{nC}}{I_{nE}} \to I_{nC} = \beta^* I_{nE} = 2{,}3068\ mA$$

$I_R = I_{NE} - I_{NC} = \dots = 2\,\mu A$

$I_E = -(I_{NE} + I_{PE}) = -2{,}319\ mA$

$I_B = I_R + I_{PE} = 12{,}36\ \mu A$



$\alpha = \gamma \cdot \beta^* = \dots = 0{,}9947$

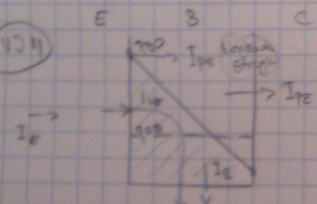
$\alpha = \dfrac{I_C}{-I_E} =$

$\beta = \dfrac{\alpha}{1-\alpha} = \dots = 188$

$\beta = \dfrac{I_C}{I_B}$

istosmjerni faktor strujnog pojačanja u SZE

NPN   PNP



BE → propusno jer $p_{B0} > p_{n0}$

BC → zaporno jer je točka ispod ravnotežne razine } NAP

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

$w_B = 1\ \mu m = 10^{-4}\ cm \qquad \tau_{pB} = 0{,}5\ \mu s$

$\gamma = 99\% = 0{,}99$

$I_{pE} = q \cdot S \cdot \underbrace{D_{pB}}_{\mu_p \cdot U_T} \dfrac{p_{B0}}{w_B} = \dots = 4{,}9\ mA$

$\gamma = \dfrac{I_{pE}}{I_{pE} + I_{nE}} \Rightarrow I_{nE} = \dfrac{I_{pE}}{\gamma} - I_{pE} = I_{pE}\left(1 - \dfrac{1}{\gamma}\right) = \dots = 49{,}5\ \mu A$

$I_R = \dfrac{Q_{pB}}{\tau_{pB}} = \dfrac{q \cdot S \cdot p_{B0} \cdot w_B}{2 \cdot \tau_{pB}} = \dfrac{1{,}6 \cdot 10^{-19} \cdot 2{,}5 \cdot 10^{-2} \cdot 1{,}75 \cdot 10^{13} \cdot 10^{-4}}{2 \cdot 0{,}5 \cdot 10^{-6}}$

$Q_{pB} = q \cdot S \cdot \dfrac{p_{B0} \cdot w_B}{2} \Rightarrow I_R = 7\ \mu A$

$I_{pC} = I_{pE} - I_R = 4{,}893\ mA \qquad I_E = I_{nE} + I_{pE} = 4{,}9495\ mA, \ I_E > 0$

$I_C = -I_{pC} = -4{,}893\ mA \qquad I_C < 0$

$$I_B = -I_R - I_{VE} = -56{,}5\,\mu A$$

$$I_B < 0$$

$$I_E + I_B + I_C = 0$$