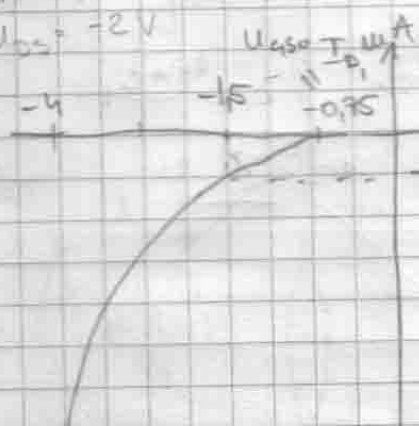


①

$$\lambda = \phi$$

$$U_{DS} = -2V$$



$$I_{D2} = f(U_{GS}) \mid U_{D2} = \text{const}$$

a) tip MOSFETa

$$U_{GS} \text{ negativniji} \Rightarrow |I_D| \uparrow$$

$$U_{GSO} = -0.75V < \phi$$

$$(U_{GS} = \phi \Rightarrow I_D = \phi)$$

obogaćeni, p-nos

b) napori praga

$$U_{GSO} = -0.75V$$

c) strujina u točki A

$$A: U_{GSA} = -1.5V$$

$$I_{DA} = -0.25A$$

$$U_{GS} - U_{GSO} = -1.5 - (-0.75) = -0.75V$$

$$U_{DS} = -2V$$

$$|U_{GS} - U_{GSO}| < |U_{DS}| \Rightarrow \text{zadržavanje}$$

$$I_D = \frac{K}{2} (U_{GS} - U_{GSO})^2$$

$$K = \frac{2I_D}{(U_{GS} - U_{GSO})^2} = \dots = -0.85 \mu A/V^2$$

$$g_m = \left. \frac{\partial I_D}{\partial U_{GS}} \right|_Q$$

$$g_m = K (U_{GSA} - U_{GSO})$$

$$= -0.85 \cdot (-0.75)$$

$$= 0.64 \mu A/V$$

d) Struja u točki B

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

$$U_{GSB} - U_{GSO} = -4 + 0,75 = -3,25$$

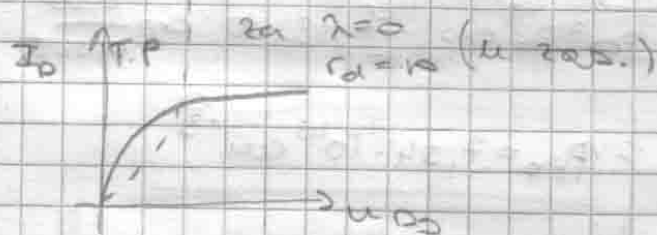
$$|U_{GSB} - U_{GSO}| > |U_{DS}|$$

B je u modulu

$$I_{DS} = K \left[ (U_{GSB} - U_{GSO}) U_{DS} - \frac{U_{DS}^2}{2} \right]$$

$$I_{DS} = -0,29 \left[ (-3,25) \cdot (-2) - \frac{4}{2} \right] = \dots = -4 \mu A$$

e) strukturni i din. otpor u točki B



$$g_m = \frac{dI_D}{dU_{GS}} \Big|_Q$$

$$= K \cdot U_{DSB}$$

$$= -0,29 \cdot (-2) = 1,78 \frac{\mu A}{V}$$

$$r_{DS} = \frac{1}{g_{DS}} = \frac{1}{\frac{dI_D}{dU_{DS}} \Big|_Q}$$

$$= \frac{1}{K(U_{GSB} - U_{GSO}) - K \cdot U_{DSB}} = \dots =$$

$$= \frac{1}{-0,29(-4 + 0,75 + 2)} = 1,125 k\Omega$$

② amiter homogena depiracija

$$N_D = 10^{19} cm^{-3}$$

$$\tau_{up} = 0,5 ps$$

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

baza  $N_A = 10^{17} cm^{-3}$

$$U_T = 25 mV$$

NAP

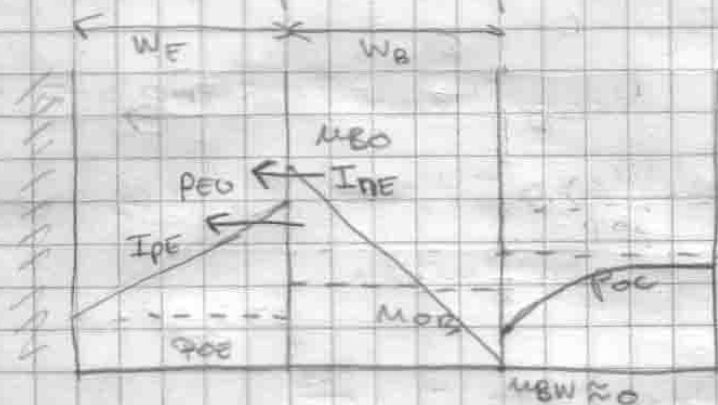
$$U_{BE} = 0,55 V$$

$$W_E = W_B = 250 nm = 0,25 \mu m = 0,25 \cdot 10^{-4} cm$$

$$\mu_n = 400 cm^2/Vs$$

$$\mu_p = 200 cm^2/Vs$$

a) koncentracije majoritetskih nosilaca (nubne)



$$n_{DE} > n_{AB} = n_{DC}$$

n p n

$$p_{OE} < n_{OE} < p_{OE}$$

RUBNE KONC. → BOLTZMANN

$$p_{OE} = \frac{n_i^2}{n_{DE}} = \frac{(1,45 \cdot 10^{10})^2}{10^{19}}$$

$$= 2,1 \cdot 10^1 \text{ cm}^{-3}$$

$$n_{OE} = \frac{n_i^2}{n_{AB}} = \frac{(1,45 \cdot 10^{10})^2}{10^{17}}$$

$$= 2,1 \cdot 10^3 \text{ cm}^{-3}$$

$$n_{BO} = n_{OE} \exp\left(\frac{u_{BE}}{u_T}\right) = 2,1 \cdot 10^3 \cdot \exp\left(\frac{0,55}{0,025}\right)$$

$$n_{BO} = 7,54 \cdot 10^{12} \text{ cm}^{-3}$$

$$p_{OE} = p_{OE} \exp\left(\frac{u_{BE}}{u_T}\right) = 2,1 \cdot 10^1 \cdot \exp\left(\frac{0,55}{0,025}\right)$$

$$p_{OE} = 7,54 \cdot 10^{10} \text{ cm}^{-3}$$

b) izračunati komponente struje čitlene

$$I_{NE} = ?$$

$$I_{PE} = ?$$

$$I_{NE} = g \cdot S \cdot D_{nB} \cdot \frac{n_{BO} - n_{BW}}{W_B}$$

$$= 1,6 \cdot 10^{-19} \cdot 10^{-2} \cdot 400 \cdot 0,025 \cdot \frac{7,54 \cdot 10^{12}}{0,25 \cdot 10^{-4}} \text{ A cm}^{-1}$$

$$= \dots = 4,83 \text{ nA}$$

$$I_{PE} = g \cdot S \cdot D_{pE} \cdot \frac{p_{OE} - p_{OE}}{W_E} = \left\{ p_{OE} \ll p_{OE} \right\}$$

$$= 1,6 \cdot 10^{-19} \cdot 200 \cdot 0,025 \cdot \frac{7,54 \cdot 10^{10}}{0,25 \cdot 10^{-4}}$$

$$= \dots = 24,13 \text{ pA}$$

DOKAŽIJEHO DA JE  
BAZA USKA

$$\tau_n = 0,5 \text{ ns}$$

$$\mu_n = 400 \text{ cm}^2/\text{Vs}$$

$$u_T = 25 \text{ mV}$$

$$D_n = \mu_n \cdot u_T$$

$$L_{nB} = \sqrt{D_n \cdot \tau_n} = \sqrt{\mu_n \cdot u_T \cdot \tau_n}$$

$$= \sqrt{400 \cdot 0,025 \cdot 0,5 \cdot 10^{-9}}$$

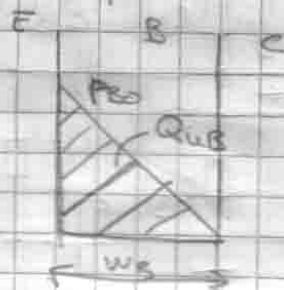
$$= 22,3 \cdot 10^{-6} \text{ cm}$$

$$= 22,3 \text{ } \mu\text{m} \gg 0,25 \text{ } \mu\text{m}$$

c) rekombinacijska strujna baze

$$I_R = ?$$

$$I_R = \frac{Q_{nB}}{2 \tau_{nB}}$$



$$Q_{nB} = \frac{n_{B0} \cdot W_B}{2} \cdot S \cdot g$$

$$= \frac{7,54 \cdot 10^{12} \cdot 0,25 \cdot 10^{-4}}{2} \cdot 10^{-2} \cdot 1,6 \cdot 10^{-19}$$

$$Q_{nB} = 0,1508 \text{ pAs} \quad \left\{ 10^{-12} \text{ As} \right\}$$

$$I_R = \frac{0,1508 \cdot 10^{-12}}{0,5 \cdot 10^{-6}} = 0,3 \text{ nA}$$

$$d) \quad \gamma = \frac{I_{nE}}{I_{nE} + I_{pE}} = \frac{1}{1 + \frac{I_{pE}}{I_{nE}}} = \frac{1}{1 + \frac{24,13 \cdot 10^{-6}}{4,83 \cdot 10^{-3}}} = 0,9950$$

$$\beta^* = \frac{I_{nE}}{I_{nE} - I_R} = \frac{I_{nE} - I_R}{I_{nE}} = 1 - \frac{I_R}{I_{nE}} = 1 - \frac{0,3 \cdot 10^{-6}}{4,83 \cdot 10^{-3}} = 0,99994$$

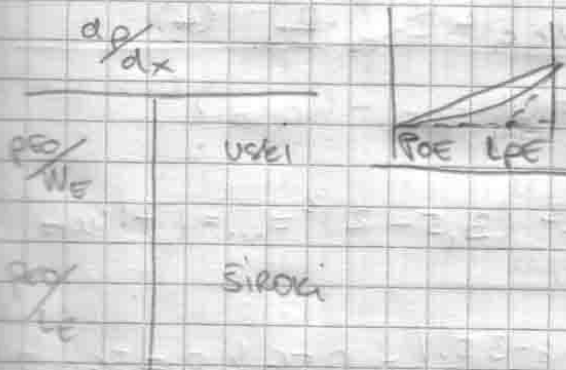
(přibližně  $\alpha = \gamma \cdot \beta^* = 0,99494$ )

$$\beta = \frac{\alpha}{1 - \alpha} \approx 198$$

e) ako je  $\gamma = 0,99$ , a  $\beta^* = 0,99$ , takže je  $\beta$

$$\alpha = \gamma \cdot \beta^* = 0,9801$$

$$\beta = \frac{\alpha}{1 - \alpha} = 50$$



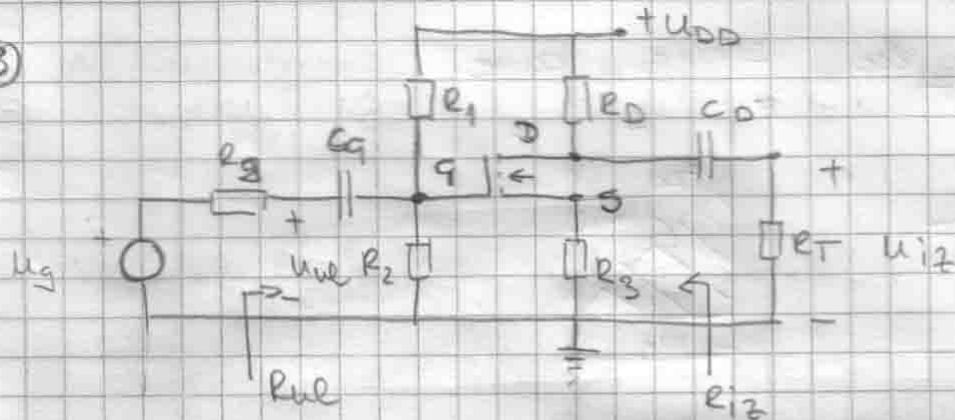
$$p(x) = p_{0E} + (p_{0B} - p_{0E}) \exp\left(-\frac{x}{L_{pE}}\right)$$

$$\frac{dp}{dx} = (p_{0B} - p_{0E}) \cdot \exp\left(-\frac{x}{L_{pE}}\right)$$

$$\frac{dp}{dx} = \frac{p_{0B} - p_{0E}}{L_{pE}} = \frac{p_{0B}}{L_{pE}}$$



③



$$U_{DD} = 15V$$

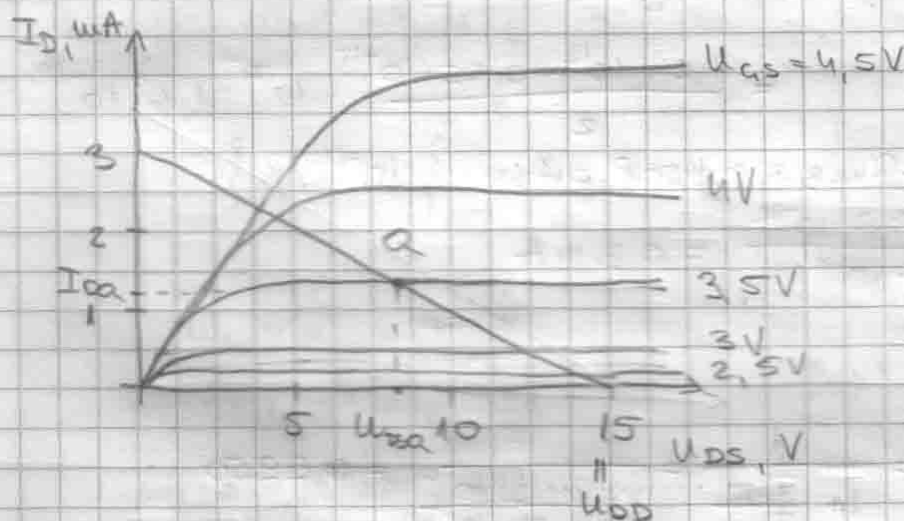
$$R_g = 500\Omega$$

$$R_1 = 7,2M\Omega$$

$$R_2 = 3,3M\Omega$$

$$R_D = 4,7k\Omega$$

$$R_T = 6,8k\Omega$$



MOSFET

$$K = 1,52mA/V^2$$

$$U_{GS0} = 2V$$

$$\lambda = 0,0021V^{-1}$$

a) koliki je  $R_S$  za izl. karakteristike:

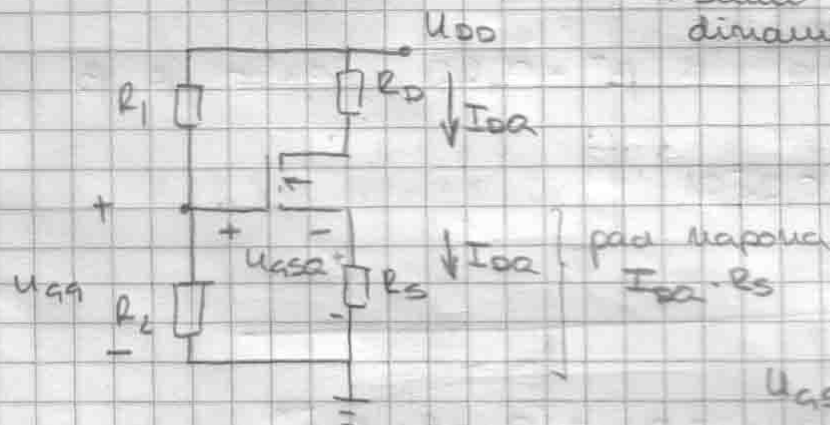
$$U_{GS0} = 3,5V$$

signal dovodim na G, izlazi sa D

$\Rightarrow$  zajednički S

u statiki:

$\lambda$  se ne koristi u statiki  
 $\rightarrow$  samo za proračun izlaznog dinamičkog otpora



$$R_S = \frac{U_{GS} - U_{GS0}}{I_{DQ}}$$

$$U_{GS} = U_{DD} \cdot \frac{R_2}{R_1 + R_2} = \dots = 4,46V$$

$$U_{GS0} = U_{GS} - I_{DQ} \cdot R_S \quad (*)$$

$$I_{DQ} = \frac{K}{2} (U_{GS0} - U_{GS0})^2$$

$$I_{DQ} = \frac{1,52}{2} (3,5 - 2)^2 = \dots = 1,71mA$$

$$R_S = \frac{U_{GS} - U_{GS0}}{I_{DQ}} = \frac{(4,46 - 3,5)V}{1,71mA} = 0,56k\Omega = 560\Omega$$

b) dinamičke parametre  $g_m$ ,  $r_d$ ,  $u_z$ :

$$\left. \begin{aligned} I_{DQ} &= 2,07 \mu A \\ U_{DQ} &= 4,45 V \\ U_{GSQ} &= 3,65 V \end{aligned} \right\} \text{definiira } Q$$

$$R_G = 390 \Omega$$

$$i_D = \frac{k}{2} (u_{GS} - u_{GSQ})^2 \cdot (1 + \lambda u_{DS})$$

$$g_m = \left. \frac{\partial i_D}{\partial u_{GS}} \right|_Q = k \cdot (u_{GSQ} - u_{GSQ}) (1 + \lambda \cdot u_{DSQ})$$

$$= 1,52 \cdot 10^{-3} (3,65 - 2) (1 + 0,0021 \cdot 4,45)$$

$$= 2,53 \mu A/V$$

$$r_d = \left. \frac{1}{\frac{\partial i_D}{\partial u_{DS}}} \right|_Q = \frac{1}{\lambda \cdot \frac{k}{2} (u_{GSQ} - u_{GSQ})^2} = \dots = 230 \Omega$$

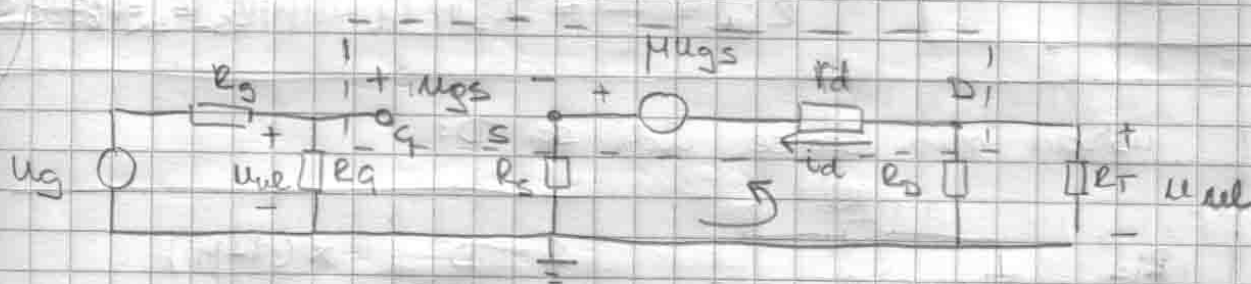
c) naponsko pojačanje:

$$H = \frac{u_{iz}}{u_{ul}} = \frac{g_m \cdot r_d}{1 + g_m R_G} = 0,71$$

$$\left\{ \begin{aligned} g_m &= 2,19 \frac{\mu A}{V} \\ r_d &= 311 \Omega \end{aligned} \right.$$

$$R_S = 680 \Omega$$

(napraviti inor)  
(koristimo Theveninovu - mi S  
mi D nisu direktno spojeni  
na masu u dinamičd)



$$A_V = \frac{u_{iz}}{u_{ul}}$$

$$i_D [(R_D \parallel R_T) + r_d + R_S] - \mu u_{GS} = 0 \quad (1)$$

$$u_{ul} = u_{GS} + i_D R_S \Rightarrow u_{GS} = u_{ul} - i_D R_S \quad (2)$$

$$u_{iz} = -i_D \cdot (R_D \parallel R_T) \Rightarrow i_D = \frac{-u_{iz}}{(R_D \parallel R_T)} \quad (3)$$

(2) i (3) u (1):

$$A_V = \frac{-\mu (R_D \parallel R_T)}{(1 + \mu) R_S + r_d + (R_D \parallel R_T)} = \dots = -2,43$$

d) ulazni otpor? (podaci iz c)

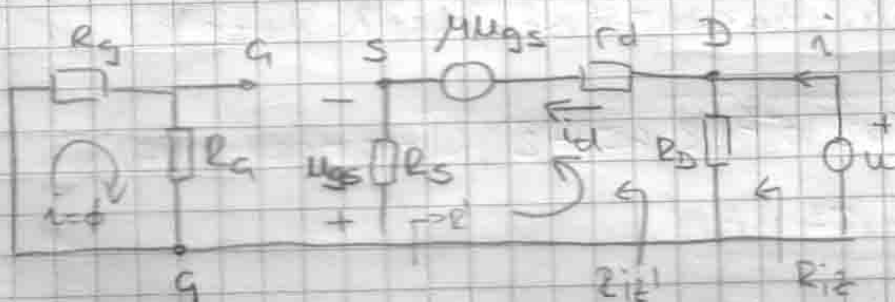
$$u_{ue} = i_{ue} \cdot R_g$$

$$R_{ue} = \frac{u_{ue}}{i_{ue}} = R_g = R_1 \parallel R_2 = 7,2 \parallel 3,3$$

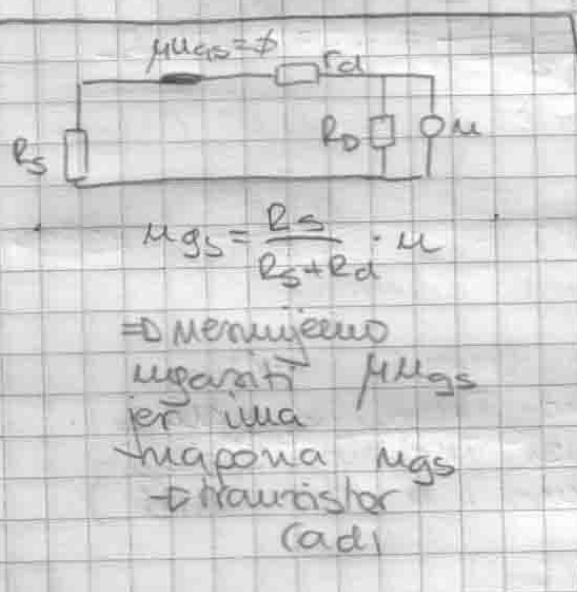
$$= 2,32 \text{ k}\Omega$$

e) izlazni otpor (podaci iz e)

gasimo  $u_g$ :



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



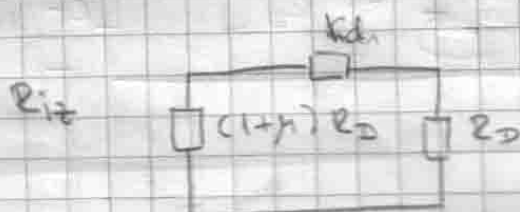
$$i = i_d + \frac{u}{R_D}$$

$$i_d R_d = \mu u_{gs} - u_{gs} = u$$

$$u_{gs} = -i_d \cdot R_s$$

$$R_{iez} = \frac{u}{i} = R_D \parallel [R_d + (1+\mu)R_s] = 5,672 \text{ k}\Omega$$

ustvari ovo što se vidi sa D:



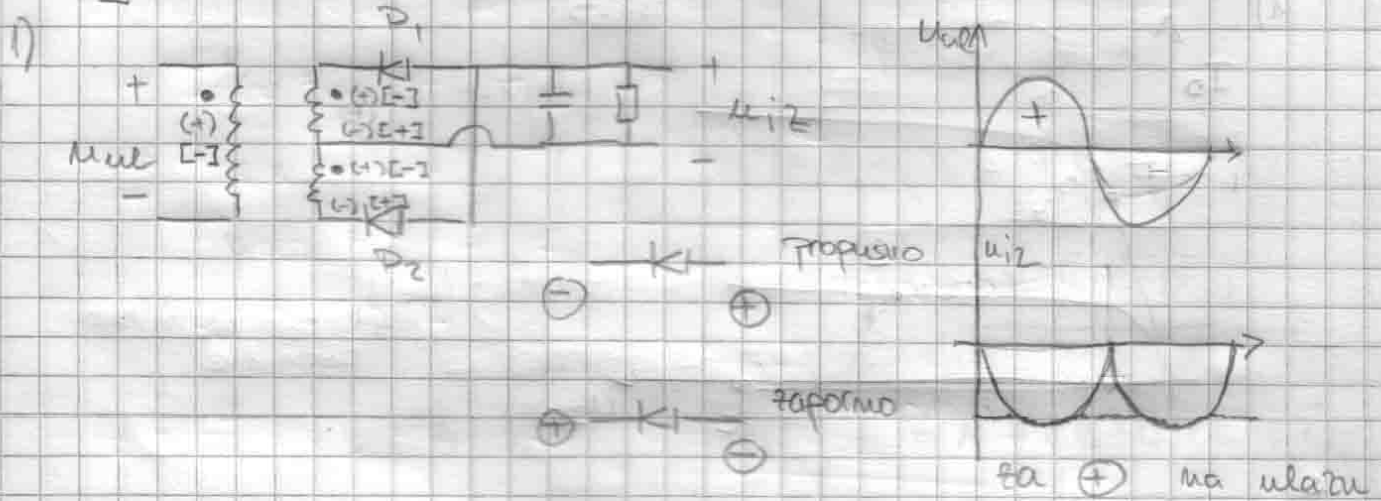
$$\begin{aligned} S \rightarrow D &= \mu(1+\mu) \\ D \rightarrow S &= \mu \frac{1}{(1+\mu)} \end{aligned}$$

$$R' = \frac{R_d + R_D \parallel R_s}{(1+\mu)}$$

$$R_{iez} = R_d + (1+\mu)R_s$$

(točnice - točke u fazi s ul. naponom)

teorija:



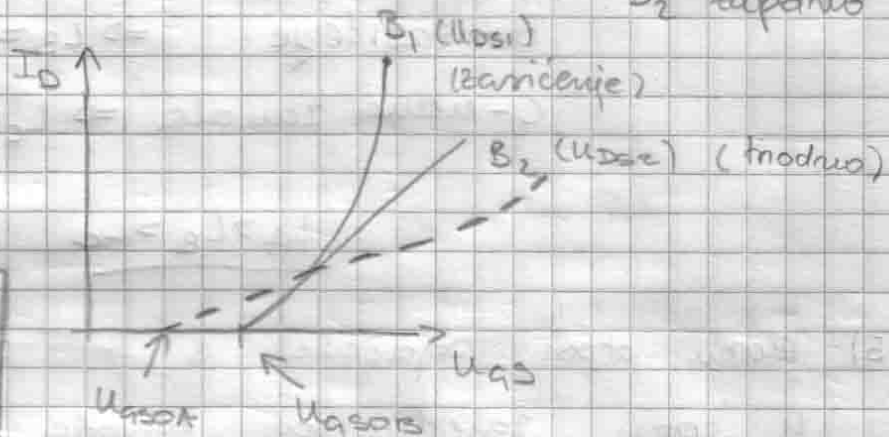
→ punovalno ispravljanje

→ na negativno

2)  $U_{GS0}$   
 $K$

$$U_{GS0A} < U_{GS0B}$$

$$K_B > K_A$$



$$I_{DA} = \frac{K_A}{2} (U_{GS} - U_{GS0})^2$$

$$I_{DB} = \frac{K_B}{2} (U_{GS} - U_{GS0})^2$$

→ veći  $K \Rightarrow$  struje raste

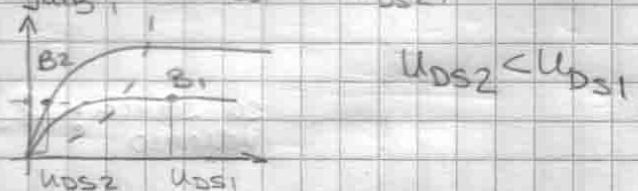
$$\Rightarrow K_B > K_A$$

3) ista struja, usporedjemo  $g_{mB}$  i  $g_{mA}$ , i  $U_{GS1}$  i  $U_{GS2}$

$$g_m = K(U_{GS} - U_{GS0}) = \sqrt{2KI_D}$$

$$g_{mB} > g_{mA}$$

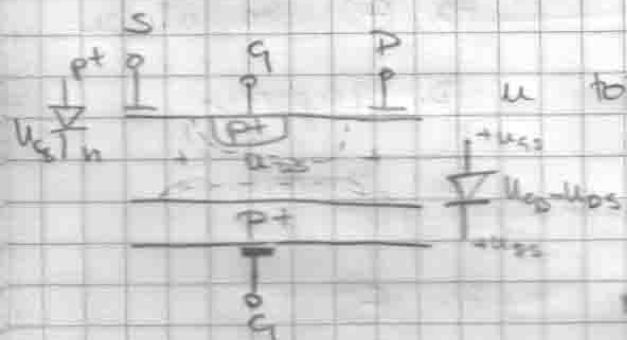
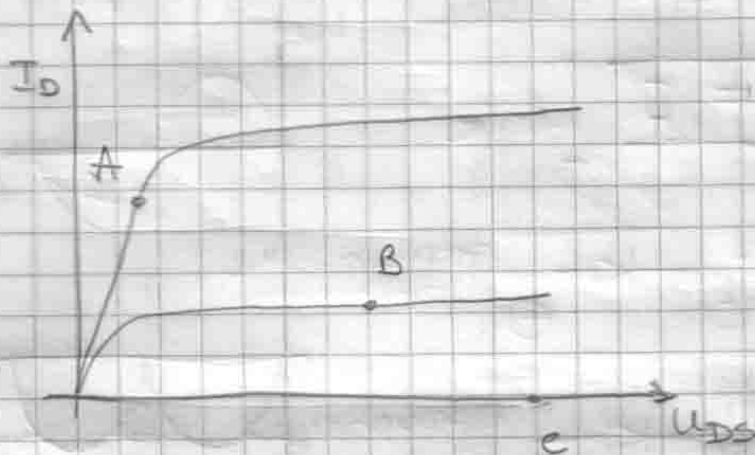
→ ili  $g_m = \frac{di_D}{dU_{GS}}$  (gledamo promjenu struje za istu promjenu napona)





# JFET

4)



u točki C  $\rightarrow |U_{GS}| \geq |U_{p}|$

(spoji se kanal pa menja struju)

odnos efektivnih dužina kanala  
u A i B i C

A - moduo p  $\Rightarrow L_A = L$

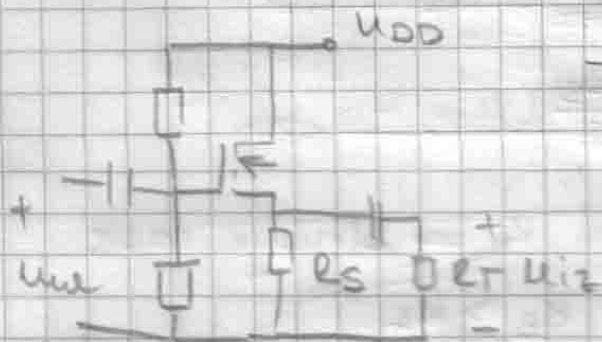
B - zasićenje  $\Rightarrow L_B = L - \Delta L$

C - mena kanala  $\Rightarrow L_C = \phi$

$$L_A > L_B > L_C$$

5) ikavni otpor pojačala s FET-om

u spoju zajedničkog odvoda inua  
iznos reda?



$\rightarrow$  gledamo za

source: sve se diči

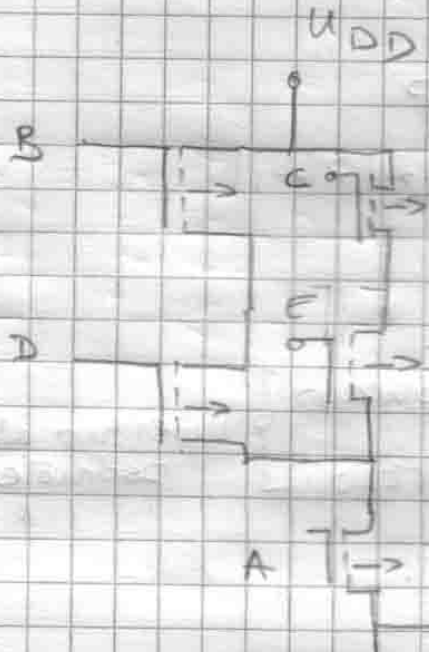
sa  $(1+\mu) \Rightarrow$  mali  
otpor

$$r_d = 100 \text{ k}\Omega$$

$$\mu = 200$$

$$\text{sa source: } R_S \parallel \frac{r_d}{(1+\mu)} \approx \frac{r_d}{(1+\mu)} \approx \frac{100 \text{ k}}{200} = 500$$

6)

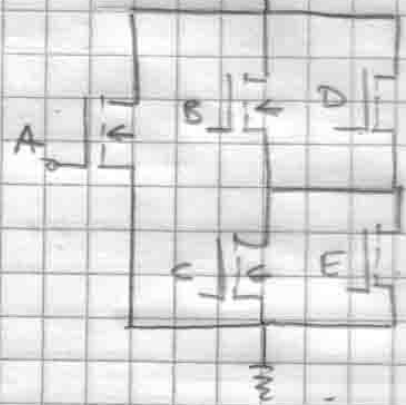


$$Y = \overline{A} \cdot (\overline{B} \cdot \overline{D} + \overline{C} \cdot \overline{E})$$

$$= \overline{A} \cdot (\overline{B+D} + \overline{C+E})$$

$$= \overline{A} \cdot (\overline{(B+D)(C+E)})$$

$$= \overline{A + (B+D)(C+E)}$$



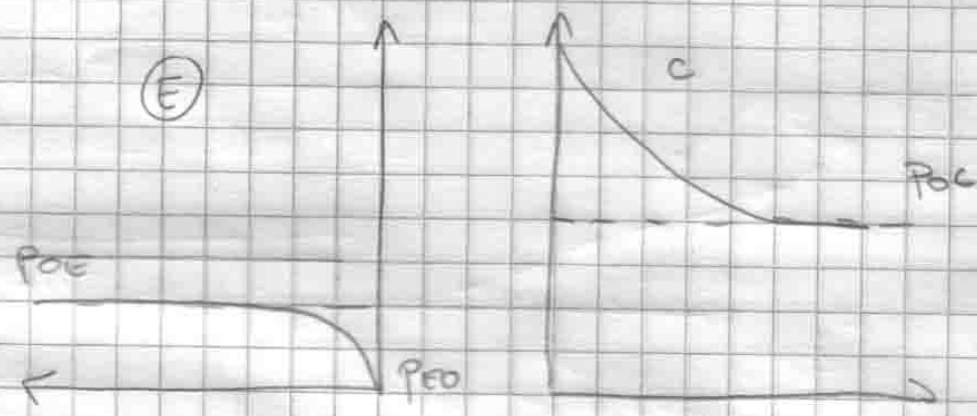
NMOS

$$Y = A + (B+D)(C+E)$$

$$Y = A + (B+D)(C+E)$$

7)

(E)



manjiuski - supline  
većiuski - electroni

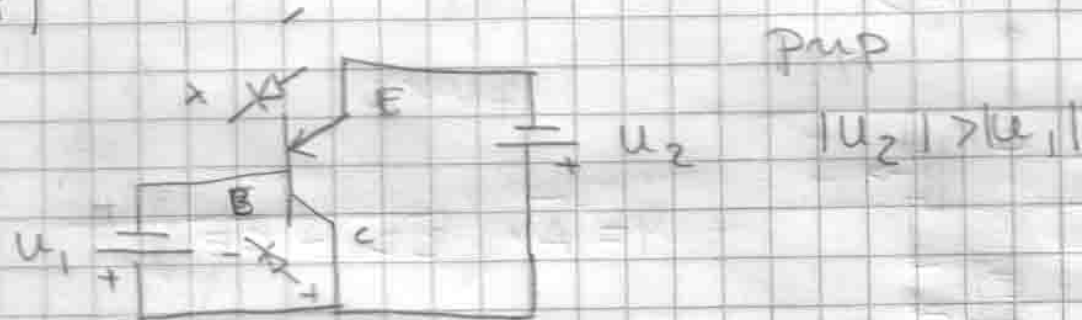
mpu - transistor

$P_{ce} < P_{dc} \Rightarrow$  topornos BE

$P_{ce} > P_{dc} \Rightarrow$  propurnos BC

↳ inverzno aktivno područje

8)



Prup

$$|U_2| > |U_1|$$

BC  $\rightarrow$  propulzno

BE  $\rightarrow$  reverzno

} inverzno arhivno  
podroje