5.4. DINAMIČKI PARAMETRI

▸ Dinamički parametri FET-ova

- opisuje odnose malih izmjeničnih veličina u režimu malog signala

$i_D = I_{DQ} + i_d$ (statička + dinamička)

$u_{GS} = U_{GSQ} + u_{gs}$

$u_{DS} = U_{DS} + u_{ds}$

$\longrightarrow i_D = (u_{GS}, u_{DS})$

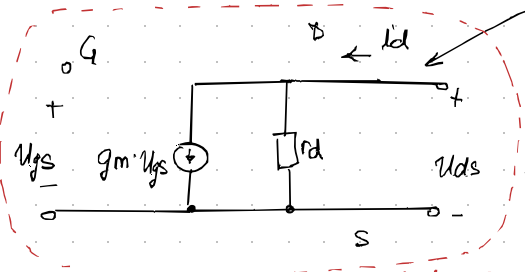
$$di = \frac{di_D}{du_{GS}} du_{GS} + \frac{di_D}{du_{DS}} \cdot du_{DS}$$

$\frac{di_D}{du_{GS}}$ → g_m strmina; $\frac{di_D}{du_{DS}}$ → g_d izl. dim. vodljivost

dinamički otpor:

$$r_d = \frac{1}{g_d}$$

$$\Rightarrow i_d = g_m \cdot u_{gs} + g_d \cdot u_{ds}$$



$$\rightarrow g_m = \frac{di_D}{du_{GS}} = \frac{di_D}{du_{GS}}\Big|_{u_{DS}=konst.} = \frac{di_d}{du_{gs}}$$

$$\rightarrow g_d = \frac{di_D}{du_{DS}} = \frac{di_D}{du_{DS}}\Big|_{u_{GS}=konst} = \frac{di_d}{du_{ds}}$$

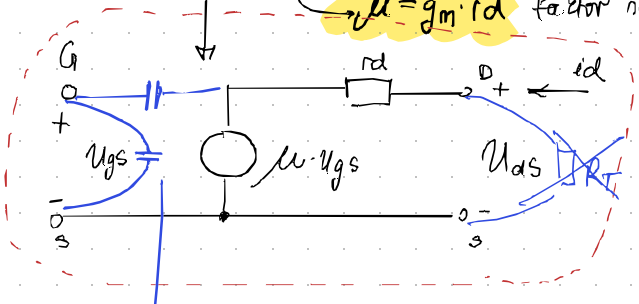
nadomjesna shema za mali signal

$$i_d = g_m \cdot u_{gs} + \frac{u_{ds}}{r_d} \quad / \cdot r_d$$

$$\Rightarrow i_d \cdot r_d = g_m \cdot r_d \cdot u_{gs} + u_{ds}$$

$u_{ds} = i_d \cdot r_d - g_m \cdot r_d \cdot u_{gs}$ → kako u_{ds} ovisi o u_{gs}

$\mu = g_m \cdot r_d$ faktor naponskog pojačanja

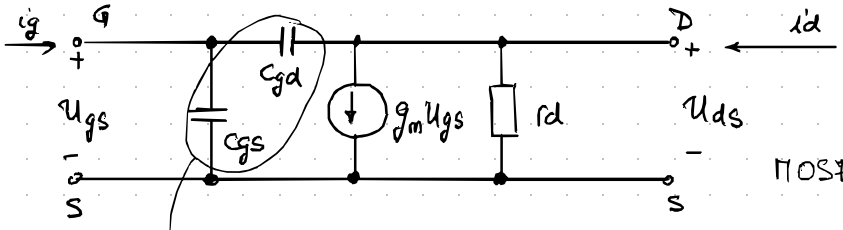


parazitni kapaciteti (djeluju tek na višim f)

$$\mu = -\frac{du_{DS}}{du_{GS}}\Big|_{I_D=konst} = -\frac{u_{ds}}{u_{gs}}\Big|_{i_d=0}$$

$R_T = \infty$

▶ Model za visoke frekvencije



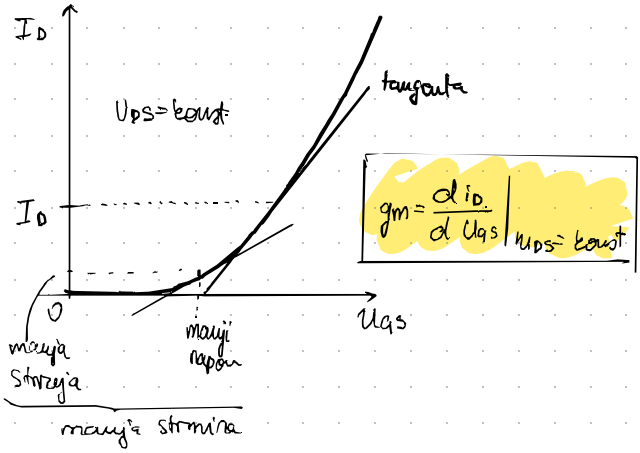
ako su f ≪, → Z ≪
(tada zanemarive struje, kao da ih nema)
→ na visokim f ih moramo uzeti u obzir

MOSFET → kapacitet MOS strukture

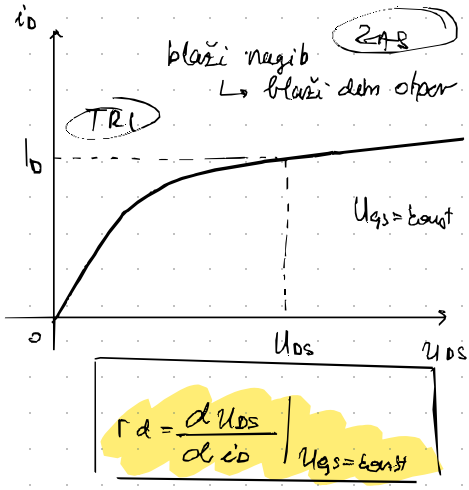
JFET → kapacitet zaporno pol. pn spoja

MESFET → kapacitet zaporno pol. metal-poluvodič

Grafičko određivanje parametara



$$g_m = \left.\frac{d i_D}{d u_{GS}}\right|_{u_{DS}=konst}$$



$$r_d = \left.\frac{d u_{DS}}{d i_D}\right|_{u_{GS}=konst}$$

Analitičko određivanje

MOSFET

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

$$g_m = \frac{d i_D}{d u_{GS}} = K(u_{GS} - u_{GSO}) = \sqrt{2K I_D}$$

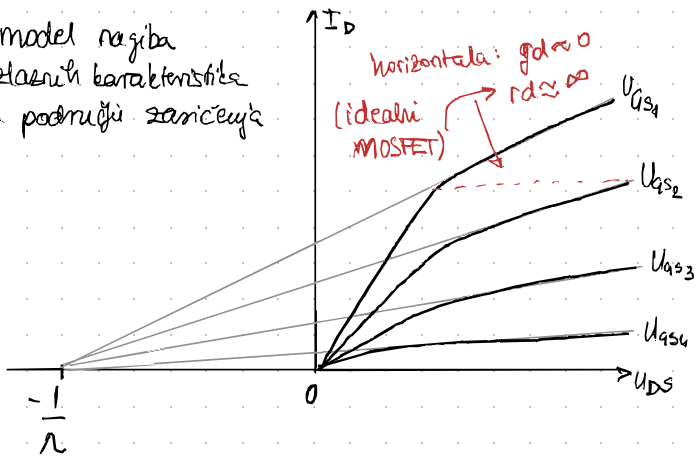
JFET

$$i_D = I_{DSS}\left(1 - \frac{u_{GS}}{U_P}\right)^2$$

$$g_m = \frac{d i_D}{d u_{GS}} = \frac{2 I_{DSS}}{-U_P}\left(1 - \frac{u_{GS}}{U_P}\right)$$

$$g_m = \frac{2}{-U_P}\sqrt{I_{DSS} \cdot I_D}$$

→ model nagiba izlaznih karakteristika u području zasićenja



MOSFET

$$i_D = \frac{K}{2}(u_{GS} - u_{GSO})^2 (1 + \lambda u_{DS})$$

$$g_d = \frac{d i_D}{d u_{DS}} = \lambda \frac{K}{2}(u_{GS} - u_{GSO})^2$$

JFET

$$i_D = I_{DSS}\left(1 - \frac{u_{GS}}{U_P}\right)^2 (1 + \lambda u_{DS})$$

$$g_d = \frac{d i_D}{d u_{DS}} = \lambda I_{DSS}\left(1 - \frac{u_{GS}}{U_P}\right)^2$$

Za oba FET-a:

$$r_d = \frac{1}{g_d} = \frac{1 + \lambda u_{DS}}{\lambda I_D} \approx \frac{1}{\lambda I_D}$$

Primjer 5.3

$K = 80\,\mu A/V^2$

$U_{GSO} = 2V$

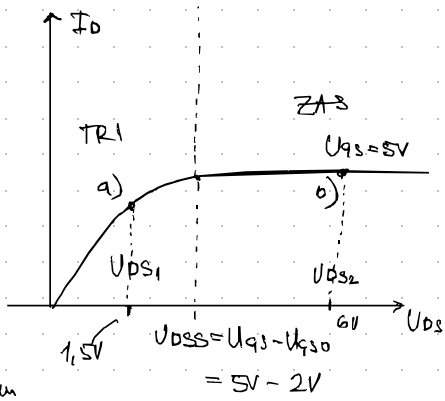
$\lambda = 0{,}005/V$

$U_{GS} = 5V$

$I_D = ?$ $g_m = ?$ $r_d = ?$ $\mu = ?$

a) $U_{DS_1} = \frac{(U_{GS} - U_{GSO})}{2}$

b) $U_{DS_2} = 2\,(U_{GS} - U_{GSO})$



→ $U_{DSS} = 3V$

Kpro moramo odredit di se radne točke da znamo koji formulu

a) $U_{DS_1} = \frac{5-2}{2} = 1{,}5V$ → triodno područje

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

→ $I_{D_1} = 80\times10^{-6}\left[3 \cdot 1{,}5 - \frac{1{,}5^2}{2}\right]$

$I_{D_1} = 0.27\,mA$

$g_m = \left.\frac{d\,i_D}{d\,u_{GS}}\right|_{U_{DS_1}}$

$r_d = \frac{1}{g_d} = \left(\left.\frac{d\,i_D}{d\,U_{DS}}\right|_{U_{GS}}\right)^{-1}$

$\mu = g_m \cdot r_d = \frac{g_m}{g_d}$

→ $g_m = K\,U_{DS_1}$

$g_m = 80\times10^{-6} \cdot 1{,}5V$

$g_m = 0.12\,mA/V$

→ $r_d = \frac{1}{g_d} = \left(K\left[(U_{GS} - U_{GSO}) - U_{DS}\right]\right)^{-1}$

$r_d = \frac{1}{K(U_{GS} - U_{GSO} - U_{DS})} = \frac{1}{80\times10^{-6}(3V - 1{,}5V)}$

$r_d = 8333{,}33\,\Omega = 8{,}333\,k\Omega$

→ $\mu = \frac{g_m}{g_d} = g_m \cdot r_d = 0.12\times10^{-3} \cdot 8{,}33\cdot10^{3}$

$\mu = 0.9996 \sim 1$

b) $U_{DS_2} = 6V$ → zasićeno područje

$i_D = \frac{K}{2}(U_{GS} - U_{GSO})^2(1 + \lambda U_{DS})$

$I_D = \frac{80\times10^{-6}}{2} \cdot 3^2 \cdot (1 + 5\times10^{-3} \cdot 6)$

$I_D = 0{,}37\,mA$

$g_m = \frac{d\,i_D}{d\,u_{GS}} = \frac{K}{2} \cdot 2(U_{GS} - U_{GSO})(1 + \lambda U_{DS_2}) =$

$g_m = 80\times10^{-6} \cdot 3(1 + 5\times10^{-3} \cdot 6)$

$g_m = 0{,}24\,mA/V$

$g_d = \frac{d\,i_D}{d\,U_{DS}} = \frac{K}{2}(U_{GS} - U_{GSO})^2 \cdot \lambda$

$g_d = \frac{80\times10^{-6}}{2} \cdot 3^2 \cdot 5\times10^{-3}$

$g_d = 1{,}8\,\mu S$ → $r_d = 555.56\,k\Omega$

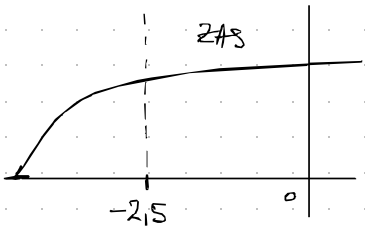
$\mu = g_m \cdot r_d = 133{,}33$

Primjer 5.4.) p-kan MOSFET

$U_{GSO} = -1.5V$

$U_{GS} = -4V \rightarrow i_D = 1mA$

$U_{GS} = ?$ $g_m = ?$ $i_D = 4mA$



ZAS:

$i_D = \frac{K}{2}(U_{GS} - U_{GSO})^2$ – budući da je p kanalni mosfet

$\hookrightarrow i_D' = (-)1mA$ i $i_D = (-)4mA$

1. slučaj → dovjerno k

$$K = \frac{2\, i_D}{(U_{GS} - U_{GSO})^2} = \frac{2 \cdot (-1 \times 10^{-3})}{(-4 + 1{,}5)^2}$$

$K = -320\,\mu A/V^2$

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

$$g_m = \frac{di_D}{dU_{GS}} \rightarrow g_m = K(U_{GS} - U_{GSO}) = \sqrt{2K I_D}$$

2. slučaj → dovjerno ostalo

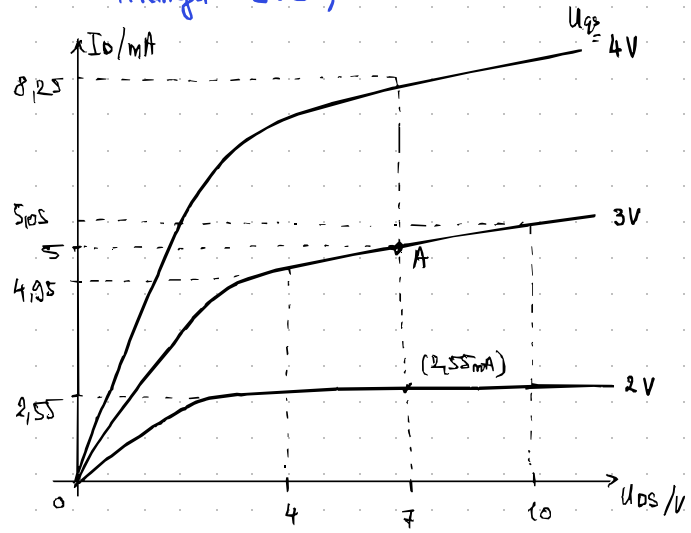
$\rightarrow K(U_{GS_2} - U_{GSO}) = \sqrt{2K I_{D_2}}$

$g_m = \sqrt{2K I_{D_2}} = \boxed{1.6\,mA/V}$

$U_{GS_2} = \frac{\sqrt{2K I_{D_2}}}{K} + U_{GSO} = \sqrt{\frac{2 I_{D_2}}{K}} + U_{GSO}$ ili $U_{GS_2} = \frac{g_m}{K} + U_{GSO}$

$\boxed{U_{GS_2} = -6.5V}$

Primjer 5.5)



A

a) g_m = ?
r_d = ?
μ = ?

b) λ = ? zasićenje

c) U_{DS} = 7V → r_d = ? zona 3 napona

a) $U_{GSA} = 3V$

$U_{DSA} = 7V \rightarrow I_{D1} = 2,55mA$ $\quad U_{GS1} = 2V$

$I_{DA} = 5mA \quad I_{D2} = 8,25mA \quad U_{GS2} = 4V$

$$g_m = \frac{\Delta i_D}{\Delta u_{GS}} = \frac{I_{D2} - I_{D1}}{U_{GS2} - U_{GS1}}$$

$$g_m = 2,85mA/V$$

$$r_d = \frac{\Delta U_{DS}}{\Delta i_D} = \frac{U_{DS2} - U_{DS1}}{I_{D2} - I_{D1}} = \frac{10 - 4}{5,05 - 4,95} \cdot X10^3$$

→ mora proći ponovno

$$r_d = 60k\Omega$$

$$\mu = r_d \cdot g_m = 171$$

b) $I_D = \frac{K}{2}(U_{GS} - U_{GS0})^2(1 + \lambda U_{DS})$, $U_{GS} = 3V$

$$4.95 \times 10^{-3} = \frac{K}{2}(3 - U_{GS0})^2(1 + \lambda \cdot 4)$$

$$5 \times 10^{-3} = \frac{K}{2}[3 - U_{GS0}^2](1 + \lambda \cdot 7)$$

$$\frac{4.95 \times 10^{-3}}{1 + \lambda \cdot 4} = \frac{5 \times 10^{-3}}{1 + \lambda \cdot 7}$$

$$\frac{1 + 7\lambda}{1 + 4\lambda} = \frac{5}{4.95}$$

$$1 + 7\lambda = 1,01 + 4,04\lambda$$

$$2.96\lambda = 0,01 \rightarrow \lambda = 3.378 \times 10^{-3}$$

$$\frac{1}{\lambda} = 296$$

c) $U_{DS} = 7V \quad r_d = \frac{1}{\lambda I_D}$

$U_{GS} = 4V \rightarrow r_d(4V) = 296 \cdot \frac{1}{8.25} \times 10^3 \rightarrow r_d = 35,88k\Omega$

$U_{GS} = 3V \rightarrow r_d(3V) = 296 \cdot \frac{1}{5} \times 10^3 \rightarrow r_d = 59.2k\Omega$

$U_{GS} = 2V \rightarrow r_d(2V) = 296 \cdot \frac{1}{2,55} \times 10^3 \rightarrow r_d = 116.08k\Omega$