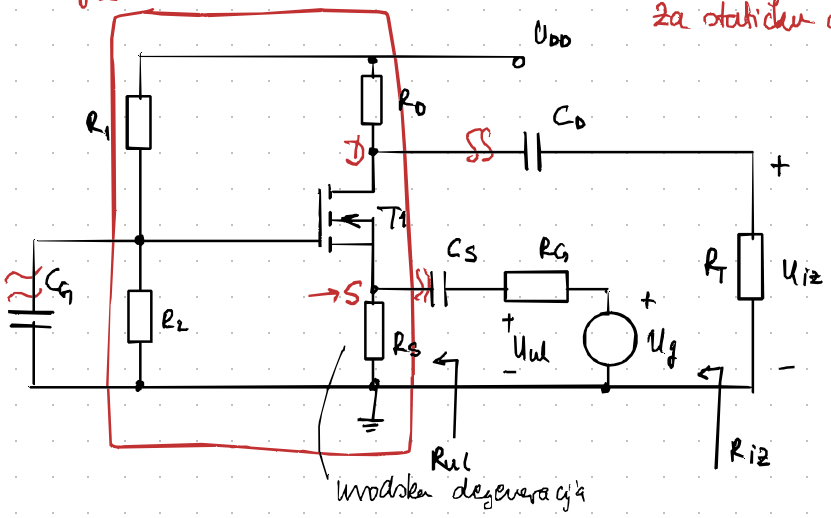
6.3 Pojačalo u spoju zajedničke upravljačke elektrode i zajedničkog odvoda

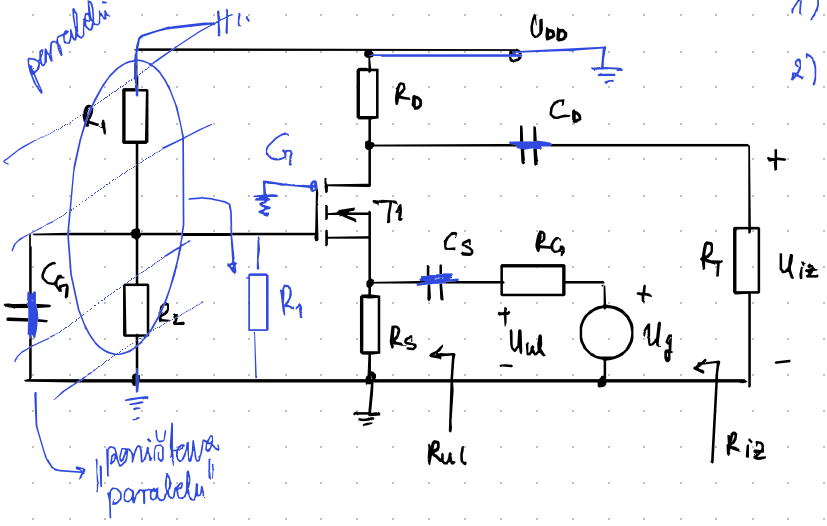
*pretpostavljamo da smo u području malog signala



za statičku analizu → C = prazan hod

— mreža identična kao prije

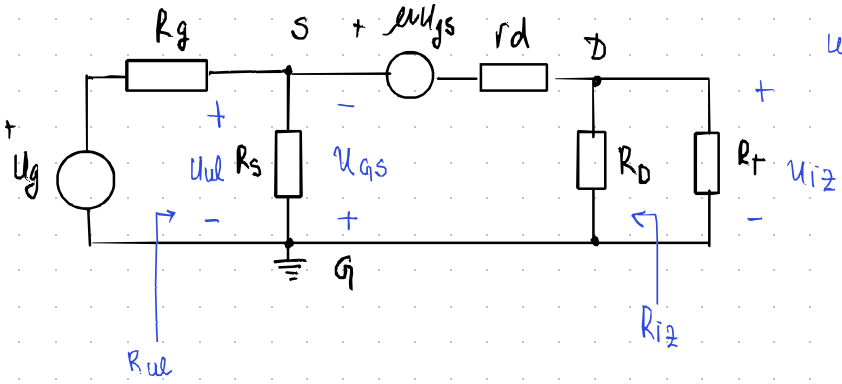
Crtanje nadomjesne sheme za DINAMIKU



1) gasimo DC izvore

2) C kratko spajamo

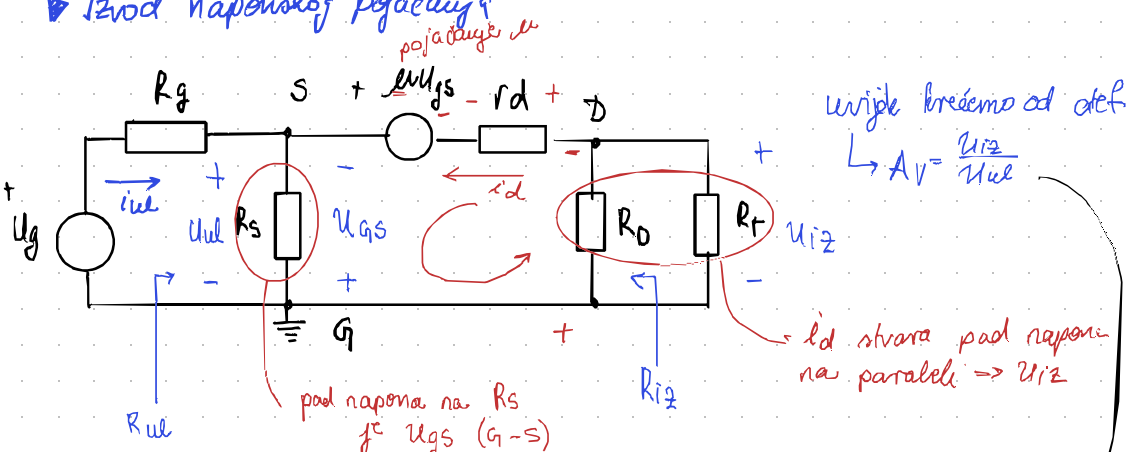
$Z_c = \frac{1}{\omega C}$



uvijek krećemo od def.

↳ $A_V = \frac{U_{iz}}{U_{ul}}$

▶ Izvod naponskog pojačanja



$u_{iz} = -i_d (R_D \parallel R_T)$

$u_{gs} + \mu u_{gs} = i_d (r_d + R_D \parallel R_T)$

$u_{ul} = -u_{gs}$

* jednake polarizacije idu na iste stranice

$$i_d = \frac{-(1+\mu)\, u_{ul}}{r_d + R_D \parallel R_T}$$

* cilj nam je izraziti sve pre ulaz-izlaz

$$\Rightarrow \frac{+u_{iz}}{R_D \parallel R_T} = \frac{+(1+\mu) u_{ul}}{r_d + R_D \parallel R_T} \longrightarrow \boxed{\frac{u_{iz}}{u_{ul}} = \frac{(1+\mu)(R_D \parallel R_T)}{r_d + R_D \parallel R_T} = A_v}$$

$= g_m \cdot \frac{r_d (R_D \parallel R_T)}{r_d + R_D \parallel R_T}$

$\approx \mu = g_m \cdot r_d$

u spoju naponske upravljačke elektrode pojačanje je > 0

! paralela

$$\Rightarrow \boxed{A_v = g_m \cdot (r_d \parallel R_D \parallel R_T)}$$

identičan izraz za spoj zajedničke uvode samo > 0 !

▶ Ulazni otpor

po definiciji $R_{ul} = \frac{u_{ul}}{i_{ul}}$

$i_{ul} + i_d = \frac{u_{ul}}{R_S}$

$i_d = -\frac{(1+\mu) u_{ul}}{r_d + R_D \parallel R_T}$

$\Rightarrow i_{ul} = \frac{u_{ul}}{R_S} + \frac{(1+\mu) u_{ul}}{r_d + R_D \parallel R_T}$

$i_{ul} = u_{ul} \left(\frac{1}{R_S} + \frac{(1+\mu)}{r_d + R_D \parallel R_T} \right)$

* vježbi se za osnove $\rightarrow i = \frac{u}{R_1} + \frac{u}{R_2}$

$\longrightarrow R = R_1 \parallel R_2 \rightarrow$ $\boxed{R_{ul} = R_S \parallel \frac{r_d + R_D \parallel R_T}{1+\mu}}$ $\Rightarrow R_{ul} = R_S \parallel \frac{r_d}{\mu}$

$>> \mu$

* $\mu = r_d \cdot g_m$

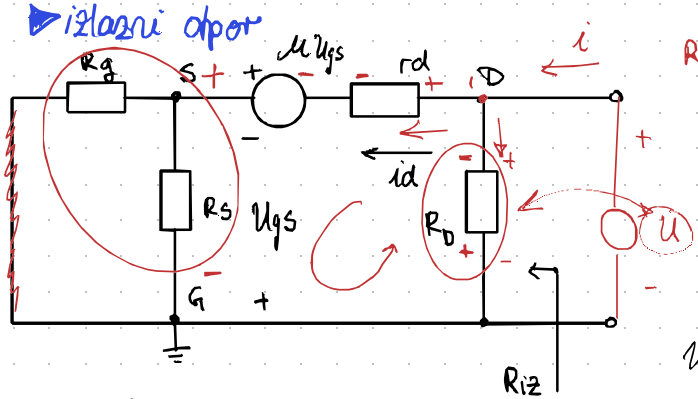
$$\Rightarrow \boxed{R_{ul} = R_S \parallel \frac{1}{g_m}}$$

ulazni otpor čitavog pojačala određen je s vrlo velikim otporom R_S, ali i sa strmином MOSFET-a u R.T.

$R_{ul} << !$

• ulazni otpor u spoju zajedničke elektrode je NIZAK → na ulazne stezaljke se predikavaju otpori iz izlaznog dijela sklopa ali SMANJENI $(1+\mu)$ puta

Izlazni otpor



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

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

$$u_{gs} = -i_d (R_S \| R_g)$$

$$\mu \cdot u_{gs} + u = i_d \left(r_d + R_g \| R_S\right)$$

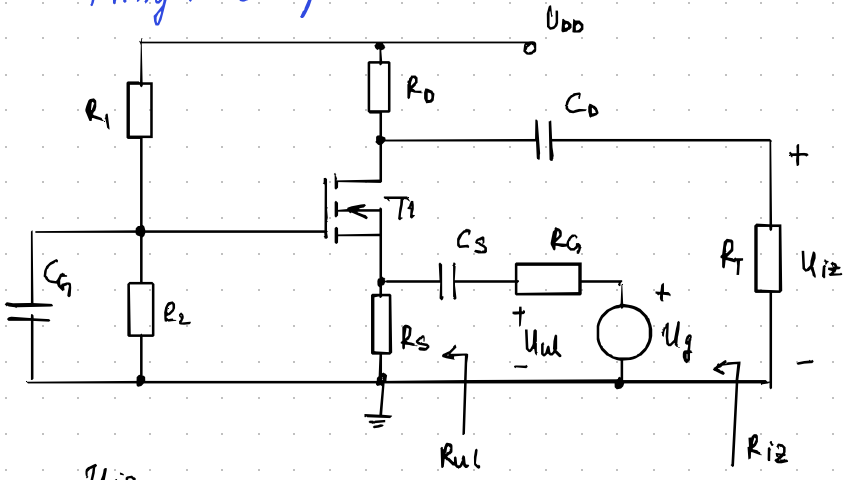
$$\Rightarrow i_d = \frac{u}{r_d + R_g \| R_S} - \frac{\mu (R_S \| R_g)}{r_d + R_g \| R_S}$$

$$-\mu \cdot i_d (R_S \| R_g) + u = i_d (r_d + R_g \| R_S)$$

$$i_d = \frac{u}{r_d + (1+\mu)(R_S \| R_g)} \longrightarrow i = u \left(\frac{1}{r_d + (1+\mu)(R_S \| R_g)} + \frac{1}{R_D} \right)$$

$$\Rightarrow \boxed{R_{iz} = R_D \| \left[r_d + (1+\mu)(R_S \| R_g) \right]}$$

Primjer 6.9.)



$U_{DD} = 15V$
$R_g = 500\Omega$
$R_1 = 518 M\Omega$
$R_2 = 1.7 M\Omega$
$R_D = 4k\Omega$
$R_T = 6k\Omega$
$R_S = 400\Omega$
*n-kanalni
$K = 2mA/V^2$
$U_{gso} = 1V$
$\lambda = 0,005/V$

$A_V = \frac{U_{iz}}{U_{ul}} = ?$ $A_{Vg} = \frac{U_{iz}}{U_g} = ?$

* statika ostaje ista jer su isti zadani parametri
(i shema je ista → SRT je ista)

(1) Statika i (2) Dinamički parametri (primjer 6.5 i 6.7)

$g_m = 3,08\ mA/V$ $r_d = 88k\Omega$ $\mu = 273 >> 1$

(3.) Dinamika: shema + izvodi (prošla stranica pa nećeš sad) $A_V = \frac{U_{iz}}{U_{ul}}$

$$A_V = \frac{(1+\mu)(R_D \| R_T)}{r_d + R_D \| R_T} \quad \text{ili (za } \mu >> 1) \rightarrow \quad A_V = g_m \cdot (r_d \| R_D \| R_T)$$

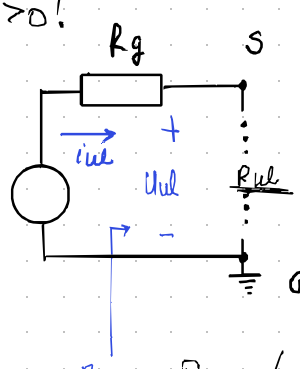
$$A_V = g_m \left(\frac{1}{r_d} + \frac{1}{R_D} + \frac{1}{R_T} \right)^{-1}$$

$\boxed{A_V = 7.2}$ >0!

$$A_{Vg} = \frac{U_{iz}}{U_g} = \frac{U_{iz}}{U_{ul}} \cdot \frac{U_{ul}}{U_g} = A_V \cdot \frac{R_{ul}}{R_g + R_{ul}}$$

$$A_{Vg} = 7,2 \cdot \frac{179,21}{500 + 179,21}$$

$\boxed{A_{Vg} = 1.9}$



$U_{ul} = U_g \cdot \frac{R_{ul}}{R_g + R_{ul}}$

$R_{ul} = R_S \| \frac{r_d + R_D \| R_T}{1+\mu}$

$\Downarrow$

$R_{ul} = R_S \| \frac{1}{g_m}$

$R_{ul} = \left(\frac{1}{R_S} + g_m \right)^{-1}$

$\boxed{R_{ul} = 179.21\Omega}$

budući da je $R_{ul} <<$, onda će se ulazni signal slabo prenositi $\Rightarrow$ $A_{Vg} < A_V$

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

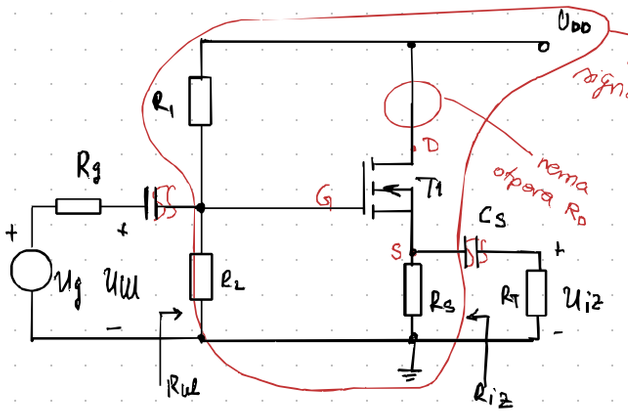
$$R_{iz} = \left(\frac{1}{R_D} + \frac{1}{r_d + (1+\mu)\left(\frac{R_S \cdot R_g}{R_S + R_g} \right)} \right)^{-1} = 4k\Omega \| 149k\Omega \rightarrow \boxed{R_{iz} = 3.9k\Omega}$$

Zaključak: $A_V > 0$!

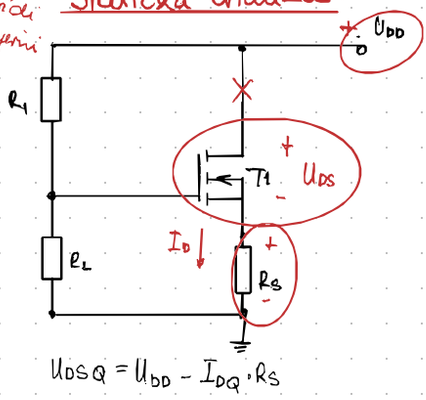
$R_{ul} <<< \longrightarrow A_{Vg} < A_V$.

▽ iznimno bitno!

Pojačalo u spoju zajedničkog odvoda (D) - uvodsko sljedilo

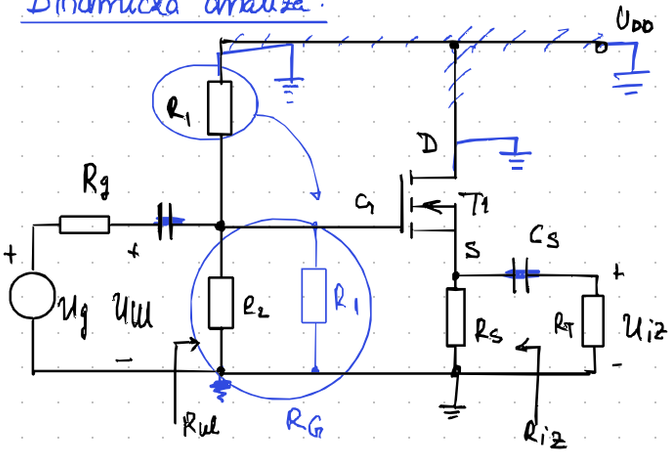


Statička analiza:



$U_{DSQ} = U_{DD} - I_{DQ} \cdot R_S$

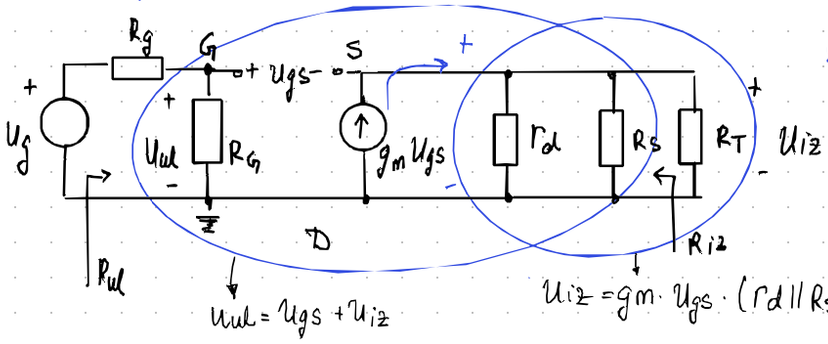
Dinamička analiza:



1) gasimo DC izvore
2) C spajamo kratko

1) $A_V = \frac{U_{iz}}{U_{ul}}$

▶ pojačanje A_V



2) R_{ul}

3) R_{iz}

$U_{ul} = U_{gs} + U_{iz}$

$U_{iz} = g_m \cdot U_{gs} \cdot (r_d \| R_S \| R_T)$

$$\Rightarrow A_V = \frac{g_m U_{gs} (r_d \| R_S \| R_T)}{U_{gs} + U_{iz}} = \frac{g_m U_{gs} (r_d \| R_S \| R_T)}{U_{gs} (1 + g_m (r_d \| R_S \| R_T))}$$

$$A_V = \frac{g_m (r_d \| R_S \| R_T)}{1 + g_m (r_d \| R_S \| R_T)} \approx 1 \quad (< 1)$$

($g_m (r_d \| R_S \| R_T) >> 1$)

pojačalo koje u principu ne pojačava

$\Rightarrow$ UVODSKO SLIJEDILO

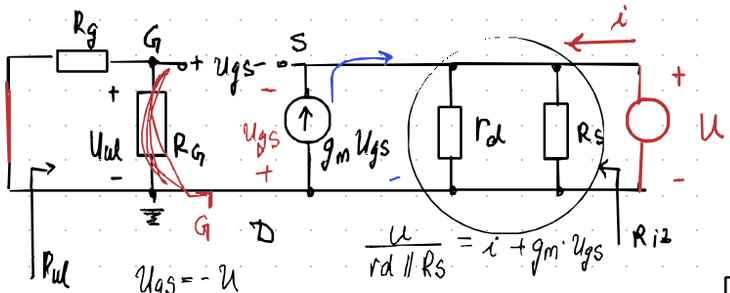
* ovo „pojačalo" je korisno za R_{ul} i R_{iz}

▶ ulazni otpor R_{ul}

$$R_{ul} = \frac{U_{ul}}{i_{ul}} = R_G = R_1 \| R_2$$

$\sim M\Omega$ $>>>$ $A_{VG} = A_V$

▶ izlazni otpor



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

$U_{gs} = -u$

$\frac{u}{r_d \| R_S} = i + g_m \cdot U_{gs}$

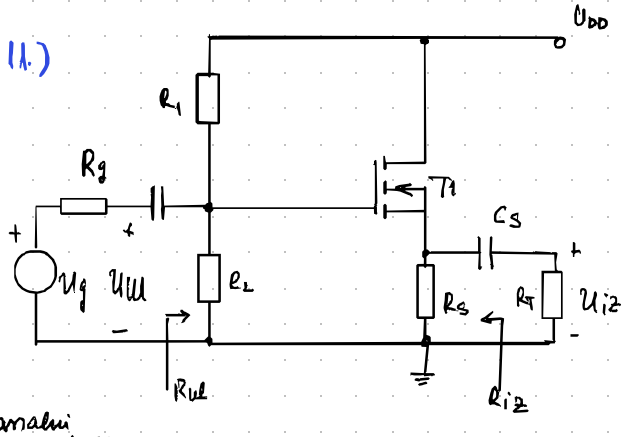
$$i = \frac{u}{r_d \| R_S} + g_m u \Rightarrow \boxed{R_{iz} = (r_d \| R_S) \| \frac{1}{g_m}} \rightarrow \boxed{R_{iz} = R_S \| \frac{1}{g_m}} \ll$$

($r_d >> R_S$)

$\Rightarrow$ ovo pojačalo služi kao TRANSFORMATOR IMPEDANCIJE

↳ čuva amplitudu signala, ali smanjuje impedanciju

Primjer 6.11.)



$U_{DD} = 15V$

$R_g = 500\,\Omega$

$R_1 = 2M\Omega$

$R_2 = 5M\Omega$

$R_S = 4k\Omega$

$R_T = 5k\Omega$

*n-kanalni MOSFET

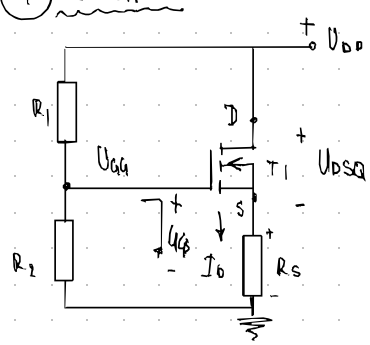
$K = 2mA/V^2$

$U_{gso} = 1V \quad \lambda = 0{,}005/V$

$A_v = \frac{U_{iz}}{U_{ul}} = ? \quad R_{ul} = ?$

$A_{vg} = \frac{U_{iz}}{U_g} = ? \quad R_{iz} = ?$

(1) Statika



$U_{GG} = U_{DD} \cdot \frac{R_2}{R_1+R_2} = 15 \cdot \frac{5}{2+5} \rightarrow U_{GG} = 10{,}7V$

$U_{GG} = U_{GSQ} + I_{DQ} \cdot R_S = U_{GSQ} + R_S \cdot \frac{K}{2}(U_{GSQ} - U_{GSO})^2$

$\Rightarrow U_{GSQ}^2 + \left(\frac{2}{R_S K} - 2U_{GSO}\right) \cdot U_{GSQ} + \left(U_{GSO}^2 - \frac{2U_{GG}}{R_S K}\right) = 0$

$U_{GSQ}^2 - 1{,}75\,U_{GSQ} - 1{,}675 = 0$

$\Rightarrow U_{GSQ} = \begin{cases} 2{,}44V > U_{GSO} \\ -0{,}69V \end{cases}$

$I_{DQ} = \frac{K}{2}(U_{GSQ} - U_{GSO})^2 = 2{,}07mA$

$U_{DSQ} = U_{DD} - I_{DQ} \cdot R_S = 15 - 4\times10^3 \cdot 2{,}07\times10^{-3} \rightarrow U_{DSQ} = 6.72V$

$U_{DSQ} > U_{GSQ} - U_{GSO} = 1.44V$ (zanemarujemo)

(2) Dinamički parametri

$i_D = \frac{K}{2}(U_{GS} - U_{GSO})^2(1+\lambda U_{DS}) \rightarrow g_m = \left.\frac{\partial i_D}{\partial U_{GS}}\right|_Q = K(U_{GSQ} - U_{GSO})(1+\lambda U_{DSQ})$

$g_m = 2.98mA/V$

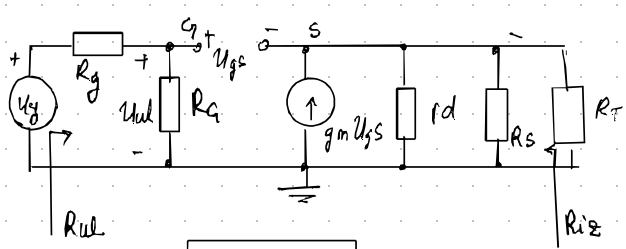
$\rightarrow \frac{1}{r_d} = \left.\frac{\partial i_D}{\partial U_{DS}}\right|_Q = \lambda \frac{K}{2}(U_{GSQ} - U_{GSO})^2 \rightarrow r_d = 96{,}5k\Omega$

(3) Dinamika (shema + izvodi $A_v, A_{vg}, R_{ul}, R_{iz}$) (prošla str., sad reći).

$A_v = \frac{U_{iz}}{U_{ul}} = \frac{g_m(r_d \parallel R_S \parallel R_T)}{1+g_m(r_d \parallel R_S \parallel R_T)} = 0.866 = A_v$

$R_{ul} = R_G = R_1 \parallel R_2 \rightarrow R_{ul} = 1.42M\Omega$

$R_{iz} = R_S \parallel \frac{1}{g_m} \rightarrow R_{iz} = 309.6\Omega$



$A_{vg} = \frac{U_{iz}}{U_g} = \frac{U_{iz}}{U_{ul}} \cdot \frac{U_{ul}}{U_g} = A_v \cdot \frac{R_G}{R_g+R_G}$

$R_g \ll R_G = R_{ul} \Rightarrow A_{vg} = A_v$

Usporedba osnovnih spojeva pojačala s FET-ovima

Spoj pojačala	Av	Rul	Riz
Zajednički uvod	$-g_m(r_d \parallel R_D \parallel R_T)$	$R_G >>> ?$	$R_D \parallel r_d$
Zajednička upravljačka elektroda	$+g_m(r_d \parallel R_D \parallel R_T)$	$R_S \parallel \frac{1}{g_m}$ $<<$	$R_D \parallel [r_d + (1+\mu)(R_S \parallel R_g)]$ $\approx R_D$
Zajednički odvod	$+\frac{g_m(r_d \parallel R_S \parallel R_T)}{1+g_m(r_d \parallel R_S \parallel R_T)} < 1$ ≈ 1 (sljedbenik)	$R_G >>>$	$R_S \parallel \frac{1}{g_m}$ $<<<$

→ analiza ovih pojačala temelji se na metodi superpozicije

→ $R_{Jul} = R_{j\,DC} + R_{j\,AC}$

• nakon pronalaska SRT → tražimo din. parametre → izmjenični signal mora biti MALI da bi linearnost ostala sačuvana!

Dinamika
- gasimo V_{DD}
- kratko spajamo C