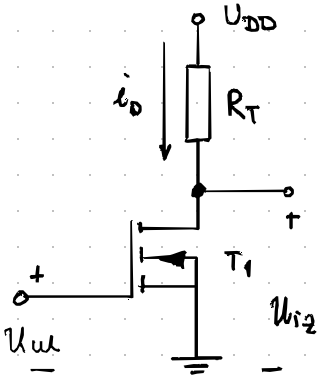
6.2. SKLOPOVI S UNIPOLARNIM TRANZISTORIMA

Uvjeti rada pojačala s FET-om u režimu malog signala



→ kakav odziv ima pojačalo za male signale

$u_{UL} = \underbrace{U_{UL}}_{DC} + \underbrace{u_{ul}}_{AC} = u_{GS} = \underbrace{U_{GSQ}}_{DC} + \underbrace{u_{gs}}_{AC}$

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

linearizacija u radnoj točki → Taylorov red

$\hookrightarrow i_D = i_D\Big|_Q + \left.\frac{di_D}{du_{GS}}\right|_Q (u_{GS} - U_{GSQ}) + \left.\frac{d^2 i_D}{du_{GS}^2}\right|_Q \frac{(u_{GS} - U_{GSQ})^2}{2!} + \dots$

u radnoj točki Q!

$\left.\frac{di_D}{du_{GS}}\right|_Q = K(u_{GS} - U_{GSO})\Big|_Q = K(U_{GSQ} - U_{GSO})$

$\left.\frac{d^2 i_D}{du_{GS}^2}\right|_Q = K$

* $u_{GS} - U_{GSO} = u_{gs}$

$\Rightarrow i_D = I_{DQ} + K(U_{GSQ} - U_{GSO}) \cdot u_{gs} + \frac{K}{2} u_{gs}^2 \rightarrow i_D = I_{DQ} + g_m u_{gs} + \frac{K}{2} u_{gs}^2$

strmina g_m

i_D mora biti linearno → eliminiramo $\frac{K}{2} u_{gs}^2$

- uvjet za režim malog signala: $u_{gs} \ll 2(U_{GSQ} - U_{GSO})$ → LINEARNI REŽIM

$\hookrightarrow u_{DS} = \underbrace{U_{DSQ}}_{DC} + \underbrace{u_{ds}}_{AC} = U_{DD} - R_T i_D = U_{DD} - R_T(I_{DQ} + i_d)$

$= \underbrace{U_{DD} - R_T I_{DQ}}_{U_{DSQ}} - \underbrace{R_T i_d}_{u_{ds}}$

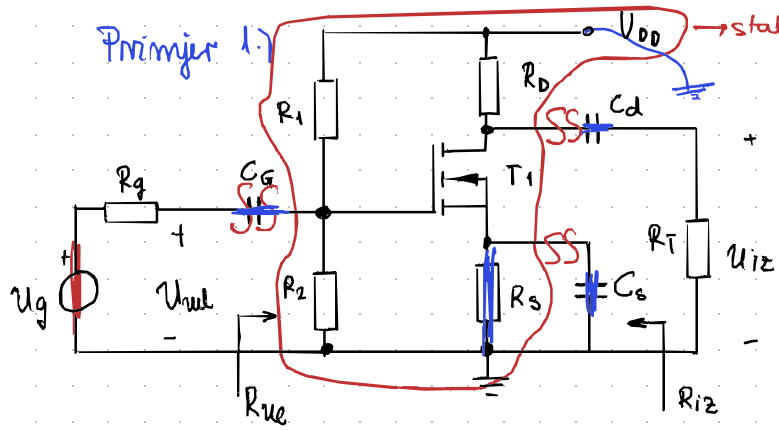
statičko (DC) | dinamičko (AC)

Da bismo mogli riješiti dinamičku analizu moramo biti u režimu malog signala da bi se osigurala linearnost

* $A_V = \frac{u_{iz}}{u_{ul}} = \frac{u_{ds}}{u_{gs}} = \frac{-R_T i_d}{u_{gs}}$

$\rightarrow A_V = -g_m R_T$

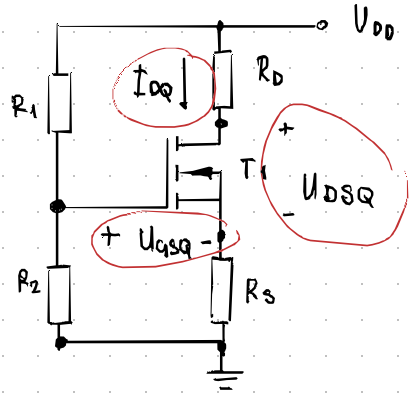
Primjer 1.)



→ statički sklop ovog sklopa

① Statika – gasimo izmjenične izvore
- odspajamo $C \rightarrow Z_C = \frac{1}{\omega C}$ $\omega \to 0$ $Z \to \infty$

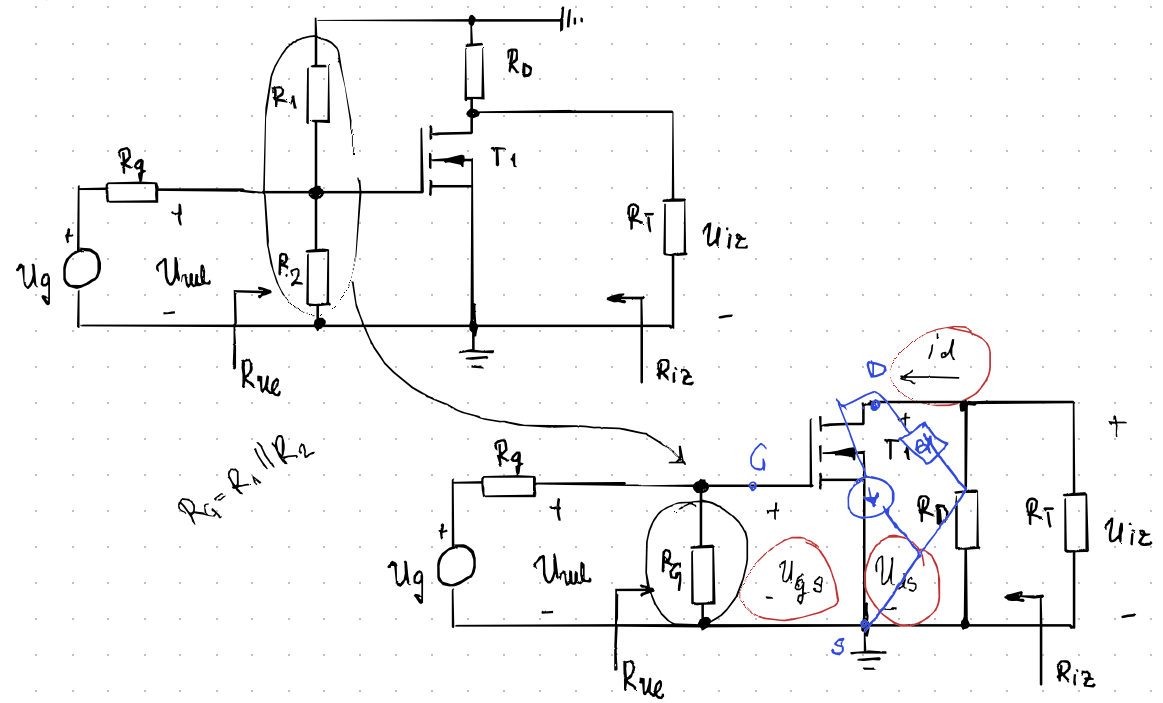
↳ trebamo dobiti statičku radnu točku SRT (U_{GSQ}, U_{DSQ}, I_{DQ}) ↑ u zasićenju
- izračunati dinamičke parametre (g_m, r_d, μ)



② Dinamika – gasimo istosmjerne izvore
- kratko spajamo $C \rightarrow Z_C \to 0$

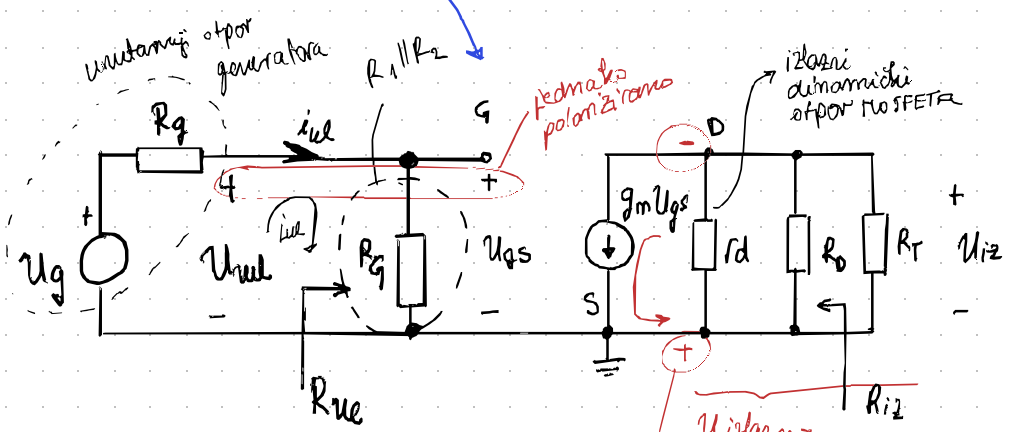
↳ izmjenični signal ne vidi R_S jer je u paralleli s C_S?

↳ A_V, R_{ue}, R_{iz} ....



Model za dinamičku analizu

T1 - nadomjesna shema



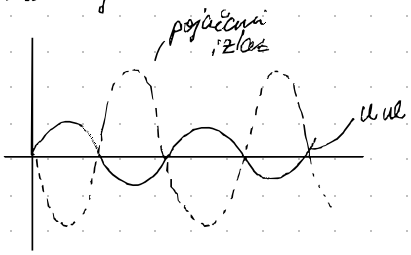
1) Naponsko pojačanje **Av**

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

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

$$U_{ul} = U_{gs}$$

$$A_V = \frac{U_{ul}}{U_{iz}} = -g_m (r_d \| R_D \| R_T)$$



obično jako velik

$$\Rightarrow A_V \approx -g_m (R_D \| R_T)$$

A_{Vg} = (naponsko pojačanje u odnosu na generator) $= \frac{U_{iz}}{U_g} = \frac{U_{iz}}{U_{ul}} \cdot \frac{U_{ul}}{U_g}$

$$A_{Vg} = -g_m (r_d \| R_D \| R_T) \cdot \frac{R_G}{R_g + R_G} \cdot \frac{1}{U_g}$$

$$A_{Vg} = -g_m (r_d \| R_D \| R_T) \cdot \frac{R_G}{R_g + R_G}$$

želimo da su gubici unutarnjeg otpora što manji ($R_g \ll R_G$)

$\hookrightarrow A_{Vg} \approx A_V$

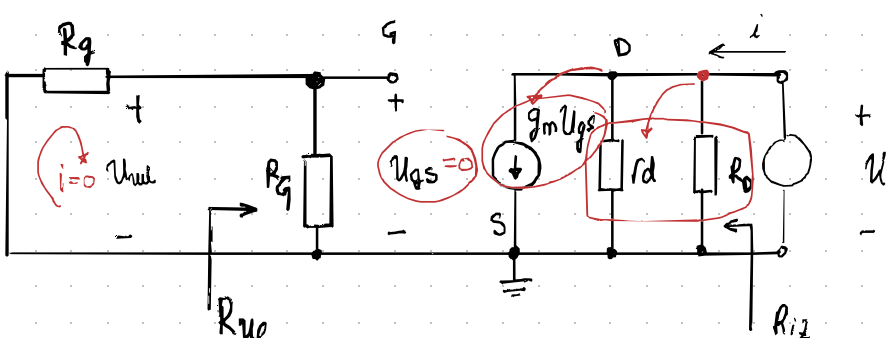
2) Ulazni otpor R_{ul}

$$R_{ul} = \frac{U_{ul}}{i_{ul}} = R_G$$

3) izlazni otpor R_{iz} (crtamo novu shemu)

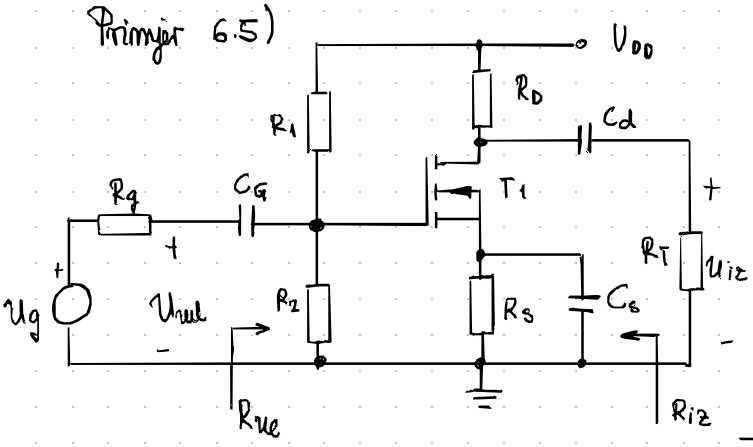
1) gasimo sve nezavisne izvore
2) odspojimo trošilo
3) spojimo naponski izvor U

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



$$i = g_m U_{gs} + \frac{U}{r_d \| R_D} \rightarrow R_{iz} = \frac{U}{i} \rightarrow \boxed{R_{iz} = r_d \| R_D}$$

Primjer 6.5)



$U_{DD} = 15V$ $\quad K = 2mA/V^2$

$R_g = 500\Omega$ $\quad U_{GSO} = 1V$

$R_1 = 5{,}8M\Omega$ $\quad \lambda = 5\times10^{-3}V^{-1}$

$R_2 = 1{,}7M\Omega$

$R_D = 4k\Omega$ $\quad A_V = \frac{u_{iz}}{u_{ul}} = ?$

$R_T = 6k\Omega$ $\quad A_{Vg} = \frac{u_{iz}}{u_g} = ?$

$R_S = 400\Omega$ $\quad R_{ul}, R_{iz} = ?$

n-kanalni

1) Statika

→ za ovaj zadatak već rješeno u 6.2.

$U_{GSQ} = 2{,}5V$ $\quad I_{DQ} = 2{,}25mA$ $\quad U_{DSQ} = 5{,}1V$

2) Dinamika u SRT

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

$g_m = 2\times10^{-3}(2{,}5-1)V\,(1+5\times10^{-3}\cdot 5{,}1V)$

$g_m = 3{,}08mA/V$

$\frac{1}{r_d} = \left.\frac{\partial i_D}{\partial u_{DS}}\right|_Q = \lambda\frac{K}{2}(U_{GSQ}-U_{GSO})^2 = \lambda I_{DQ} = 5\times10^{-3}\cdot 2{,}25\times10^{-3} = 11{,}3\mu S$

→ $r_d = 88{,}5\,k\Omega$

3) Dinamika SHEMA + izvod A_V, A_{Vg}, R_{ul}, R_{iz}

$A_V = -g_m(r_d \parallel R_D \parallel R_T) = -3.08mA\,(88{,}5 \parallel 4 \parallel 6) \approx -3{,}08\left(\frac{1}{4}+\frac{1}{6}\right)^{-1}$

$\boxed{A_V = -7.4}$

$R_{ul} = R_G = R_1 \parallel R_2 = 5{,}8 \parallel 1{,}7 = \boxed{1{,}32\,M\Omega}$

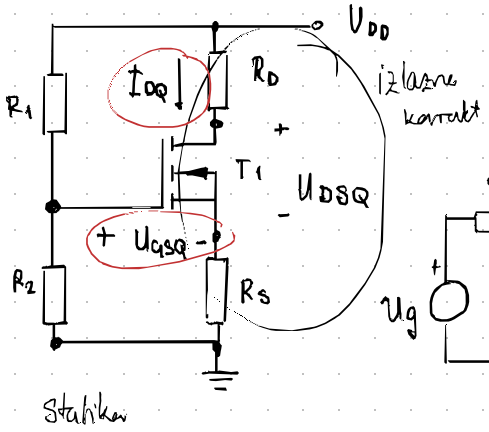
→ $A_{Vg} = A_V \cdot \frac{R_G}{R_g + R_G} \approx 1 \approx A_V$

$\boxed{A_{Vg} = -7.4}$

$R_{iz} = r_d \parallel R_D = 88{,}5 \parallel 4 = \boxed{3.83\,k\Omega}$

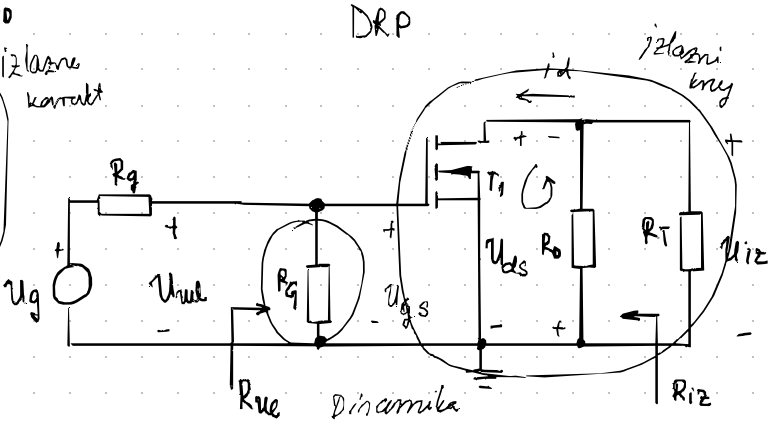
Primjer 6.6) Za pl. 6.5 ucrtati u polje izlaznih karakt MOSFETA statički i dinamički radni pravac

SRP



Statika

DRP



Dinamika

$U_{DS} = U_{DD} - I_D (R_S + R_D)$

$I_D = 0 \longrightarrow U_{DS} = U_{DD}$

$U_{DD} = 0 \longrightarrow I_D = \frac{U_{DD}}{R_S + R_D}$

statički radni pravac

$u_{ds} = -i_d (R_D \,//\, R_T)$

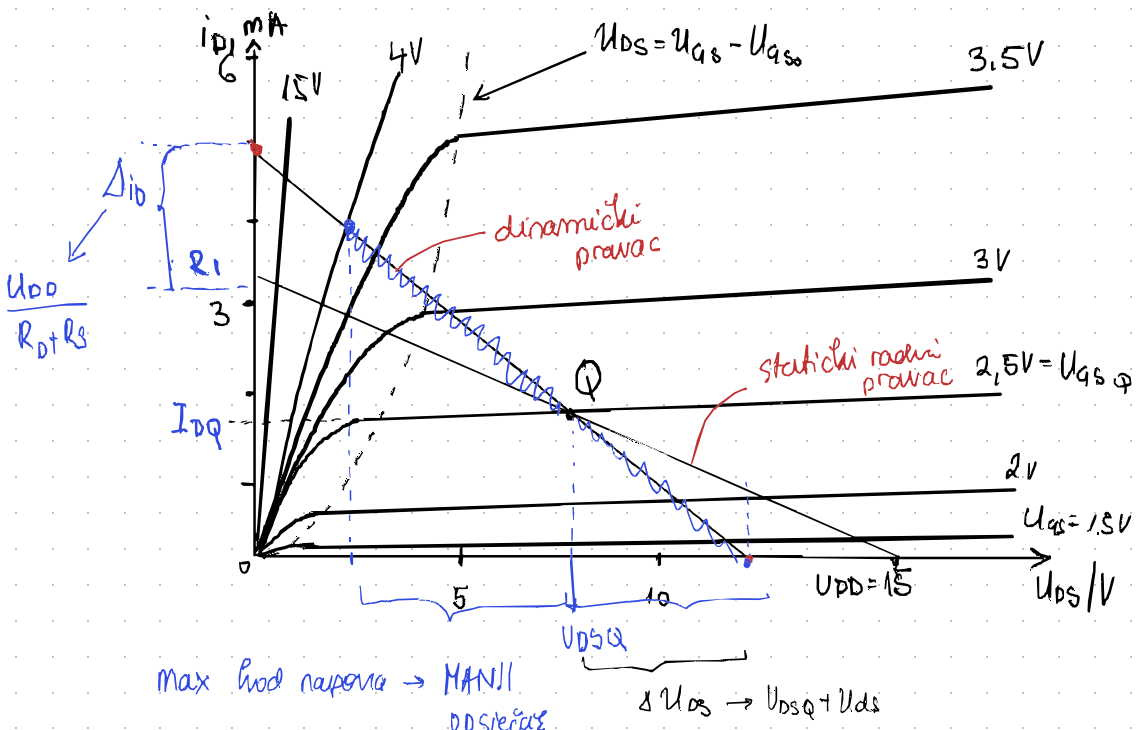
$U_{DS} - U_{DSQ} = -(i_D - I_{DQ})(R_D \,//\, R_T)$

$i_D = 0 \longrightarrow U_{DS} = I_{DQ}(R_D \,//\, R_T) + U_{DSQ}$

$U_{DS} = 0 \longrightarrow i_D = I_{DQ} + \frac{U_{DSQ}}{R_D \,//\, R_T}$

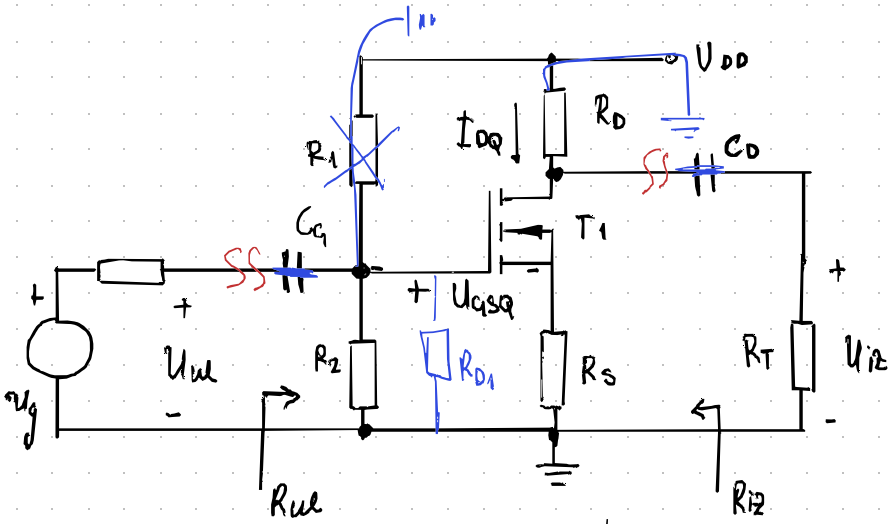
dinamički radni pravac

prijelaz je u statičkoj radnoj točki



Max hod napona → MANJI odsječak

Pojačalo u spoju zajedničkog uvoda s uvodnom degeneracijom

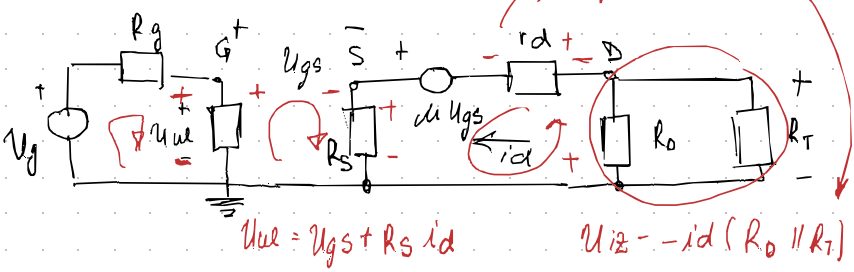


1) Statika

- gasimo kondenzatore

↳ nema paralelno spojenog C_S

2) Dinamika



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

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

$\mu u_{gs} = (R_S + r_d + R_D \parallel R_T)\, i_d$ $\qquad u_{gs} = U_{ul} - R_S i_d$

$\mu U_{ul} = [(1+\mu) R_S + r_d + R_D \parallel R_T]\, i_d$ $\qquad U_{iz} = -(R_D \parallel R_T) i_d$

$$A_V = \frac{U_{iz}}{U_{ul}} = \frac{-\mu (R_D \parallel R_T)}{(1+\mu) R_S + r_d + R_D \parallel R_T}$$

$r_d \gg R_D \parallel R_T$ i $\mu = g_m r_d$ →

$$A_V \approx \frac{-g_m (R_D \parallel R_T)}{1 + g_m R_S}$$

(veći broj - čvrsta degeneracija)

$g_m R_S \gg 1$

$$A_V = -\frac{R_D \parallel R_T}{R_S}$$

↳ puno stabilnije pojačalo na temperaturne promjene

→ uvodna degeneracija smanjuje iznos pojačanja ALI ga stabilizira!

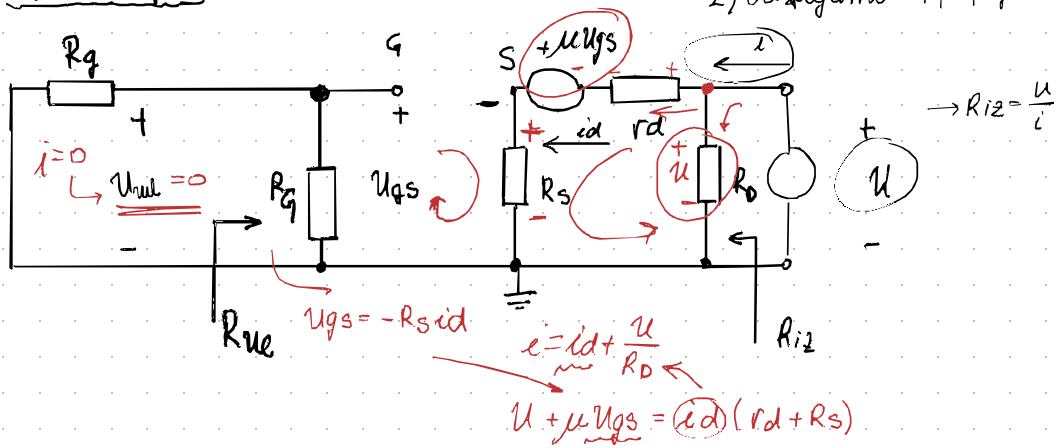
→ otpori imaju manju toleranciju od tranzistora

↳ na R manje utječe temperatura nego na T

Ulazni otpor: $R_{ul} = R_g$

Izlazni otpor:

1) gasimo nezavisne izvore
2) odspajamo R_T, spojimo U



$\Rightarrow U = \mu R_s i_d + i_d (r_d + R_s)$

$U = i_d (\mu R_s + r_d + R_s) = i_d \left[R_s (1+\mu) + r_d \right]$

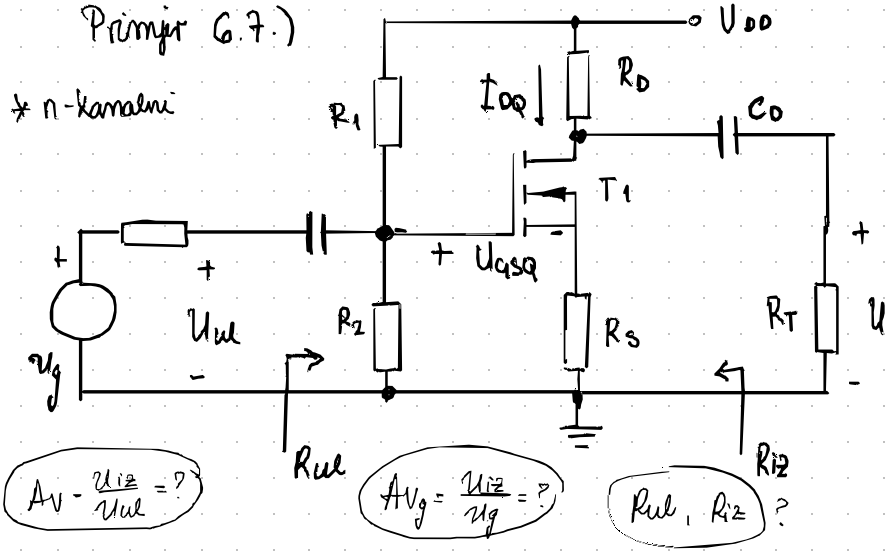
$U = \left(i - \frac{U}{R_D} \right) \left[R_s (1+\mu) + r_d \right]$

$$\Rightarrow i = \frac{U}{R_d} + \frac{U}{(1+\mu)R_s + r_d}$$

$$\Rightarrow R_{iz} = \frac{U}{i} = R_D \parallel \left[(1+\mu)R_s + r_d \right]$$

$\approx R_D$

Primjer 6.7.)



$U_{DD} = 15V$
$R_g = 500\Omega$
$R_1 = 5{,}8\,M\Omega$
$R_2 = 1{,}7\,M\Omega$
$R_D = 4k\Omega$
$R_T = 6k\Omega$
$R_S = 400\Omega$
$K = 2mA/V^2$
$U_{GSQ} = 1V$
$\lambda = 0{,}005/V$

$A_V = \frac{U_{iz}}{U_{ul}} = ?$ $\quad A_{Vg} = \frac{U_{iz}}{u_g} = ?$ $\quad R_{ul}, R_{iz}$?

1) Statiku imamo otprije (ista je) 6.2/6.5

2) Dinamički parametri u SRT (također isti)

$g_m = 3{,}08\,mA/V \qquad r_d = 88{,}5\,k\Omega$

trebamo μ → lakše nam je koristiti model MOSFETA s naponskim kaskadnim invertorom generacije

$\mu = g_m \cdot r_d = 3{,}08 \times 10^{-3} \cdot 88{,}5 \times 10^{3} = 273$

3) Shema i izvod jednadžbi (ali nećemo raditi)

$$A_V = \frac{U_{iz}}{U_{ul}} = \frac{-\mu (R_D \| R_T)}{(1+\mu)R_S + r_d + (R_D \| R_T)} = \frac{-273\,(4 \| 6)}{274 \cdot 0{,}4 + 88{,}5 + 4 \| 6} = -3.27$$

Bez degeneracije A_V nam je bio -7.4!

smanjeno ← stabilniji izraz

$$A_{Vg} = \frac{U_{iz}}{u_g} = \frac{U_{iz}}{U_{ul}} \cdot \frac{U_{ul}}{u_g} = A_V \cdot \frac{R_G}{R_g + R_G} \rightarrow A_{Vg} \approx A_V = -3.27$$

$R_{ul} = R_1 \| R_2 = R_G = 5{,}8 \| 1.7 = 1.32\,M\Omega$

$R_{iz} = R_D \| [(1+\mu)R_S + r_d] = 4 \| [274 \cdot 0{,}4 + 88.5] \rightarrow R_{iz} = 3.92\,k\Omega$

* Aproks. izraz za $A_V = \frac{-g_m (R_D \| R_T)}{1 + g_m \cdot R_S} = \dots = -3{,}31$ (mala razlika od -3.27)

* sa degeneracijom je stručnije