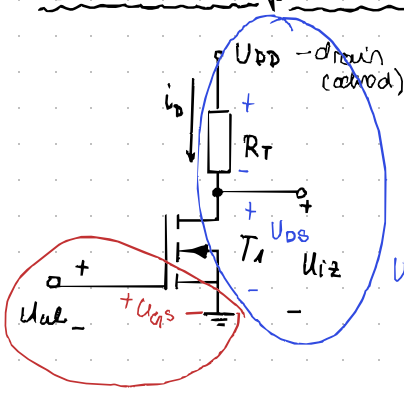
do 30.4.

6.1. PODEŠAVANJE RADNE TOČKE

Osnovni sklop MOSFET-a



Ulazni krug

$U_{ul} = U_{GS}$

Izlazni krug

$U_{iz} = U_{DS} = U_{DD} - R_T \cdot i_D$

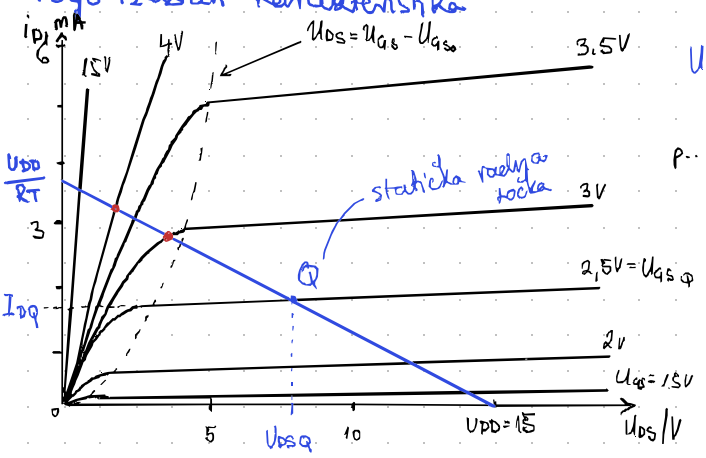
↳ ukupni signal (sadržava AC i DC dio signala)

$U_{DD} - R_T \cdot i_D - U_{DS} = 0$

$i_D = f(U_{DS}, U_{GS})$

izlazna karakteristika

Polje izlaznih karakteristika



$U_{DS} = U_{DD} - R_T i_D$ (pomoću odbijača)

p... $i_D = -\frac{1}{R_T} U_{DS} + \frac{U_{DD}}{R_T}$

Primjer:

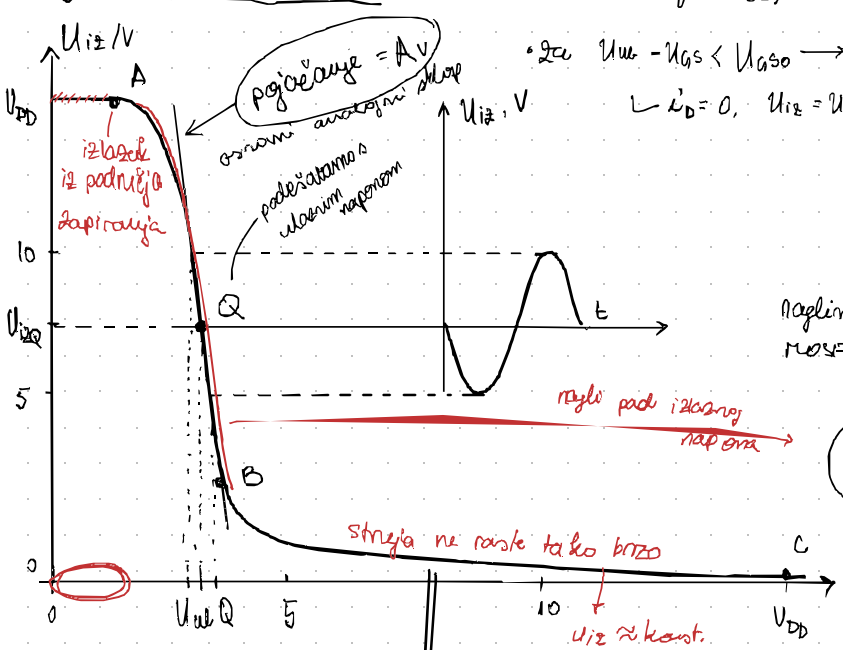
$U_{DD} = 15V$, $R_T = 4k\Omega$

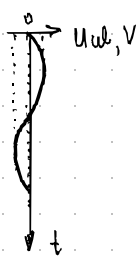
$U_{GSQ} = 2,5V$

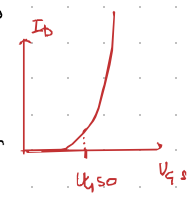
$I_{DQ} = 1,8mA$ $U_{DSQ} = 7,1V$

→ ovisno o U_{GS} → podešavanjem ulaznog napona radna točka može od TRI do ZAS

Prijenosna karakteristika – ovisnost izlaznog (U_{DS}) o ulaznom naponu (U_{GS})







• za $U_{ul} - U_{GS} < U_{GS0}$ → MOSFET NE vodi

↳ $i_D = 0$, $U_{iz} = U_{DS} = U_{DD}$

naglim porastom struje kroz MOSFET → nagli pad napona na R_T!

$U_{DS} = U_{DD} - R_T \cdot i_D$

ako ulaz naglo mijenjamo iz visoke razine u nisku → izlaz obrnuti

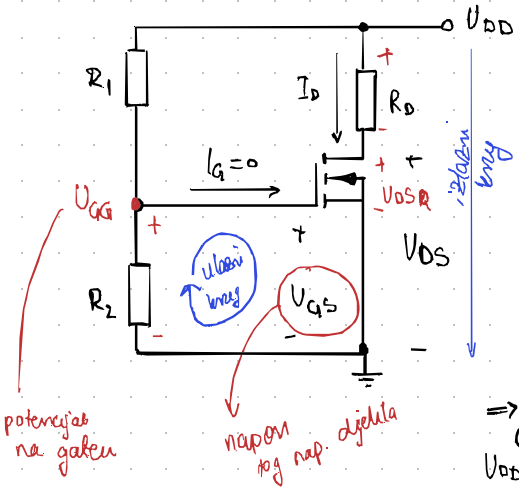
(visoka razina na izlazu za nisku na ulazu,
niska razina na izlazu za visoku na ulazu

→ SKLOPKA (inverter) (osnovni dig. sklop)

Primjer: $U_{ulQ} = 2,5V$ $U_{izQ} = 7,7V$

$$A_V = \frac{U_{iz}}{U_{ul}} = \frac{-U_{izm} \cdot \sin\omega t}{U_{ulm} \sin\omega t} = -\frac{U_{izm}}{U_{ulm}} = -\frac{2,27}{0,25} = -9,1$$

Podešavanje fiksnog napona U_{GSQ}



U_{GG} - preko naponskog djelila između R_1 i R_2

$$\Rightarrow U_{GG} = U_{GSQ} = \frac{R_2}{R_1 + R_2} U_{DD}$$ fiksan potencijal na gateu

→ da bi bilo u zasićenju mora vrijediti:

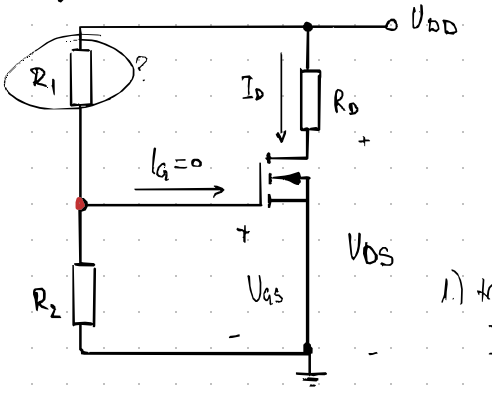
$$I_{DQ} = \frac{K}{2}(U_{GSQ} - U_{GSO})^2$$

⇒ jednadžba izlaznog strujnog kruga

$$U_{DD} = R_D \cdot I_{DQ} + U_{DSQ} \Rightarrow U_{DSQ} = U_{DD} - R_D \cdot I_{DQ}$$

! dobro je provjeriti vrijedi li uvjet zasićenja $U_{DSQ} \geq U_{GSQ} - U_{GSO}$

Primjer 6.1) n-kanalni MOSFET



$U_{DD} = 15V$ napon napajanja

$R_D = 4{,}5k\Omega$ $R_2 = 1M\Omega$ $K = 1{,}5\,mA/V^2$

$U_{GSO} = 1V$

$R_1 = ?$ za podešavanje stat. struje $I_{DQ} = 2mA$

Je li Q u području zasićenja?

1.) tranzistor mora biti u zasićenju

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

$$\rightarrow U_{GSQ} = U_{GSO} \pm \sqrt{\frac{2I_{DQ}}{K}} = 1 \pm \sqrt{\frac{2 \cdot 2 \times 10^{-3}}{1{,}5 \times 10^{-3}}}$$

$$U_{GSQ} = 1 \pm 1.63$$

$U_{GSQ_1} = 2.63\ V$ $U_{GSQ_2} = -0.63V$

→ napon praga je 1V → Fizikalno ispravno nj. $U_{GSQ} > U_{GSO}$

$$U_{GSQ} = \frac{R_2}{R_1 + R_2} \cdot U_{DD} \rightarrow R_1 = \frac{U_{DD} - U_{GSQ}}{U_{GSQ}} R_2 = \frac{15 - 2{,}63}{2{,}63} \cdot 10^5$$

$$R_1 = 4.7M\Omega$$

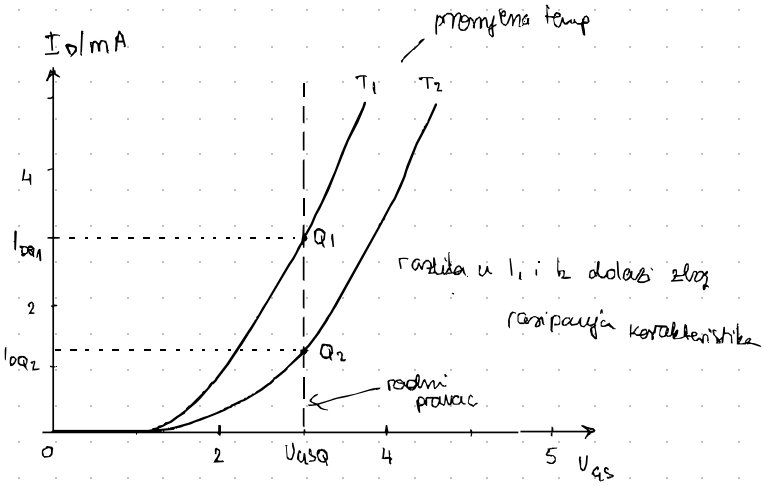
Je li točka Q u zasićenju? → $U_{DSQ} \geq U_{GSQ} - U_{GSO}$

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

$U_{DSQ} = 15 - 4{,}5 \times 10^3 \cdot 2 \times 10^{-3} \rightarrow U_{DSQ} = 6V \geq 2{,}63 - 1\ V$ Da, u zasićenju je

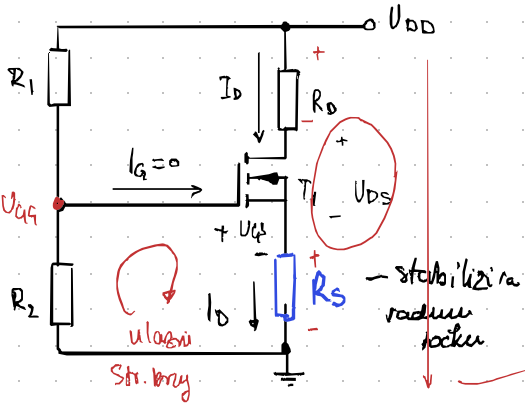
Nedostatci sklopa za podešavanje fiksnog napona U_{GSQ}

- osjetljivost na promjenu karakteristike MOSFETA



razlika u I_1 i I_2 dolazi zbog raspršenja karakteristika

Podešavanje radne točke primjenom uvodske degeneracije



– stabilizira radnu točku

$$U_{GG} = \frac{R_2}{R_1+R_2} \cdot U_{DD}$$

$$U_{GG} = U_{GS} + R_S I_D$$

} jed. ulaznog strujnog kruga

jednadžba MOSFETA u zasićenju

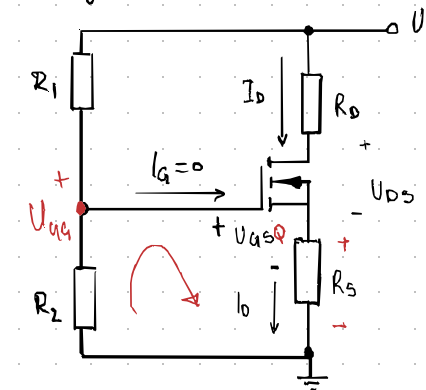
$$I_D = \frac{K}{2}(U_{GS} - U_{GSO})^2$$

jednadžba izlaznog strujnog kruga

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

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

Primjer 6.2)



$U_{DD} = 15V$ n-kanalni

$R_D = 4000\,\Omega$ $R_S = 400\,\Omega$ $R_1 = 5.8 \times 10^6\,\Omega$

$R_2 = 1{,}7 \times 10^6\,\Omega$

$K = 2\,mA/V^2$ $U_{GSO} = 1V$

$I_{DQ} = ?$ $U_{GSQ} = ?$ je li Q u zasićenju

$$U_{GG} = U_{GSQ} + R_S I_{DQ}$$

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

$$U_{GG} = \frac{R_2}{R_1+R_2} \cdot U_{DD}$$

$$\frac{R_2}{R_1+R_2} \cdot U_{DD} = U_{GSQ} + R_S \cdot \frac{K}{2}(U_{GSQ} - U_{GSO})^2$$

$U_{GSQ} =$ { 2,5V / −3V } $> U_{GSO}$

$$\Rightarrow I_{DQ} = 10^{-3} \cdot (2{,}5-1)^2 = 2{,}25\,mA$$

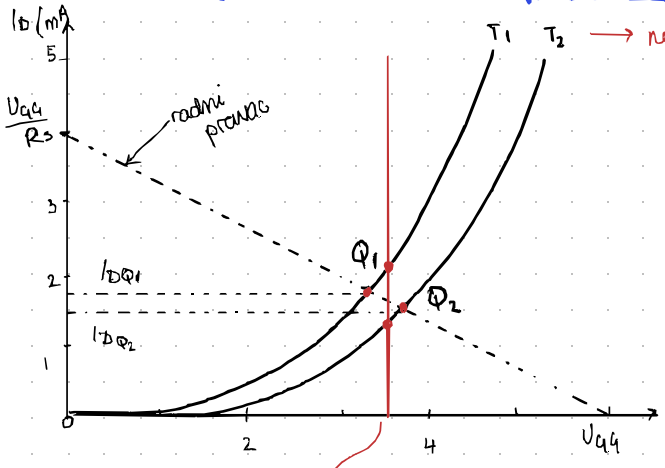
Je li Q u zasićenju?

$$U_{DSQ} = U_{DD} - I_{DQ}(R_S + R_D) \rightarrow U_{DSQ} = 15 - 2{,}25 \times 10^{-3}(400+4000)$$

$$U_{DSQ} = 5{,}1V$$

UVJET: $U_{DSQ} \geq U_{GSQ} - U_{GSO}$ $5.1 \geq 1.5$ ✓

Stabilizacija radne točke primjenom UNDSke degeneracije



→ nominalno isti tranz., ali rasipanje snižava mijenjaju se karakteristike

$U_{GG} = U_{GSQ} + R_S I_{DQ}$

$I_{DQ} = \left(-\frac{1}{R_S}\right) U_{GSQ} + \frac{U_{GG}}{R_S}$

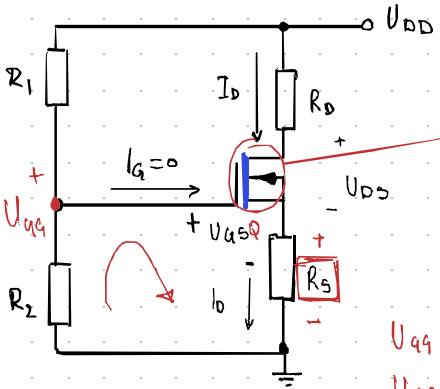
opadajući pravac

↳ ovisimo o U_{GG} i R_S → položaj pravca

U_{GSQ} ~~nije~~ više fiksan

→ manje razlike među strujama (bliske su)

Primjer 6.3.)



osiromašeni n-kanalni MOSFET

$U_{DD} = 15V$

$R_D = 3000\,\Omega$ $\quad K = 1{,}25 \times 10^{-3}\,A/V^2$

$R_1 = 9 \times 10^6\,\Omega$ $\quad U_{GSO} = -3V$

$R_2 = 10^6\,\Omega$ $\quad U_{GSQ} = -1V$

$R_S = ?$

$U_{GG} = U_{GSQ} + R_S I_{DQ}$

$U_{GSQ} = U_{GG} - R_S I_{DQ}$

ovdje taj sklop možemo koristiti i za osiromašeni MOSFET

$U_{GG} = U_{GSQ} + R_S \cdot I_{DQ}$?

↳ $U_{GSQ} = -1V$

$U_{GG} = U_{DD} \cdot \frac{R_2}{R_1 + R_2}$ → $U_{GG} = 1.5V$

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

$I_{DQ} = \frac{1{,}25 \times 10^{-3}}{2}(-1+3)^2$

$I_{DQ} = 2{,}5mA$

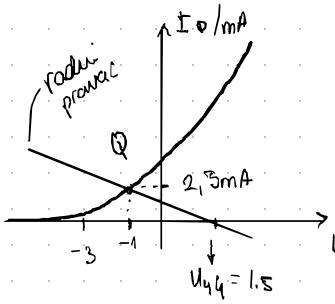
$\Rightarrow R_S = \frac{U_{GG} - U_{GSQ}}{I_{DQ}}$ → $R_S = \frac{1.5 + 1}{2.5 \times 10^{-3}}$ → $R_S = 1\,k\Omega$

$U_{DSQ} = ?$ da proširimo uvjet zasićenja → $U_{DSQ} = U_{DD} - I_{DQ}(R_S + R_D)$

$U_{DSQ} = 15 - 2{,}5 \times 10^{-3}(1 \times 10^3 + 3 \times 10^3)$

$U_{DSQ} = 5V$

$U_{DSQ} \geq U_{GSQ} - U_{GSO}$ → $5 \geq -1+3$ u zasićenju → može se koristiti i za osiromašeni mosfet



n-kanalni osiromašeni

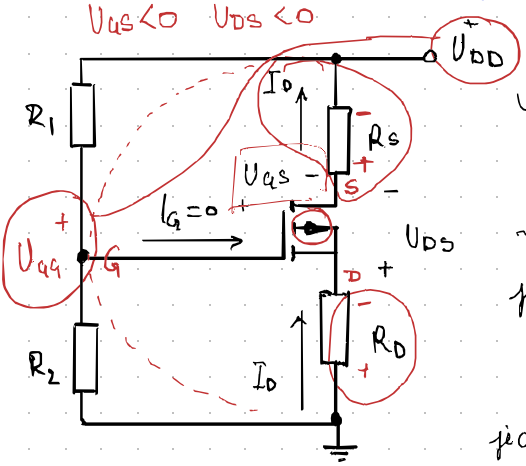
↳ $U_{GSO} < 0$

$U_{GG} = U_{GSQ} + R_S \cdot I_{DQ}$

$I_D = \frac{-1}{R_S} U_{GS} + \frac{U_{GG}}{R_S}$

Podešavanje radne točke pojačala s p-kanalnim MOSFET-om

$U_{GS} < 0 \quad U_{DS} < 0$



jednadžba ulaznog strujnog kruga

$$U_{GG} = \frac{R_2}{R_1 + R_2} U_{DD}$$

$$U_{GG} - U_{GSQ} - R_S I_{DQ} = U_{DD}$$

jednadžba MOSFET-a u zasićenju

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

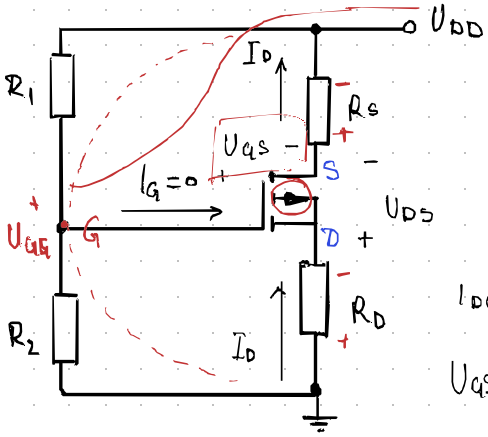
! $K < 0$ za p-kanal

jednadžba izlaznog strujnog kruga

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

Uvjet zasićenja: $U_{DSQ} \leq U_{GSQ} - U_{GSO}$

Primjer 6.4)



$U_{DD} = 15\,V$ p-kanalni!

$R_S = 500\,\Omega$

$R_D = 4000\,\Omega$

$R_2 = 4 \times 10^6\,\Omega$

$K = -1\,mA/V^2$

$U_{GSO} = -2\,V$

$R_1 = ?$

$I_{DQ} = -2\,mA$

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

$$U_{GSQ} = U_{GSO} \pm \sqrt{\frac{2 I_{DQ}}{K}} = -2 \pm \sqrt{\frac{2 \cdot 2\,mA}{1\,mA}}$$

$$U_{GSQ} = -2 \pm 2 \begin{cases} 0\,V \\ -4\,V \end{cases} \rightarrow U_{GSQ} < U_{GSO} \text{ (p-kanal)}$$

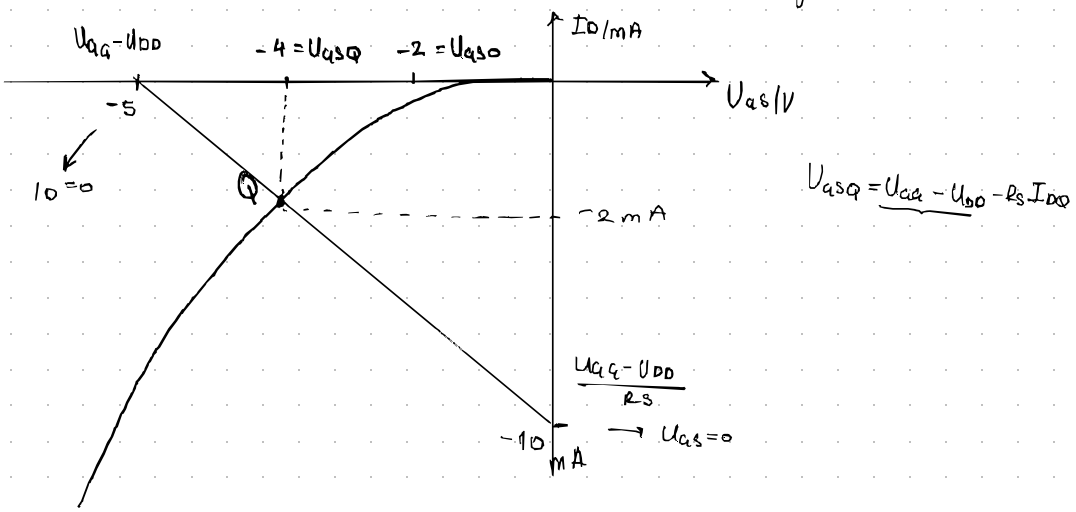
$$U_{GG} = U_{DD} + U_{GSQ} + R_S I_{DQ}$$

$$U_{GG} = 15 + (-4) + 500 \cdot (-2) \times 10^{-3} \rightarrow U_{GG} = 10\,V \rightarrow U_{GG} = \frac{R_2}{R_1 + R_2} U_{DD}$$

$$\rightarrow R_1 = 2 \times 10^6\,\Omega$$

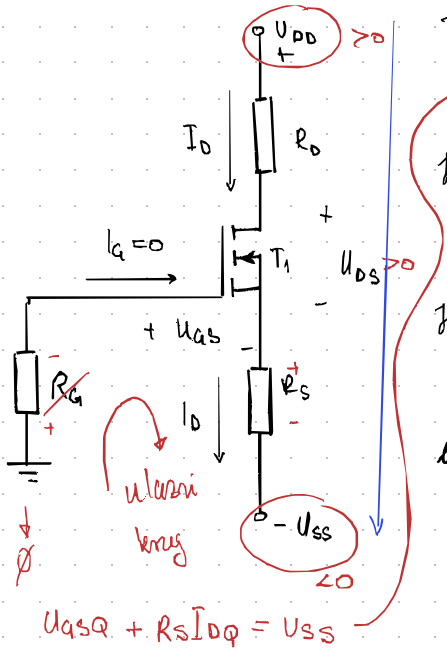
$$U_{DSQ} = -U_{DD} - I_{DQ}(R_S + R_D) = -6\,V$$

$U_{DSQ} \leq U_{GSQ} - U_{GSO} \rightarrow -6 \leq -4 + 2 = -2\,V$ zasićenje



$$U_{GSQ} = U_{GG} - U_{DD} - R_S I_{DQ}$$

Podešavanje radne točke o dva napona napajanja



$U_{GSQ} + R_S I_{DQ} = U_{SS}$

jednadžba ulaznog strujnog kruga

$U_{SS} = U_{GS} + R_S I_D$

jednadžba MOSFETA u zasićenju

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

jednadžba izlaznog strujnog kruga

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

uvjet zasićenja: $U_{DSQ} \geq U_{GSQ} - U_{GSO}$

izlazni krug — U_{DD} i U_{SS} su jednako usmjereni

$U_{DD} + U_{SS} = R_D I_D + R_S I_D + U_{DS}$

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

poprima puno veće iznose (ali ramu treba veći hod)