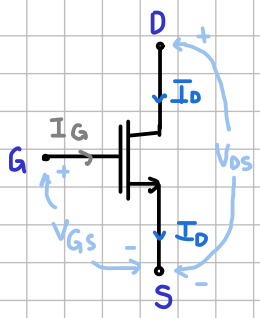
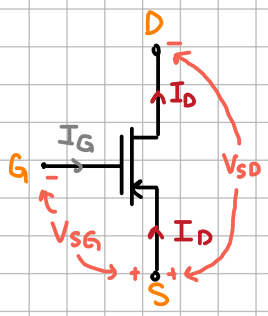
DC анализа кола са MOS транзисторима



NMOS



PMOS

Tip/Režim	Zakočenje	Zasićenje	Triodna oblast	Omska oblast
NMOS	$V_{GS} < V_{TH}$ $I_D = 0\text{A}$	$V_{GS} > V_{TH}$ $V_{DS} > V_{GS} - V_{TH}$ $I_D = A\,(V_{GS} - V_{TH})^2$	$V_{GS} > V_{TH}$ $V_{DS} < V_{GS} - V_{TH}$ $I_D = A\,(2\,(V_{GS} - V_{TH}) \cdot V_{DS} - V_{DS}^2)$	$V_{GS} > V_{TH}$ $V_{DS} \ll 2\,(V_{GS} - V_{TH})$ $I_D = 2A\,(V_{GS} - V_{TH}) \cdot V_{DS}$
PMOS	$V_{SG} < \lvert V_{TH}\rvert$ $I_D = 0\text{A}$	$V_{SG} > \lvert V_{TH}\rvert$ $V_{SD} > V_{SG} - \lvert V_{TH}\rvert$ $I_D = A\,(V_{SG} - \lvert V_{TH}\rvert)^2$	$V_{SG} > \lvert V_{TH}\rvert$ $V_{SD} < V_{SG} - \lvert V_{TH}\rvert$ $I_D = A\,(2\,(V_{SG} - \lvert V_{TH}\rvert) \cdot V_{SD} - V_{SD}^2)$	$V_{SG} > \lvert V_{TH}\rvert$ $V_{SD} \ll 2\,(V_{SG} - \lvert V_{TH}\rvert)$ $I_D = 2A\,(V_{SG} - \lvert V_{TH}\rvert) \cdot V_{SD}$

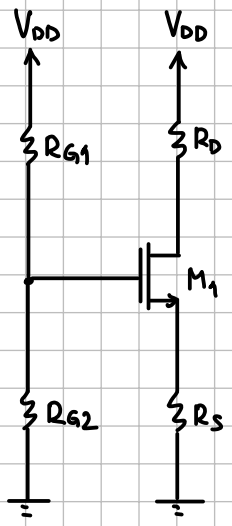
За наше потребе, сматраћемо да MOS увек ради у области засићења

$|V_{TH}|$ — напон прага провођења (threshold voltage)

$A = \frac{1}{2}\mu_{n/p} C_{ox}' \cdot \frac{W}{L}$ $\left[\frac{A}{V^2}\right]$ - фактор појачања струје (процесни параметри)

увек важи: $I_G \approx 0$

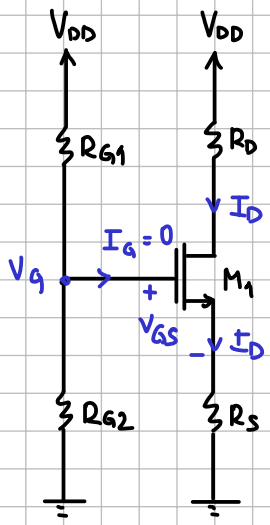
1. У датом колу, одредити вредност напона између гејта и сорса (V_{GS}) и једносмерне струје дрејна (I_D). Познати су следећи подаци:



$V_{DD} = 12V$

$R_{G1} = 1M\Omega = 10^6\Omega$
$R_{G2} = 500k\Omega = 5 \cdot 10^5\Omega$
$R_D = 4k\Omega$
$R_S = 2.5k\Omega$

$A = 0,5 \frac{mA}{V^2}$
$V_{TH} = 1V$



$I_D = ?$ $V_{GS} = ?$

$I_D = A \cdot (V_{GS} - V_{TH})^2$

$I_G = 0 \Rightarrow V_G = \frac{R_{G2}}{R_{G2} + R_{G1}} \cdot V_{DD} = \frac{5 \cdot 10^5}{5 \cdot 10^5 + 10^6} \cdot 12V = \frac{5}{5+10} \cdot 12V$

$V_G = 4V$

$V_G - V_{GS} - R_S \cdot I_D = 0$

$V_G - V_{GS} - R_S \cdot A \cdot (V_{GS} - V_{TH})^2 = 0$

$V_{ov} = V_{GS} - V_{TH}$ - "overdrive voltage"

$V_{GS} = V_{ov} + V_{TH}$

$V_G - V_{ov} - V_{TH} - R_S \cdot A \cdot V_{ov}^2 = 0 \quad / \cdot (-1)$

$AR_S \cdot V_{ov}^2 + V_{ov} - V_G + V_{TH} = 0 \Rightarrow V_{ov} = ?$

$V_{ov} = \frac{-1 \pm \sqrt{1 - 4 \cdot (-V_G + V_{TH}) \cdot AR_S}}{2AR_S}$

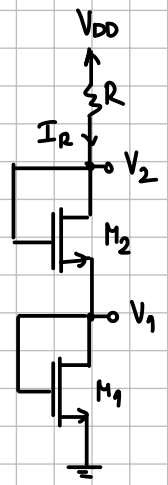
$V_{GS} > V_{TH} \Leftrightarrow V_{ov} > 0$
$\Rightarrow$ бирамо "+"

$V_{ov} = \frac{-1 + \sqrt{1 - 4 \cdot (-3) \cdot 0,5 \cdot 2.5}}{2 \cdot 0,5 \cdot 2.5} V = \frac{-1 + \sqrt{16}}{2.5} V = 1.2V$

$V_{GS} = V_{ov} + V_{TH} = 2.2V$

$I_D = A \cdot V_{ov}^2 = 0.72\ mA = 720\ \mu A$

2. У датом колу одредити вредност струје кроз отпорник, као и напоне V_1 и V_2.

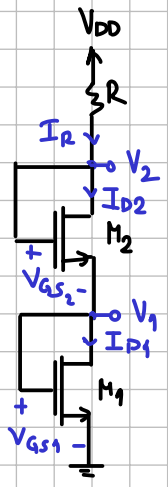


$V_{DD} = 3.3\,V$

$R = 3.2\,k\Omega$

$A_1 = 2\,\frac{mA}{V^2} \qquad A_2 = 500\,\frac{\mu A}{V^2}$

$V_{TH_1} = V_{TH_2} = 0.4\,V$



$V_{TH} = V_{TH_1} = V_{TH_2} \qquad I_R = ?$

$V_{ov_1} = V_{GS_1} - V_{TH} \qquad V_1 = ?$

$V_{ov_2} = V_{GS_2} - V_{TH} \qquad V_2 = ?$

$I_R = I_{D1} = I_{D2} \Rightarrow A_1 \cdot V_{ov_1}^2 = A_2 \cdot V_{ov_2}^2 \Rightarrow \left(\frac{V_{ov1}}{V_{ov2}}\right)^2 = \frac{A_2}{A_1}$

$\left(\frac{V_{ov1}}{V_{ov2}}\right)^2 = \frac{A_2}{A_1} = \frac{500 \cdot 10^{-6}}{2 \cdot 10^{-3}} = \frac{0.5 \cdot \cancel{10^{-3}}}{2 \cdot \cancel{10^{-3}}} = \frac{1}{4} \Rightarrow \boxed{V_{ov_2} = 2V_{ov_1}}$

$V_{DD} = R \cdot I_R + V_{GS2} + V_{GS1}$

$= R \cdot A_1 \cdot V_{ov_1}^2 + \underbrace{V_{ov_2}}_{=2V_{ov1}} + V_{TH} + V_{ov_1} + V_{TH}$

$= R \cdot A_1 \cdot V_{ov_1}^2 + 3V_{ov_1} + 2V_{TH}$

$\Rightarrow \quad A_1 R\, V_{ov_1}^2 + 3V_{ov_1} + 2V_{TH} - V_{DD} = 0$

$$\boxed{V_{ov_1} = \frac{-3 + \sqrt{9 - 4 \cdot A_1 R \cdot (2V_{TH} - V_{DD})}}{2A_1 R} = \frac{-3 + \sqrt{73}}{12.8}\,V \approx 0.433\,V}$$

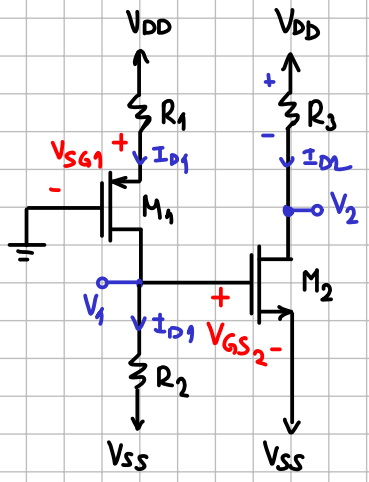
$\boxed{V_{ov_2} = 0.866\,V}$

$\boxed{I_R = A_1 \cdot V_{ov_1}^2 = 0.375\,mA}$

$\boxed{V_1 = V_{GS_1} = V_{ov_1} + V_{TH} = 0.833\,V}$

$\boxed{V_2 = V_{DD} - R \cdot I_R = 3.3\,V - 3.2k\Omega \cdot 0.375\,mA = 2.1\,V}$

3. Одредити струје дрејнова оба транзистора, као и напоне V_1 и V_2



$V_{DD} = -V_{SS} = 2{,}5V$

$R_1 = 15\,k\Omega \quad R_2 = 25\,k\Omega \quad R_3 = 6.4\,k\Omega$

$A_1 = A_2 = 125\,\frac{\mu A}{V^2} = 0.125\,\frac{mA}{V^2}$

$|V_{TH1}| = V_{TH2} = 0.5\,V$

$V_1 = ? \quad V_2 = ? \quad I_{D1} = ? \quad I_{D2} = ?$

$V_{DD} = R_1 \cdot I_{D1} + V_{SG1} \qquad V_{OV1} = V_{SG1} - |V_{TH1}|$

$= R_1 \cdot A_1 \cdot (V_{SG1} - |V_{TH1}|)^2 + V_{SG1}$

$A_1 R_1 \cdot V_{OV1}^2 + V_{OV1} + |V_{TH1}| - V_{DD} = 0$

$1{,}875\,V^{-1} \cdot V_{OV1}^2 + V_{OV1} - 2V = 0$

$$V_{OV1} = \frac{-1 + \sqrt{1 - 4 \cdot 1{,}875\,V^{-1} \cdot (-2)\,V}}{2 \cdot 1{,}875\,V^{-1}} = 0.8V$$

$I_{D1} = A_1 \cdot V_{OV1}^2 = 0.08\,mA = 80\,\mu A$

$I_{D1} = \frac{V_1 - V_{SS}}{R_2}$

$R_2 \cdot I_{D1} = V_1 - V_{SS}$

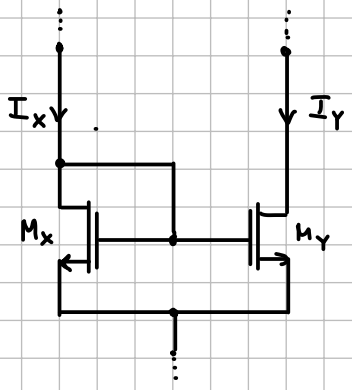
$V_1 = R_2 \cdot I_{D1} + V_{SS}$

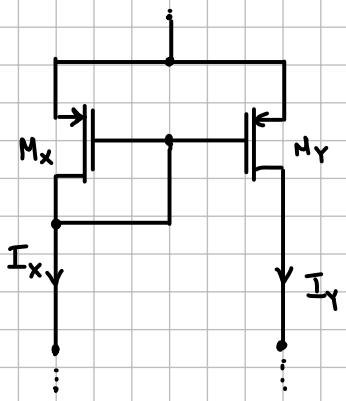
$\Rightarrow V_1 = -0.5\,V$

$V_{GS2} = V_1 - V_{SS} = 2V \Rightarrow I_{D2} = A_2 (V_{GS2} - V_{TH})^2 = 281.25\,\mu A$

$V_2 = V_{DD} - R_3 \cdot I_{D2} = 2.5V - 6.4k\Omega \cdot 281.25\,\mu A = 0.7\,V$

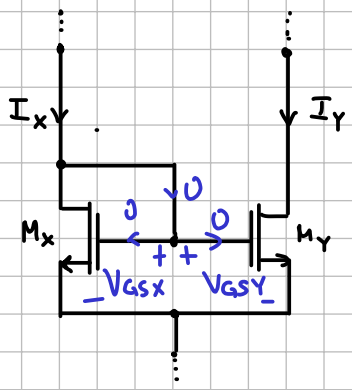
4. У датом колу (MOS струјно огледало) одредити однос струја I_Y и I_X уколико су познати коефицијенти струјног појачања оба транзистора, док су њихови напони прага провођења једнаки.





A_X, A_Y, $|V_{THX}| = |V_{THY}|$

$$\frac{I_Y}{I_X} = ?$$



$V_{GSX} = V_{GSY}$

$$I_X = A_X (V_{GSX} - V_{THX})^2$$

$$I_Y = A_Y (V_{GSY} - V_{THY})^2$$

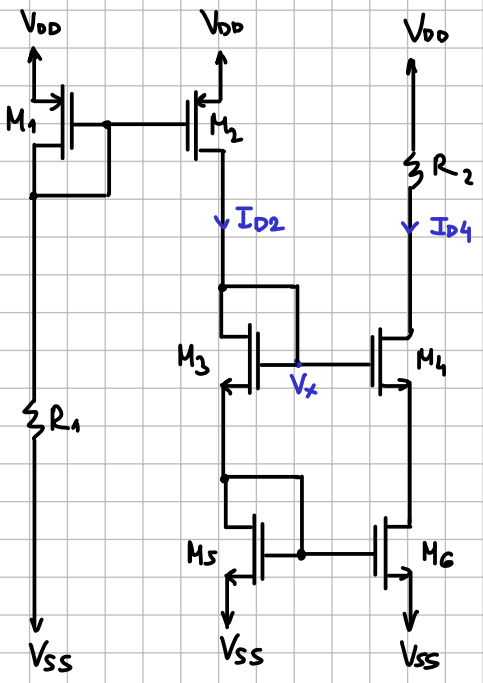
$$\frac{I_Y}{I_X} = \frac{A_Y (V_{GSY} - V_{THY})^2}{A_X (V_{GSX} - V_{THX})^2} = \frac{A_Y}{A_X}$$

$V_{GSX} = V_{GSY}$
$V_{THX} = V_{THY}$

ако важи: $V_{THX} = V_{THY}$
$G\text{-}S_X \parallel G\text{-}S_Y$

$$\boxed{\frac{I_Y}{I_X} = \frac{A_Y}{A_X}}$$

5. У датом колу, одредити вредности струја дрејна транзистора M2 и M4, као и напона гејта транзистора M3.



$R_1 = 100\,k\Omega$ $\quad V_{DD} = -V_{SS} = 5\,V$

$R_2 = 10\,k\Omega$

$V_{THn} = 0.4\,V$ $\quad V_{THp} = -0.3\,V$

$A_1 = A_2 = A_6 = 400\,\mu A/V^2$

$A_3 = 50\,\mu A/V^2$

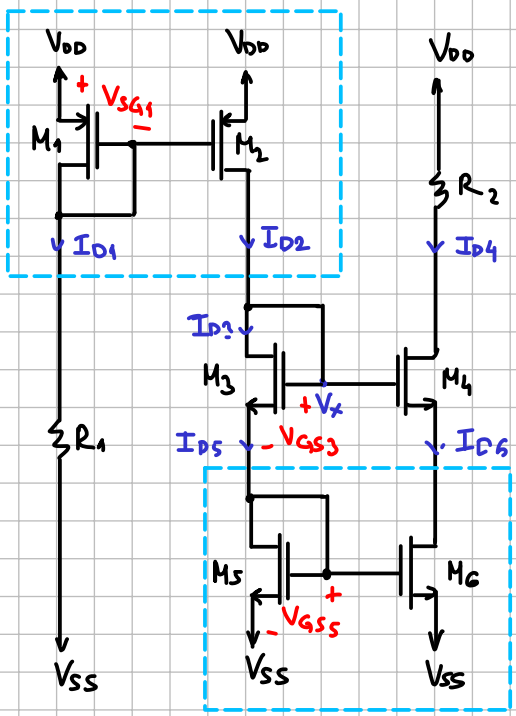
$A_4 = 200\,\mu A/V^2$

$A_5 = 100\,\mu A/V^2$

$I_{D2} = ?$

$I_{D4} = ?$

$V_x = ?$



а) $I_{D2} = ?$

Струјно огледало M1 - M2:

$$\frac{I_{D2}}{I_{D1}} = \frac{A_2}{A_1} = 1 \Rightarrow I_{D2} = I_{D1}$$

$$V_{DD} - V_{SS} = R_1 \cdot I_{D1} + V_{SG1}$$

$$2V_{DD} = R_1 \cdot A_1 \cdot V_{ov1}^2 + V_{ov1} + V_{TH1}$$

$$V_{ov1} = \frac{-1 + \sqrt{1 - 4 \cdot A_1 \cdot R_1 \cdot (V_{TH1} - 2V_{DD})}}{2A_1R_1} = 0.48\,V$$

$$\Rightarrow \boxed{I_{D2} = I_{D1} = A_1 V_{ov1}^2 \approx 92{,}16\,\mu A}$$

б) $I_{D4} = ?$

$I_{D4} = I_{D6}$

Струјно огледало M5 - M6:

$$\frac{I_{D6}}{I_{D5}} = \frac{A_6}{A_5} = 4$$

$I_{D6} = 4 I_{D5}$

$I_{D5} = I_{D3} = I_{D2}$

$$\Rightarrow \boxed{I_{D4} = I_{D6} = 4\,I_{D5} = 4\,I_{D2} = 368{,}64\,\mu A}$$

г) $V_x = ?$

$V_x - V_{SS} = V_{GS5} + V_{GS3}$

$$I_D = A(V_{GS} - V_{TH})^2 \Leftrightarrow V_{GS} = V_{TH} + \sqrt{\frac{I_D}{A}}$$

$$V_x = V_{SS} + V_{GS5} + V_{GS3}$$

$$= -V_{DD} + V_{THS} + \sqrt{\frac{I_{D5}}{A_5}} + V_{TH3} + \sqrt{\frac{I_{D3}}{A_3}}$$

$$= -V_{DD} + 2V_{THn} + \sqrt{\frac{I_{D2}}{A_5}} + \sqrt{\frac{I_{D2}}{A_3}}$$

$$\Rightarrow \boxed{V_x \approx -1.88\,V}$$