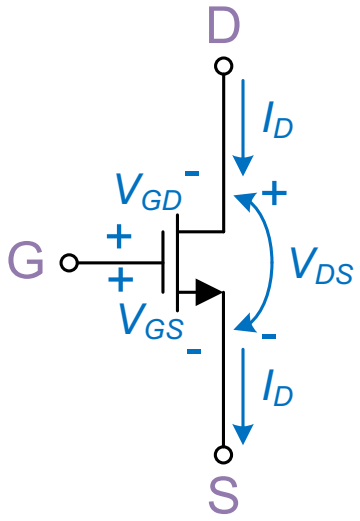
VJEŽBE 4

OSNOVE ELEKTRONIKE, ETR, IV SEMESTAR

DOC. DR MILENA ERCEG

UVOD



1° **MOSFET ne provodi**

$$V_{GS} < V_t, V_t > 0$$

$$I_D = 0$$

2° **MOSFET provodi**

a) omski režim

$$V_{GD} > V_t > 0$$

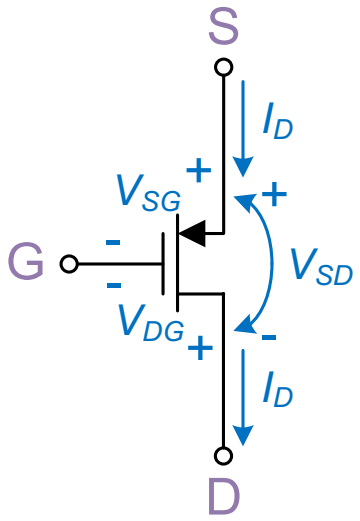
$$I_D = \beta \left[(V_{GS} - V_t) V_{DS} - \frac{V_{DS}^2}{2} \right]$$

b) zasićenje

$$V_{GD} < V_t, V_t > 0$$

$$I_D = \frac{1}{2} \beta (V_{GS} - V_t)^2 (1 + \lambda V_{DS})$$

UVOD



1° **MOSFET ne provodi**

$$V_{SG} < -V_t, V_t < 0$$

$$I_D = 0$$

2° **MOSFET provodi**

a) omski režim

$$V_{DG} > -V_t, V_t < 0$$

$$I_D = \beta \left[(V_{SG} + V_t) V_{SD} - \frac{V_{SD}^2}{2} \right]$$

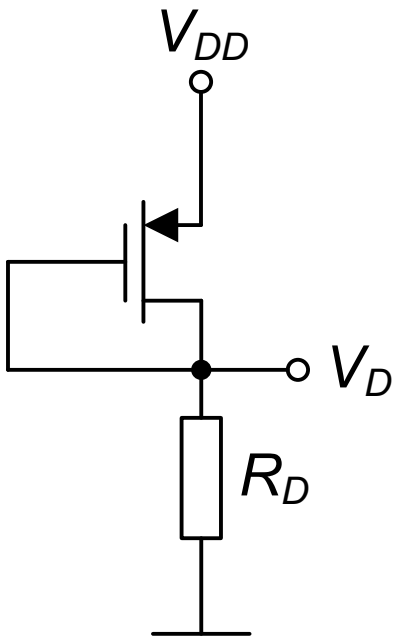
b) zasićenje

$$V_{DG} < -V_t, V_t < 0$$

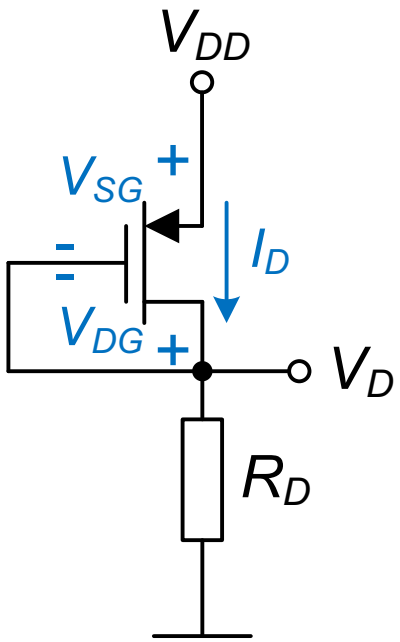
$$I_D = \frac{1}{2} \beta (V_{SG} + V_t)^2 (1 + \lambda V_{SD})$$

ZADATAK 1

Za kolo prikazano na slici odrediti širinu kanala W MOSFET-a kao i otpornost R_D. Poznato je: V_{DD}=10 V, V_t=-2 V, $\mu_p C_{ox}'$=8 μA/V^2, dužina kanala L=10 μm, koeficijent modulacije dužine kanala $\lambda \longrightarrow 0$, I_D=0.1 mA, V_D=7 V.



ZADATAK 1



$$V_{DG} = 0\ \text{V} < -V_t$$

Slijedi da je MOSFET u zasićenju.

$$I_D = \frac{1}{2}\beta(V_{SG} + V_t)^2(1 + \lambda V_{SD}) \approx \frac{1}{2}\beta(V_{SG} + V_t)^2$$

$$= \frac{1}{2}\mu_p C'_{ox}\frac{W}{L}(V_{SG} + V_t)^2$$

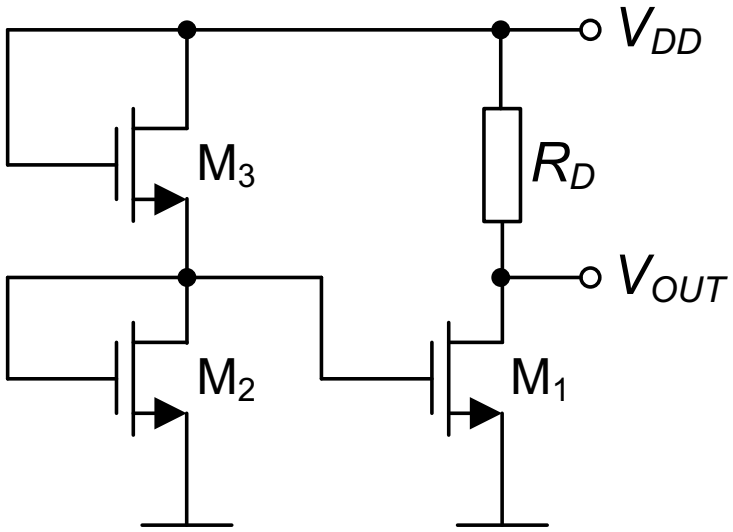
$$V_{SG} = V_{DD} - V_D$$

$$W \approx \frac{2LI_D}{\mu_p C'_{ox}(V_{DD} - V_D + V_t)^2} = 250\ \mu\text{m}$$

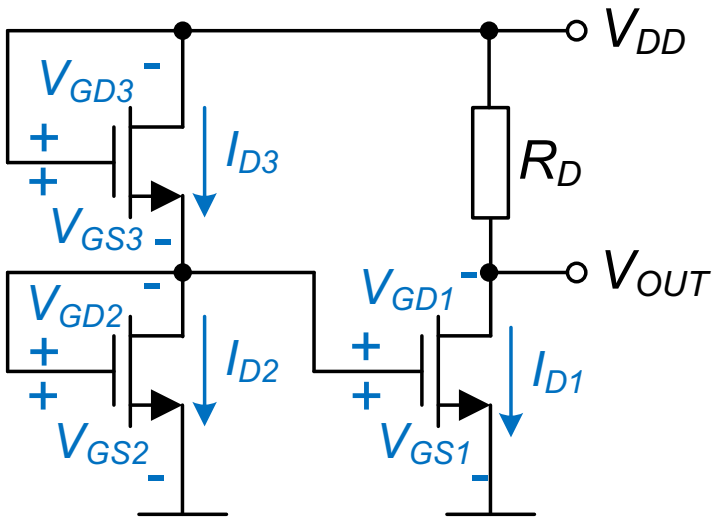
$$R_D = \frac{V_D}{I_D} = 70\ \text{k}\Omega$$

ZADATAK 2

Za kolo prikazano na slici odrediti napon V_{OUT}. Poznato je: V_{DD}=12 V, V_t=2 V, β=100 μA/V^2, R_D=25 kΩ, koeficijent modulacije dužine kanala $\lambda \longrightarrow 0$.



ZADATAK 2



$V_{GD2} = 0$ V

$V_{GD3} = 0$ V

Slijedi da su MOSFET-ovi M_2 i M_3 u zasićenju.

$I_{D2} = I_{D3}$

$V_{GS2} = V_{GS3}$ (MOSFET-ovi su identičnih karakteristika)

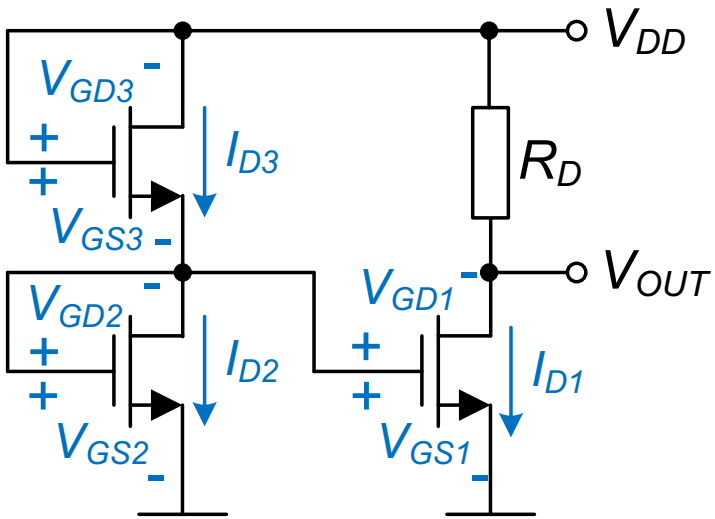
$V_{GS2} + V_{GS3} = V_{DD}$

$$V_{GS2} = V_{GS3} = \frac{V_{DD}}{2} = 6 \text{ V}$$

Uvodi se pretpostavka da je i MOSFET M_1 u zasićenju.

$$I_{D1} = \frac{1}{2}\beta(V_{GS1} - V_t)^2 = 0.8 \text{ mA}$$

ZADATAK 2



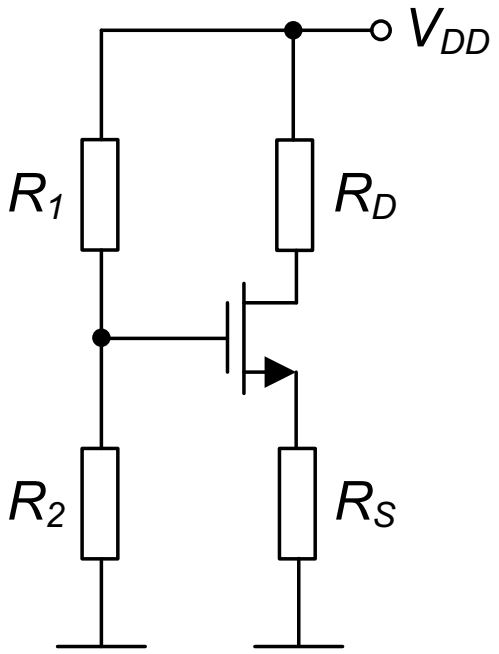
$$V_{OUT} = V_{DD} - R_D I_D = 10\ \text{V}$$

$$V_{GD1} = V_{GS1} - V_{OUT} = -4\ \text{V} < V_t$$

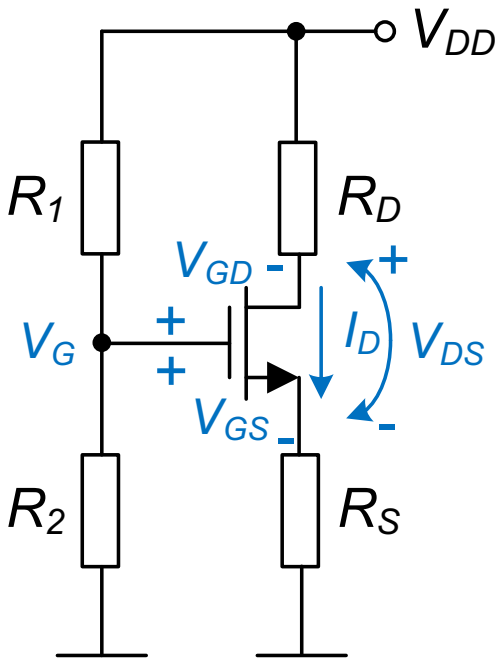
Pretpostavka o zasićenju MOSFET-a M_1 je tačna.

ZADATAK 3

Za kolo prikazano na slici odrediti vrijednosti napona V_{GS}, V_{GD}, V_{DS} kao i vrijednost struje I_D. Poznato je: V_{DD}=12 V, V_t=1 V, β=1 mA/V^2, $\lambda \longrightarrow 0$, R_1=R_2=1 MΩ, R_D=2 kΩ i R_S=3 kΩ.



ZADATAK 3



Uvodi se pretpostavka da je MOSFET u zasićenju.

$$V_G = \frac{R_2}{R_1 + R_2} V_{DD} = 5\ \text{V}$$

$$V_{GS} = V_G - R_S I_D$$

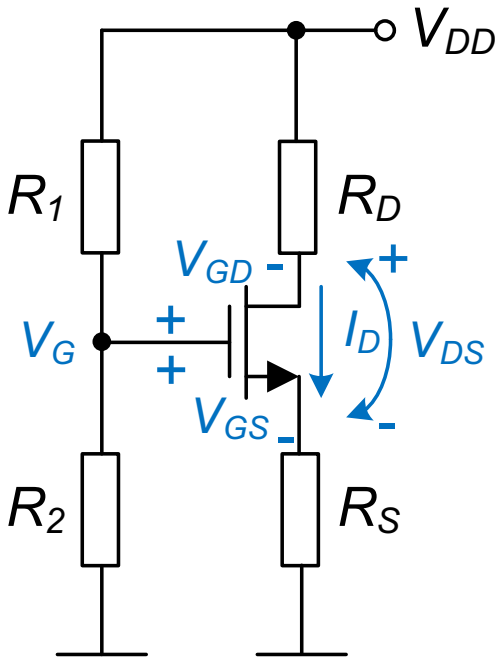
$$I_D = \frac{1}{2}\beta (V_{GS} - V_t)^2 = \frac{1}{2}\beta (V_G - R_S I_D - V_t)^2$$

$$I_D = \frac{1}{2}\beta [(V_G - V_t)^2 - 2R_S I_D (V_G - V_t) + R_S^2 I_D^2]$$

$$\frac{\beta}{2} R_S^2 I_D^2 - [1 + \beta R_S (V_G - V_t)] I_D + \frac{\beta}{2}(V_G - V_t)^2 = 0$$

$$I_{D1,2} = \frac{1 + \beta R_S (V_G - V_t) \pm \sqrt{[1 + \beta R_S (V_G - V_t)]^2 - \beta^2 R_S^2 (V_G - V_t)^2}}{\beta R_S^2}$$

ZADATAK 3



$$I_{D1,2} = \frac{1 + \beta R_S(V_G - V_t) \pm \sqrt{[1 + \beta R_S(V_G - V_t)]^2 - \beta^2 R_S^2 (V_G - V_t)^2}}{\beta R_S^2}$$

$$I_{D1,2} = \frac{1 + \beta R_S(V_G - V_t) \pm \sqrt{1 + 2\beta R_S(V_G - V_t)}}{\beta R_S^2}$$

$I_{D1} = 2\ \text{mA}$

$I_{D2} = 0.89\ \text{mA}$

$V_{GS}(I_D = 2\ \text{mA}) = V_G - R_S I_D = -1\ \text{V} < V_t$

$V_{GS}(I_D = 0.89\ \text{mA}) = V_G - R_S I_D = 2.33\ \text{V} > V_t$

$I_D = 0.89\ \text{mA}$

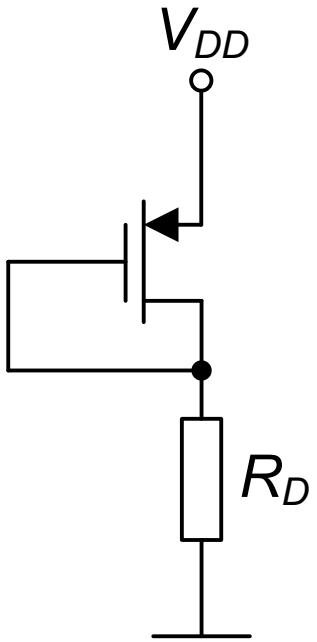
$V_{GD} = V_G + R_D I_D - V_{DD} = -3.22\ \text{V} < V_t$

Slijedi da je pretpostavka o zasićenju MOSFET-a tačna.

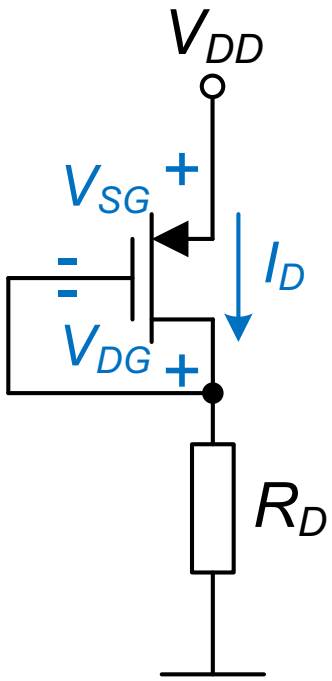
$V_{DS} = V_{DD} - R_D I_D - R_S I_D = 5.56\ \text{V}$

ZADATAK 4

Za kolo prikazano na slici odrediti struju I_D kao i napon V_{SG}. Poznato je: V_{DD}=10 V, V_t=-2 V, β=0.2 mA/V^2, $\lambda \longrightarrow 0$, R_D=70 kΩ.



ZADATAK 4



$$V_{DG} = 0\ \text{V} < -V_t$$

Slijedi da je MOSFET u zasićenju.

$$I_D = \frac{1}{2}\beta(V_{SG} + V_t)^2$$

$$V_{SG} = V_{DD} - R_D I_D$$

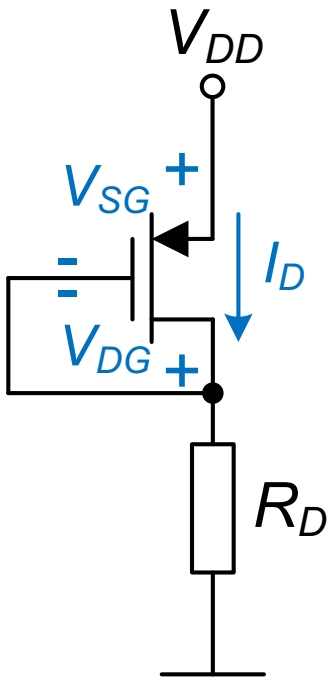
$$I_D = \frac{1}{2}\beta(V_{DD} - R_D I_D + V_t)^2$$

$$I_D = \frac{1}{2}\beta[(V_{DD} + V_t)^2 - 2R_D I_D(V_{DD} + V_t) + R_D^2 I_D^2]$$

$$\frac{\beta}{2}R_D^2 I_D^2 - [1 + \beta R_D(V_{DD} + V_t)]I_D + \frac{\beta}{2}(V_{DD} + V_t)^2 = 0$$

$$I_{D1,2} = \frac{1 + \beta R_D(V_{DD} + V_t) \pm \sqrt{[1 + \beta R_D(V_{DD} + V_t)]^2 - \beta^2 R_D^2 (V_{DD} + V_t)^2}}{\beta R_D^2}$$

ZADATAK 4



$$I_{D1,2} = \frac{1 + \beta R_D(V_{DD} + V_t) \pm \sqrt{[1 + \beta R_D(V_{DD} + V_t)]^2 - \beta^2 R_D^2 (V_{DD} + V_t)^2}}{\beta R_D^2}$$

$$I_{D1,2} = \frac{1 + \beta R_D(V_{DD} + V_t) \pm \sqrt{1 + 2\beta R_D(V_{DD} + V_t)}}{\beta R_D^2}$$

$I_{D1} = 0.13\ \text{mA}$

$I_{D2} = 0.1\ \text{mA}$

$V_{SG}(I_D = 0.13\ \text{mA}) = V_{DD} - R_D I_D = 0.9\ \text{V} < V_t$

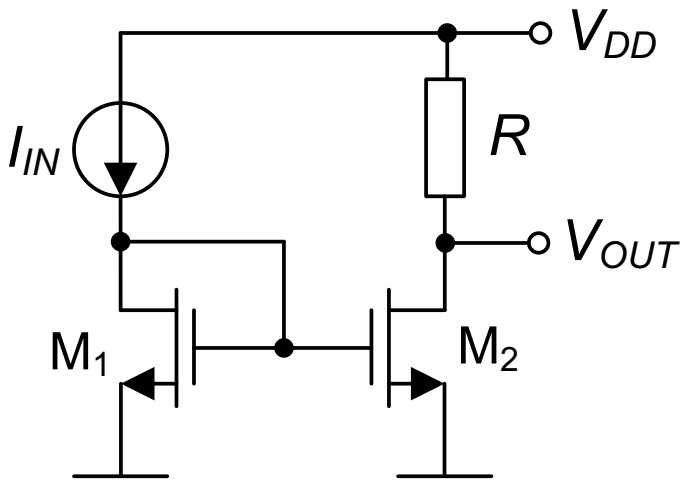
$V_{SG}(I_D = 0.1\ \text{mA}) = V_{DD} - R_D I_D = 3\ \text{V} > V_t$

$I_D = 0.1\ \text{mA}$

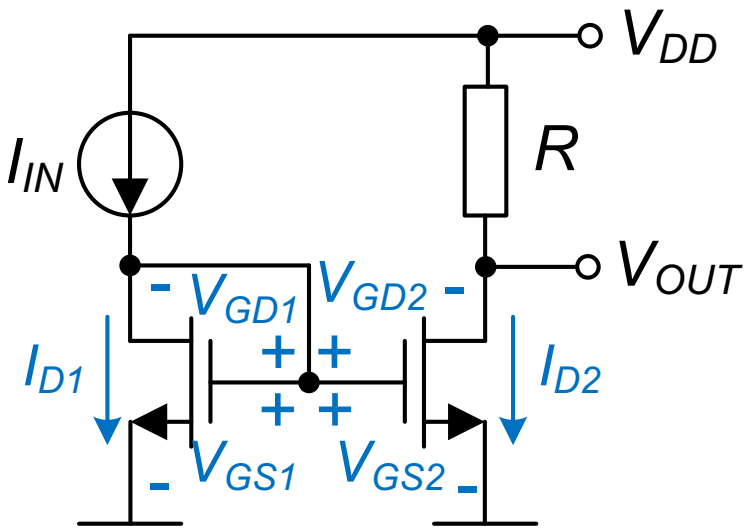
$V_{SG} = 3\ \text{V}$

ZADATAK 5

Za kolo prikazano na slici odrediti zavisnost napona V_{OUT} od ulazne struje I_{IN}, za opseg ulazne struje $0<I_{IN}<2$ mA. Poznato je: $V_{DD}=1.5$ V, $V_{t1}=V_{t2}$, $\beta_1=\beta_2=5$ mA/V^2, $\lambda_1 \longrightarrow 0$, $\lambda_2 \longrightarrow 0$ i $R=1$ kΩ.



ZADATAK 5



$$V_{GD1} = 0 < V_{t1}$$

Slijedi da je MOSFET M_1 u zasićenju.

1° Uvodi se pretpostavka da je i MOSFET M_2 u zasićenju.

$$V_{GS1} = V_{GS2} \Longrightarrow I_{D2} = I_{IN}$$

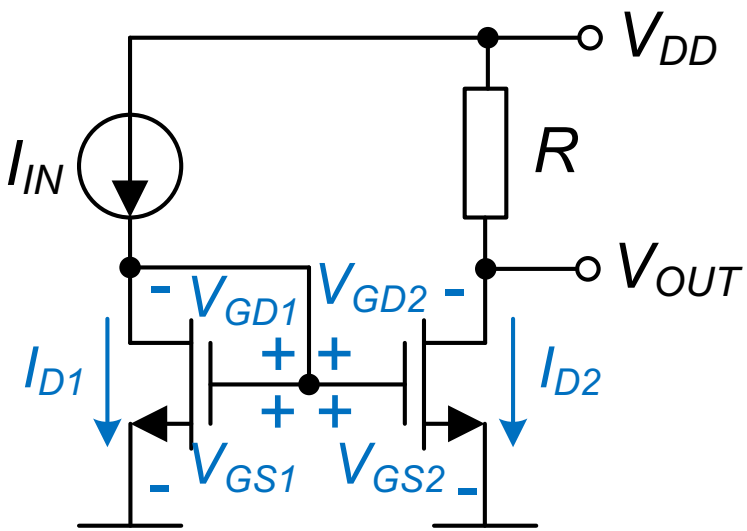
$$I_{IN} = \frac{\beta_1}{2}(V_{GS1} - V_{t1})^2 \Longrightarrow V_{GS1} = \sqrt{\frac{2I_{IN}}{\beta_1}} + V_{t1} > V_{t1}, I_{IN} > 0$$

$$V_{GS2} = V_{GS1} = \sqrt{\frac{2I_{IN}}{\beta_1}} + V_{t1}$$

$$V_{OUT} = V_{DD} - RI_{D2} = V_{DD} - RI_{IN}$$

$$V_{GD2} = V_{GS2} - V_{OUT} = \sqrt{\frac{2I_{IN}}{\beta_1}} + V_{t1} - V_{DD} + RI_{IN} < V_{t2}$$

ZADATAK 5



$$V_{GD2} = V_{GS2} - V_{OUT} = \sqrt{\frac{2I_{IN}}{\beta_1}} + V_{t1} - V_{DD} + RI_{IN} < V_{t2}$$

$$\sqrt{\frac{2I_{IN}}{\beta_1}} - V_{DD} + RI_{IN} < 0$$

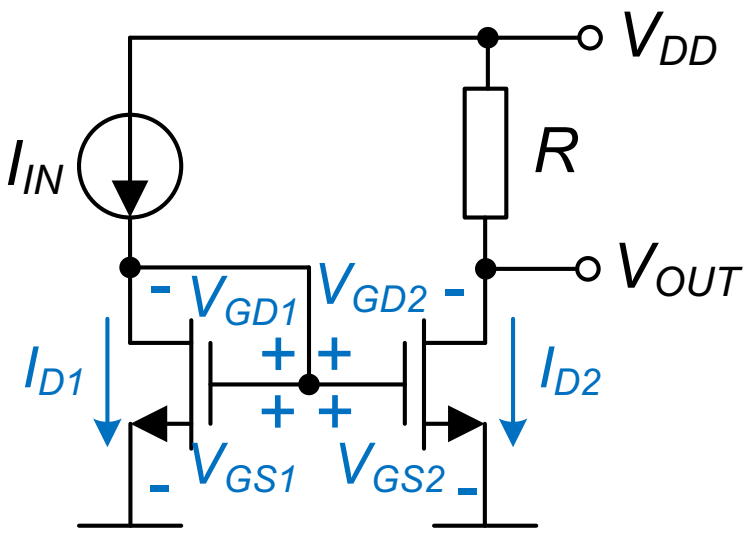
$$R\left(\sqrt{I_{IN}}\right)^2 + \sqrt{\frac{2I_{IN}}{\beta_1}} - V_{DD} < 0$$

$$\sqrt{I_{IN}}_{1,2} = \frac{-\sqrt{\frac{2}{\beta_1}} \pm \sqrt{\frac{2}{\beta_1} + 4RV_{DD}}}{2R}$$

$$\sqrt{I_{IN}}_1 = 0.03\sqrt{\text{A}}$$

$$\sqrt{I_{IN}}_2 = -0.05\sqrt{\text{A}}$$

ZADATAK 5



$$0 < \sqrt{I_{IN}} < 0.03\sqrt{\text{A}}$$

$$0 < I_{IN} < 0.9\ \text{mA}$$

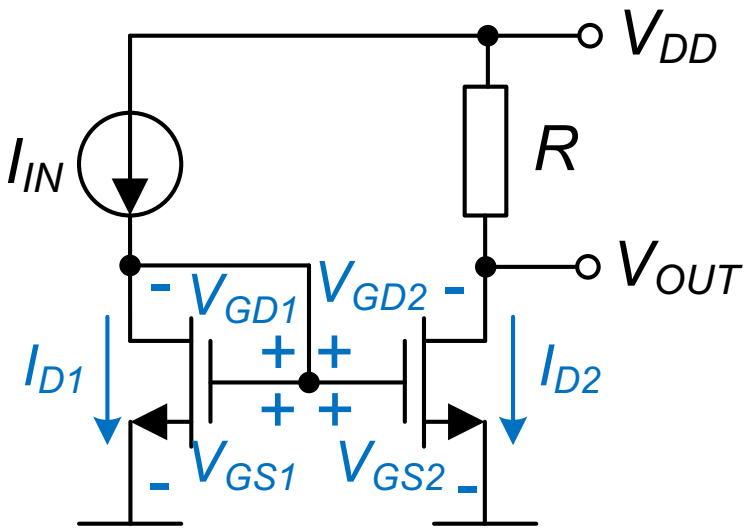
$$V_{OUT}(I_{IN} = 0.9\ \text{mA}) = V_{DD} - RI_{IN} = 0.6\ \text{V}$$

$$V_{GS1}(I_{IN} = 0.9\ \text{mA}) = \sqrt{\frac{2I_{IN}}{\beta_1}} + V_{t1} = 0.6\ \text{V} + V_{t1}$$

$$V_{GD2}(I_{IN} = 0.9\ \text{mA}) = V_{GS2} - V_{OUT} = V_{t1}$$

Daljim padom napona V_{OUT}, MOSFET M_2 prelazi u omski režim rada.

ZADATAK 5



2º Uvodi se pretpostavka da je MOSFET M_2 u omskom režimu.

$$I_{D2} = \beta_2 \left[(V_{GS2} - V_{t2}) V_{DS2} - \frac{V_{DS2}^2}{2} \right]$$

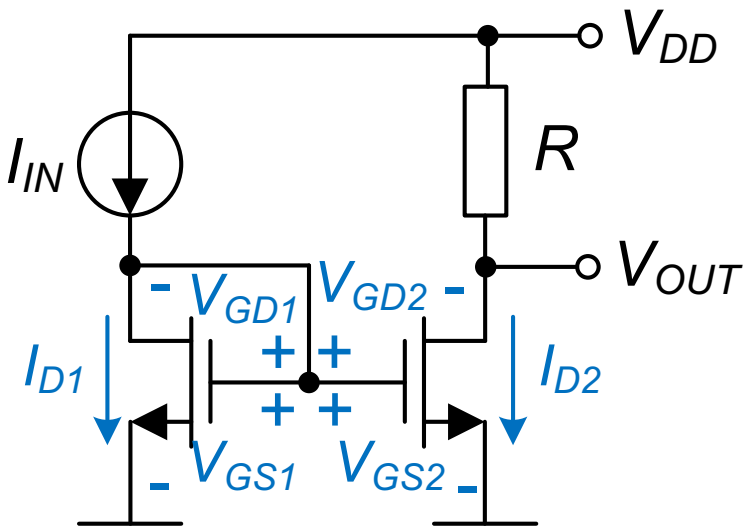
$$I_{D2} = \beta_2 \left[\left(\sqrt{\frac{2I_{IN}}{\beta_1}} + V_{t1} - V_{t2} \right) V_{OUT} - \frac{V_{OUT}^2}{2} \right]$$

$$= \beta_2 \left(\sqrt{\frac{2I_{IN}}{\beta_1}} V_{OUT} - \frac{V_{OUT}^2}{2} \right)$$

$$V_{OUT} = V_{DD} - R I_{D2} = V_{DD} - R\beta_2 \left(\sqrt{\frac{2I_{IN}}{\beta_1}} V_{OUT} - \frac{V_{OUT}^2}{2} \right)$$

$$\frac{R\beta_2}{2} V_{OUT}^2 - \left(1 + R\beta_2 \sqrt{\frac{2I_{IN}}{\beta_1}} \right) V_{OUT} + V_{DD} = 0$$

ZADATAK 5



$$\frac{R\beta_2}{2}V_{OUT}^2 - \left(1 + R\beta_2\sqrt{\frac{2I_{IN}}{\beta_1}}\right)V_{OUT} + V_{DD} = 0$$

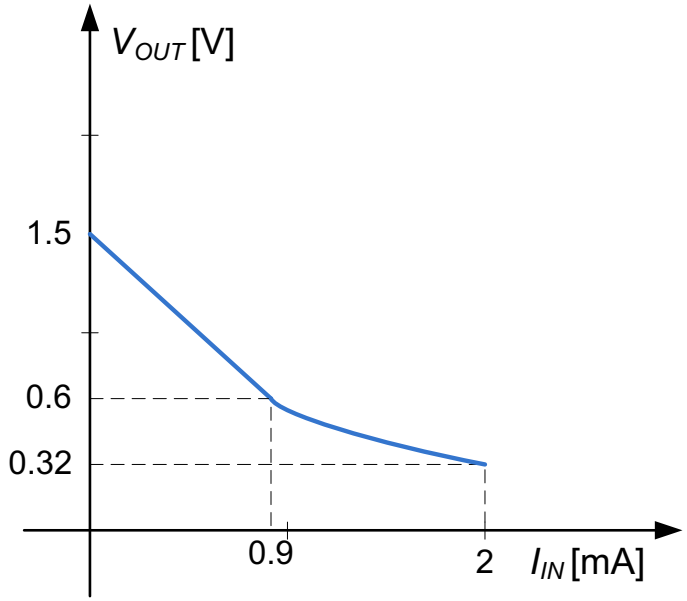
$$V_{OUT1,2} = \frac{1 + R\beta_2\sqrt{\frac{2I_{IN}}{\beta_1}} \pm \sqrt{\left(1 + R\beta_2\sqrt{\frac{2I_{IN}}{\beta_1}}\right)^2 - 2R\beta_2 V_{DD}}}{R\beta_2}$$

$$V_{OUT} = \frac{1 + R\beta_2\sqrt{\frac{2I_{IN}}{\beta_1}} - \sqrt{\left(1 + R\beta_2\sqrt{\frac{2I_{IN}}{\beta_1}}\right)^2 - 2R\beta_2 V_{DD}}}{R\beta_2}$$

$$V_{OUT}(I_{IN} = 0.9\ \text{mA}) = 0.6\ \text{V}$$

$$V_{OUT}(I_{IN} = 2\ \text{mA}) = 0.32\ \text{V}$$

ZADATAK 5



$0 < I_{IN} < 0.9$ mA:

$$V_{OUT} = V_{DD} - RI_{IN}$$

$0.9 \text{ mA} < I_{IN} < 2$ mA:

$$V_{OUT} = \frac{1 + R\beta_2\sqrt{\frac{2I_{IN}}{\beta_1}} - \sqrt{\left(1 + R\beta_2\sqrt{\frac{2I_{IN}}{\beta_1}}\right)^2 - 2R\beta_2 V_{DD}}}{R\beta_2}$$