# VJEŽBE 9

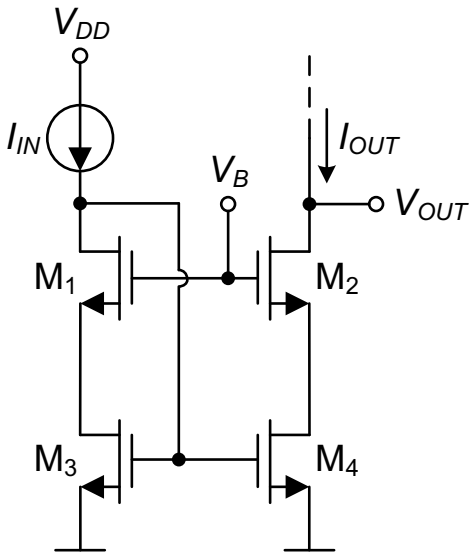
OSNOVE ELEKTRONIKE, ETR, IV SEMESTAR

DOC. DR MILENA ERCEG

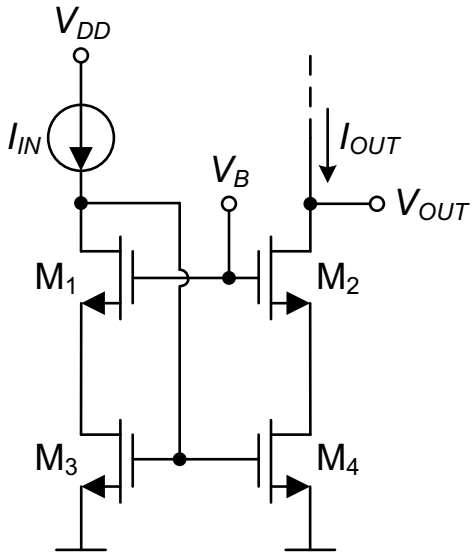
# ZADATAK 1

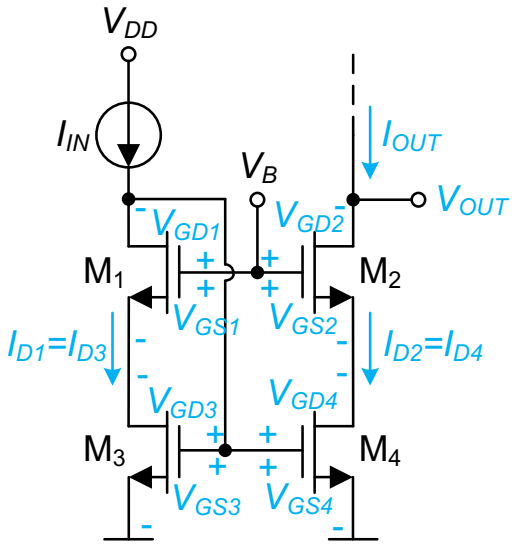
a) Utvrditi opseg napona $V_B$ i $V_{OUT}$ tako da kolo prikazano na slici 1 ispravno radi. MOSFET- ovi su identičnih karakteristika, $\lambda_i = \lambda \longrightarrow 0$, $\beta_i = \beta$, $V_{ti} = V_t$, $i = \overline{1,4}$.

b) Ukoliko koeficijent modulacije dužine kanala ima vrijednost različitu od nule, odrediti izlaznu otpornost kola.



# ZADATAK 1 – DC ANALIZA



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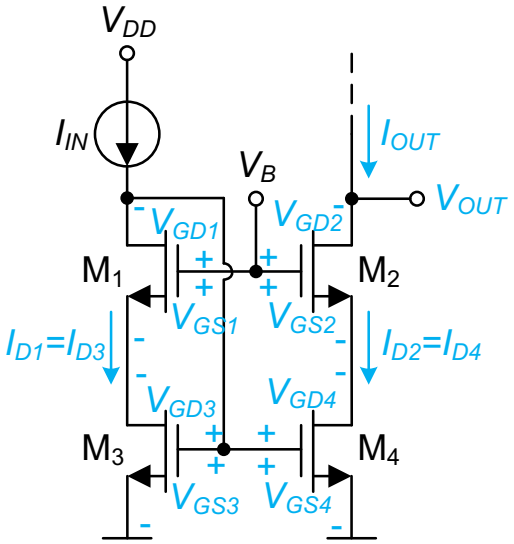



$$V_{GS3} = V_{GS4}$$

$$I_{D3} = I_{D4}$$

$$I_{D1} = I_{D2} = I_{D3} = I_{D4}$$

$$I_{IN} = I_{D1} = I_{D3}$$

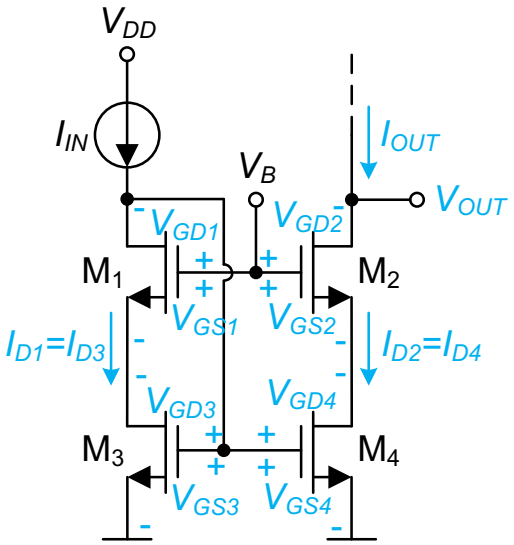
$$I_{OUT} = I_{D2} = I_{D4}$$

$$I_{OUT} = I_{IN} = \frac{1}{2}\beta(V_{GS1} - V_t)^2$$

$$V_{GS1} = \sqrt{\frac{2I_{IN}}{\beta}} + V_t$$

$$V_{GS1} > V_t$$

# ZADATAK 1 – DC ANALIZA




$$V_{GD1} = V_B - V_{GS3} = V_B - \sqrt{\frac{2I_{IN}}{\beta}} - V_t < V_t$$

$$V_B < \sqrt{\frac{2I_{IN}}{\beta}} + 2V_t$$

$$V_{GD2} = V_B - V_{OUT} < V_t$$

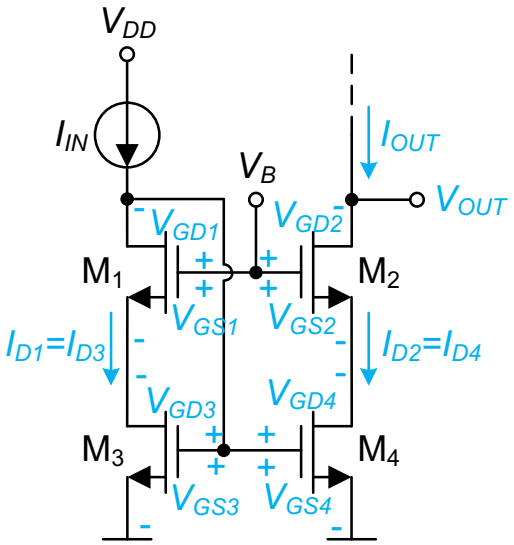
$$V_{OUT} > V_B - V_t$$

$$V_{GD3} = V_{GS3} + V_{GS1} - V_B = 2\sqrt{\frac{2I_{IN}}{\beta}} + 2V_t - V_B < V_t$$

$$V_B > 2\sqrt{\frac{2I_{IN}}{\beta}} + V_t$$

$$V_{GD4} = V_{GS3} + V_{GS2} - V_B = V_{GD3}$$

# ZADATAK 1 – DC ANALIZA



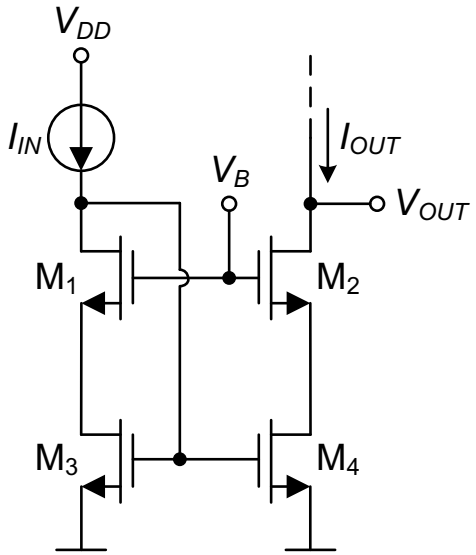

$$V_B < \sqrt{\frac{2I_{IN}}{\beta}} + 2V_t \qquad V_B > 2\sqrt{\frac{2I_{IN}}{\beta}} + V_t$$

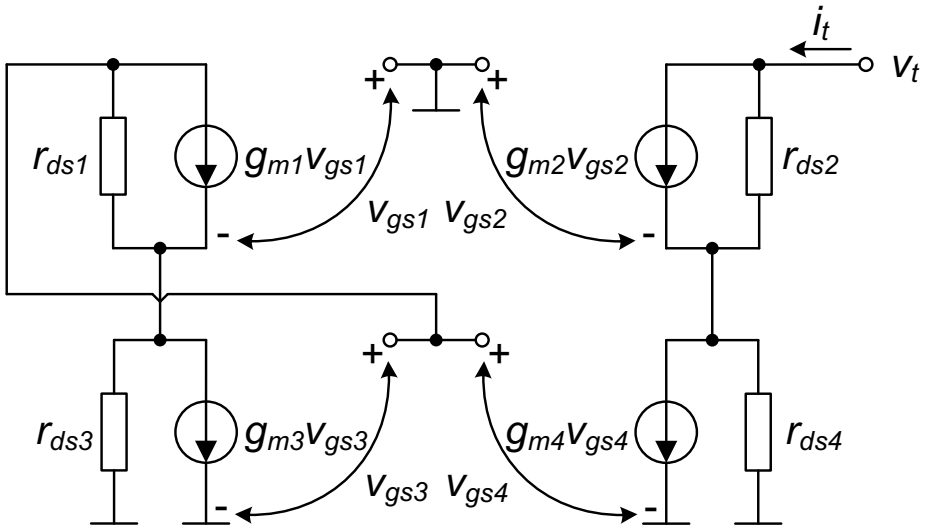
$$2\sqrt{\frac{2I_{IN}}{\beta}} + V_t < V_B < \sqrt{\frac{2I_{IN}}{\beta}} + 2V_t$$

$$2\sqrt{\frac{2I_{IN}}{\beta}} + V_t < \sqrt{\frac{2I_{IN}}{\beta}} + 2V_t$$

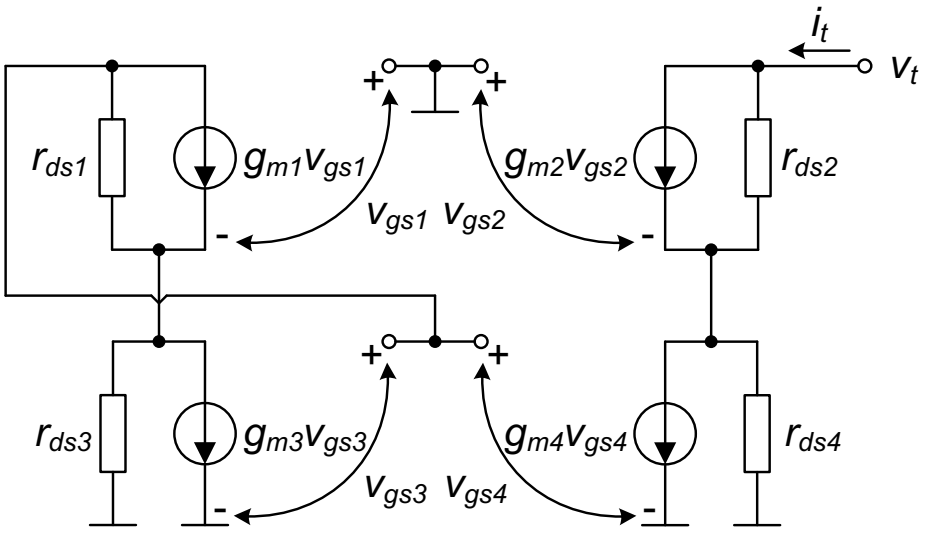
$$\sqrt{\frac{2I_{IN}}{\beta}} < V_t$$

# ZADATAK 1 – AC ANALIZA



# ZADATAK 1 – AC ANALIZA




$$g_{m1}v_{gs1} + \frac{v_{gs1} + v_{gs3}}{r_{ds1}} = 0$$

$$v_{gs3} = -r_{ds1}\left(g_{m1} + \frac{1}{r_{ds1}}\right)v_{gs1} \approx -g_{m1}r_{ds1}v_{gs1}$$

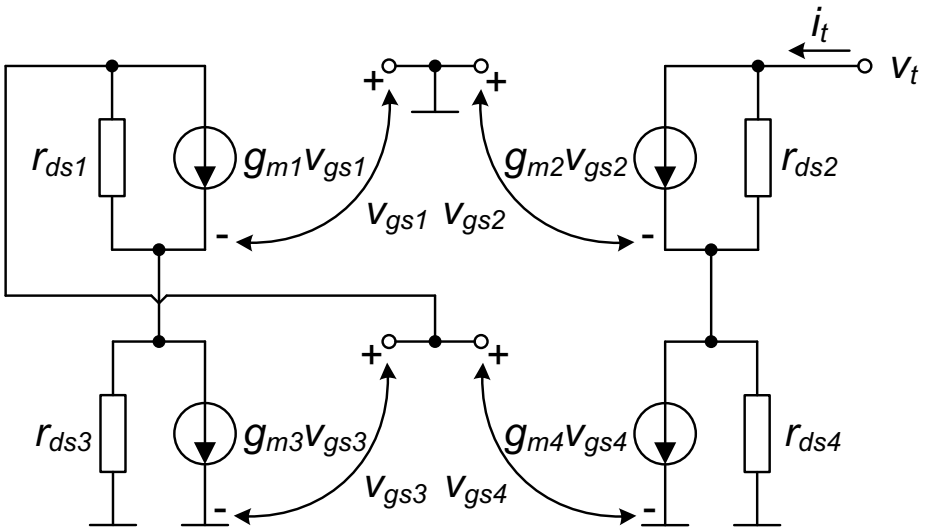
$$g_{m3}v_{gs3} - \frac{v_{gs1}}{r_{ds3}} = 0$$

$$-g_{m1}g_{m3}r_{ds1}v_{gs1} - \frac{v_{gs1}}{r_{ds3}} = 0$$

$$\Rightarrow v_{gs1} = 0, v_{gs3} = 0$$

$$v_{gs4} = v_{gs3} = 0$$

# ZADATAK 1 – AC ANALIZA




$$i_t = g_{m4}v_{gs4} - \frac{v_{gs2}}{r_{ds4}} = -\frac{v_{gs2}}{r_{ds4}}$$

$$v_{gs2} = -r_{ds4}i_t$$

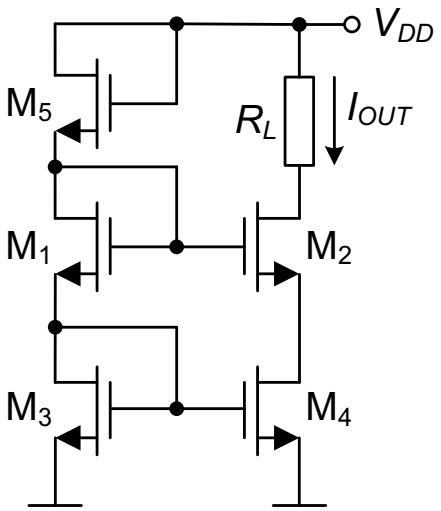
$$i_t = g_{m2}v_{gs2} + \frac{v_t + v_{gs2}}{r_{ds2}} = \left(g_{m2} + \frac{1}{r_{ds2}}\right)v_{gs2} + \frac{v_t}{r_{ds2}}$$

$$\approx -g_{m2}r_{ds4}i_t + \frac{v_t}{r_{ds2}}$$

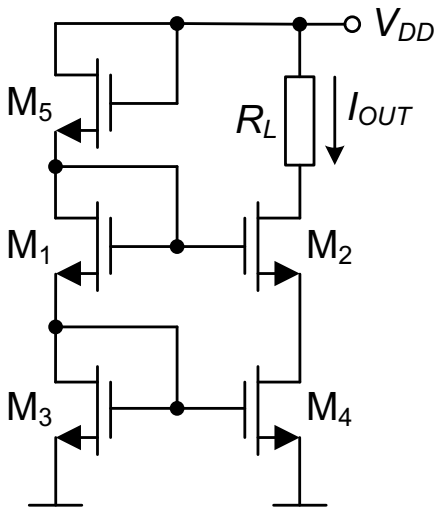
$$R_{out} = \frac{v_t}{i_t} \approx (1 + g_{m2}r_{ds4})r_{ds2} \approx g_{m2}r_{ds2}r_{ds4}$$

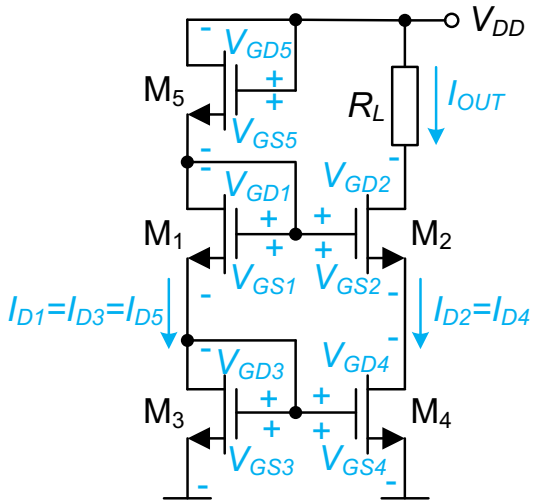
# ZADATAK 2

Za kolo prikazano na slici izračunati izlaznu otpornost. MOSFET-ovi $M_1$, $M_2$, $M_3$ i $M_4$ su identičnih karakteristika, $\lambda_i = \lambda$, $\beta_i = \beta$, $V_{ti} = V_t$, $i = \overline{1,4}$. Parametar $\beta_5$ MOSFET-a $M_5$ je $\beta_5 = \beta / 4$, dok su ostali parametri ovog MOSFET-a isti kao kod ostalih MOSFET-ova. Poznato je: napon napajanja kola $V_{DD}$ = 12 V, otpornost $R_L$ = 10 kΩ, napon praga $V_t$ = 2 V, koeficijent modulacije dužine kanala $\lambda$ = 0.005 $V^{-1}$ i izlazna struja $I_{OUT}$ = 4 mA.

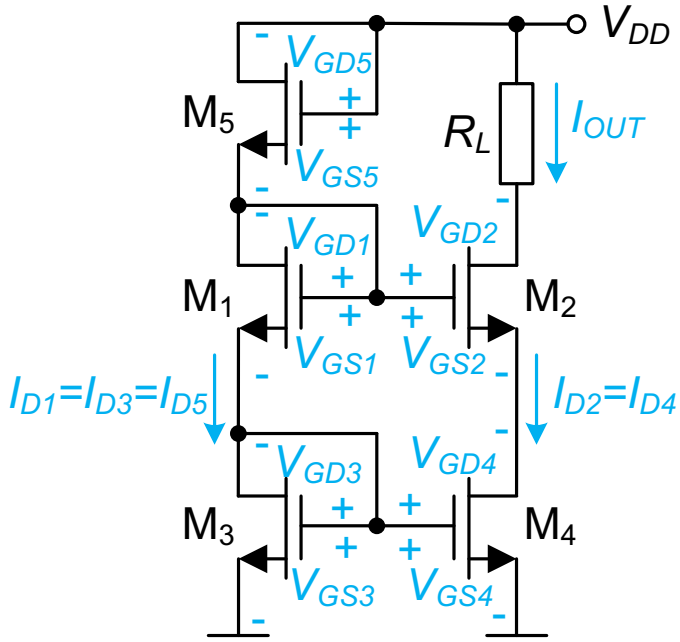


# ZADATAK 2 – DC ANALIZA



# ZADATAK 2 – DC ANALIZA




$$V_{GS3} = V_{GS4}$$

$$I_{D3} = I_{D4}$$

$$I_{D1} = I_{D2} = I_{D3} = I_{D4} = I_{D5} = I_{OUT}$$

$$V_{GS1} = V_{GS2} = V_{GS3} = V_{GS4}$$

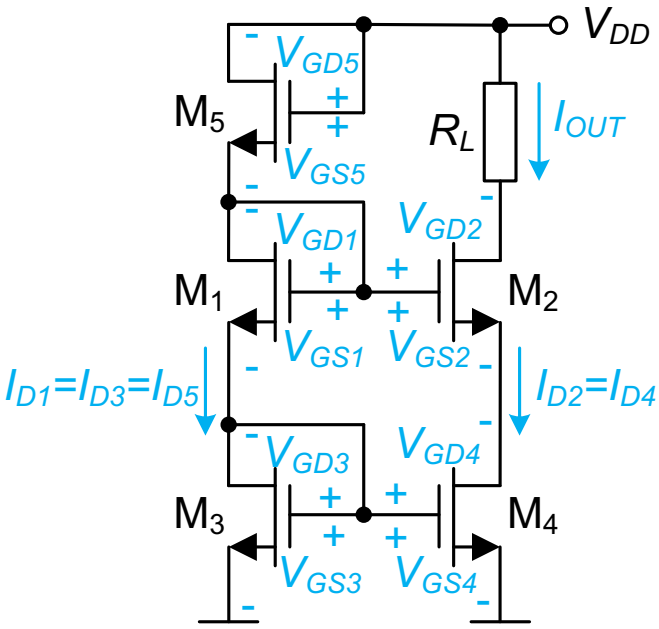
$$V_{GS1} = \sqrt{\frac{2I_{OUT}}{\beta}} + V_t$$

$$V_{GS5} = \sqrt{\frac{2I_{OUT}}{\beta/4}} + V_t$$

$$V_{GS1} > V_t$$

$$V_{GS5} > V_t$$

# ZADATAK 2 – DC ANALIZA




$$V_{GS1} + V_{GS3} + V_{GS5} = V_{DD}$$

$$2\sqrt{\frac{2I_{OUT}}{\beta}} + 2V_t + \sqrt{\frac{2I_{OUT}}{\beta/4}} + V_t = V_{DD}$$

$$\beta = \frac{32I_{OUT}}{(V_{DD} - 3V_t)^2} = 3.55\ \text{mA/V}^2$$

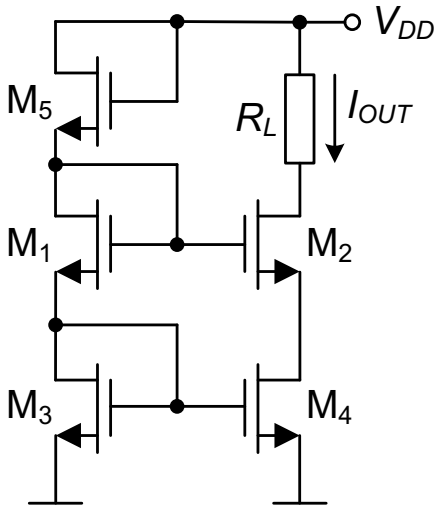
$$V_{GS1} = V_{GS2} = V_{GS3} = V_{GS4} = \sqrt{\frac{2I_{OUT}}{\beta}} + V_t = 3.5\ \text{V}$$

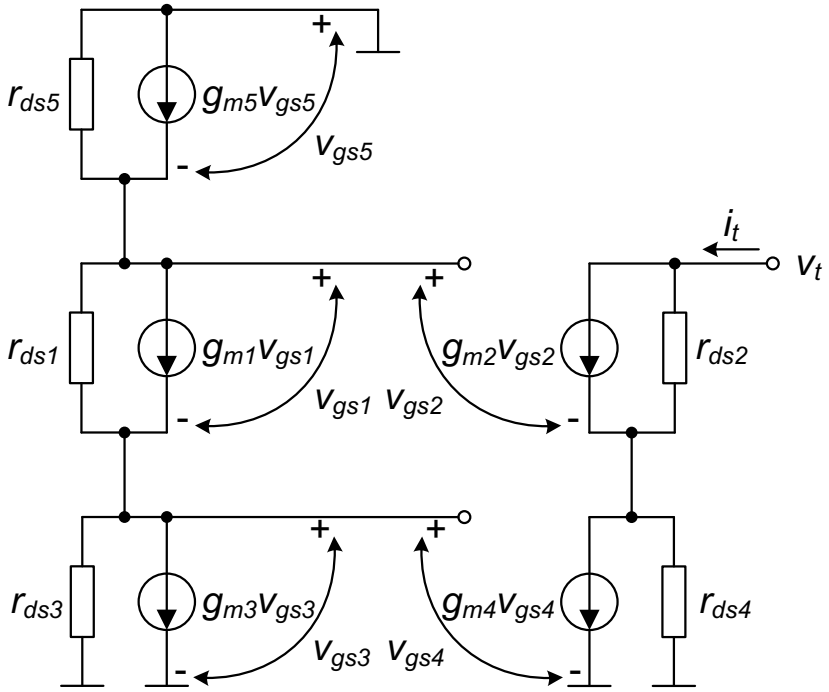
$$V_{GS5} = \sqrt{\frac{2I_{OUT}}{\beta/4}} + V_t = 5\ \text{V}$$

$$V_{GD4} = -V_{GS1} + V_{GS2} = 0\ \text{V}$$

$$V_{GD2} = -V_{GS5} + R_L I_{OUT} = -1\ \text{V}$$

# ZADATAK 2 – AC ANALIZA



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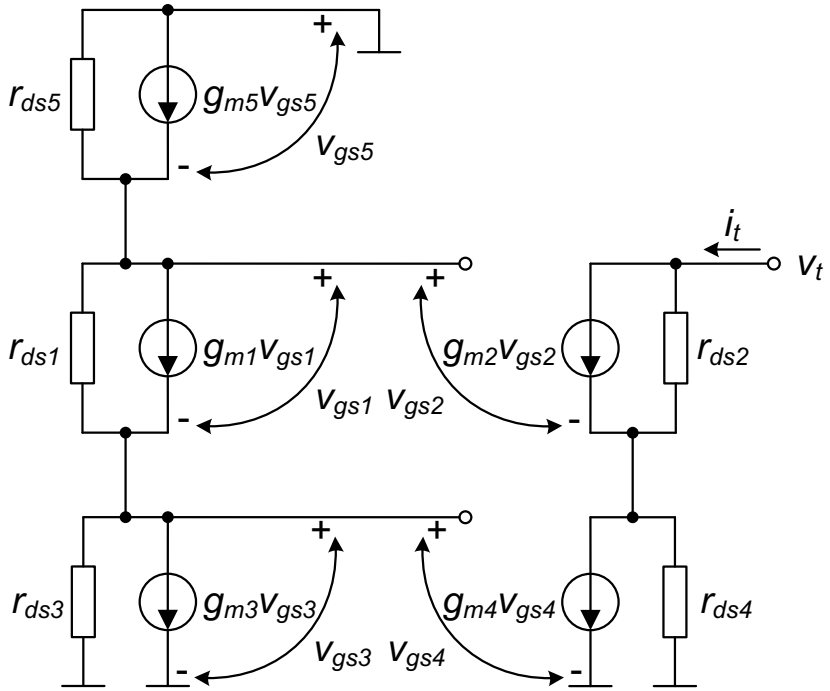



$$g_{m5}v_{gs5} + \frac{v_{gs5}}{r_{ds5}} = g_{m1}v_{gs1} + \frac{v_{gs1}}{r_{ds1}}$$

$$v_{gs5} \approx \frac{g_{m1}}{g_{m5}}v_{gs1}$$

$$g_{m1}v_{gs1} + \frac{v_{gs1}}{r_{ds1}} = g_{m3}v_{gs3} + \frac{v_{gs3}}{r_{ds3}}$$

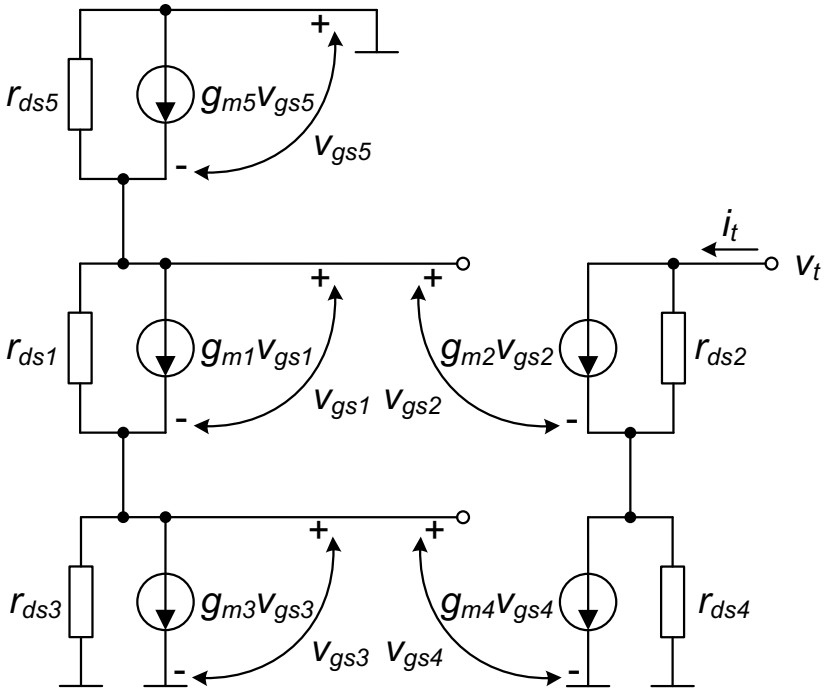
$$v_{gs3} \approx \frac{g_{m1}}{g_{m3}}v_{gs1}$$

$$v_{gs1} + v_{gs3} + v_{gs5} = 0$$

$$\Rightarrow v_{gs1} = 0, v_{gs3} = 0, v_{gs5} = 0$$

$$v_{gs4} = v_{gs3} = 0$$

# ZADATAK 2 – AC ANALIZA




$$i_t = g_{m4}v_{gs4} - \frac{v_{gs2}}{r_{ds4}} = -\frac{v_{gs2}}{r_{ds4}}$$

$$v_{gs2} = -r_{ds4}i_t$$

$$i_t = g_{m2}v_{gs2} + \frac{v_t + v_{gs2}}{r_{ds2}} = \left(g_{m2} + \frac{1}{r_{ds2}}\right)v_{gs2} + \frac{v_t}{r_{ds2}}$$

$$\approx -g_{m2}r_{ds4}i_t + \frac{v_t}{r_{ds2}}$$

$$R_{out} = \frac{v_t}{i_t} \approx (1 + g_{m2}r_{ds4})r_{ds2} \approx g_{m2}r_{ds2}r_{ds4}$$

$$= \sqrt{2\beta I_{OUT}}\,\frac{1}{(\lambda I_{OUT})^2} = 13.32\ \text{M}\Omega$$