



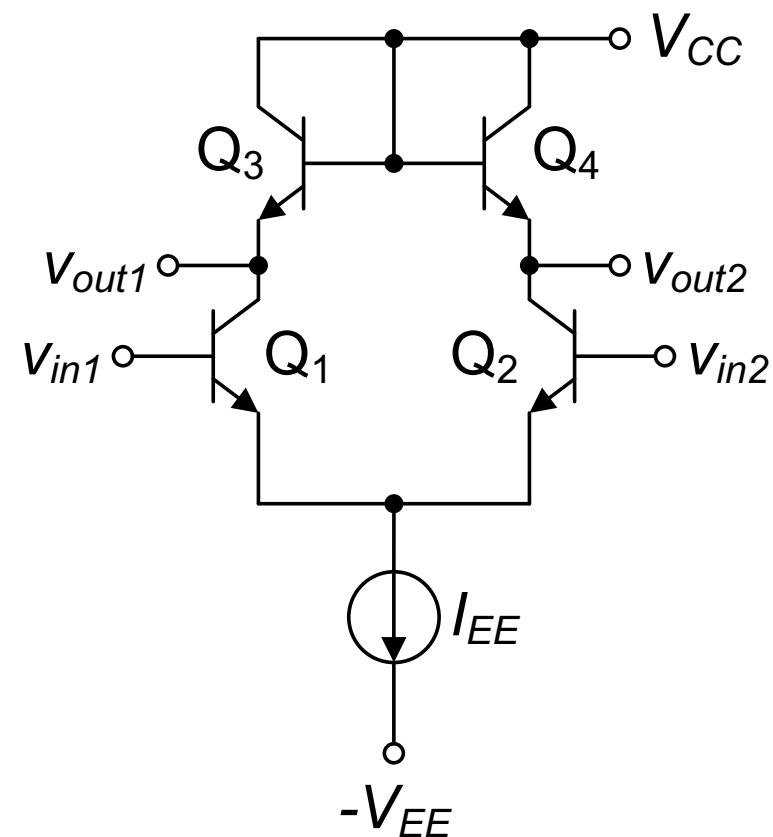
VJEŽBE 12

OSNOVE ELEKTRONIKE, ETR, IV SEMESTAR

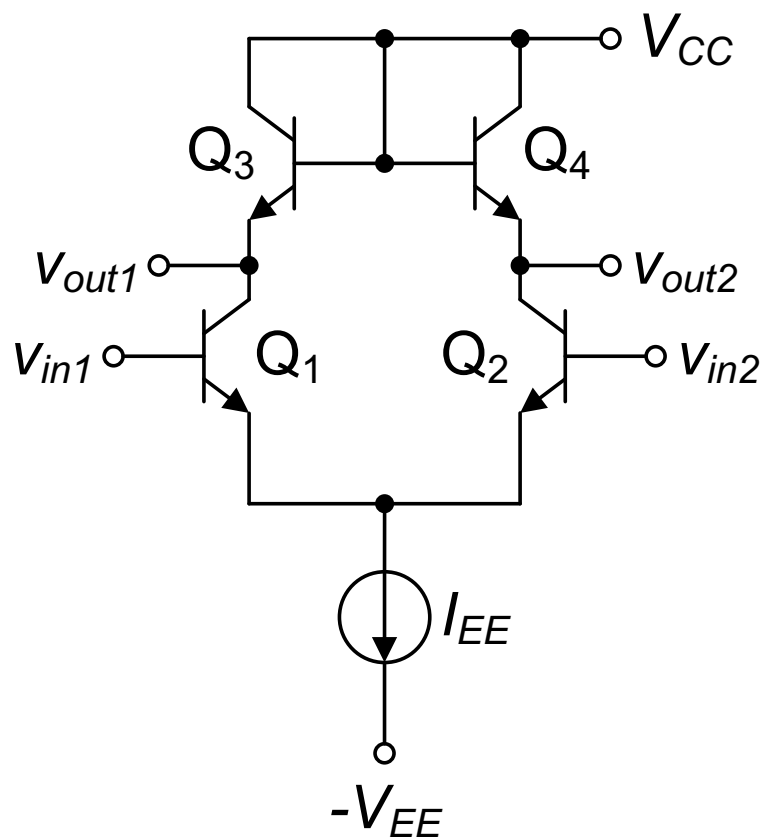
DOC. DR. MILENA ERCEG

ZADATAK 1

Za kolo prikazano na slici, odrediti diferencijalno naponsko pojačanje $A_d = (v_{out1} - v_{out2}) / (v_{in1} - v_{in2})$. Bipolarni tranzistori Q_1 i Q_2 su identičnih karakteristika, kroz njih teku iste jednosmjerne struje i rade u direktnom aktivnom režimu. Bipolarni tranzistori Q_3 i Q_4 su identičnih karakteristika i kroz njih teku iste jednosmjerne struje. Pretpostaviti da je $g_m r_{ce} \gg 1$ i $g_m r_{\pi} \gg 1$.



ZADATAK 1

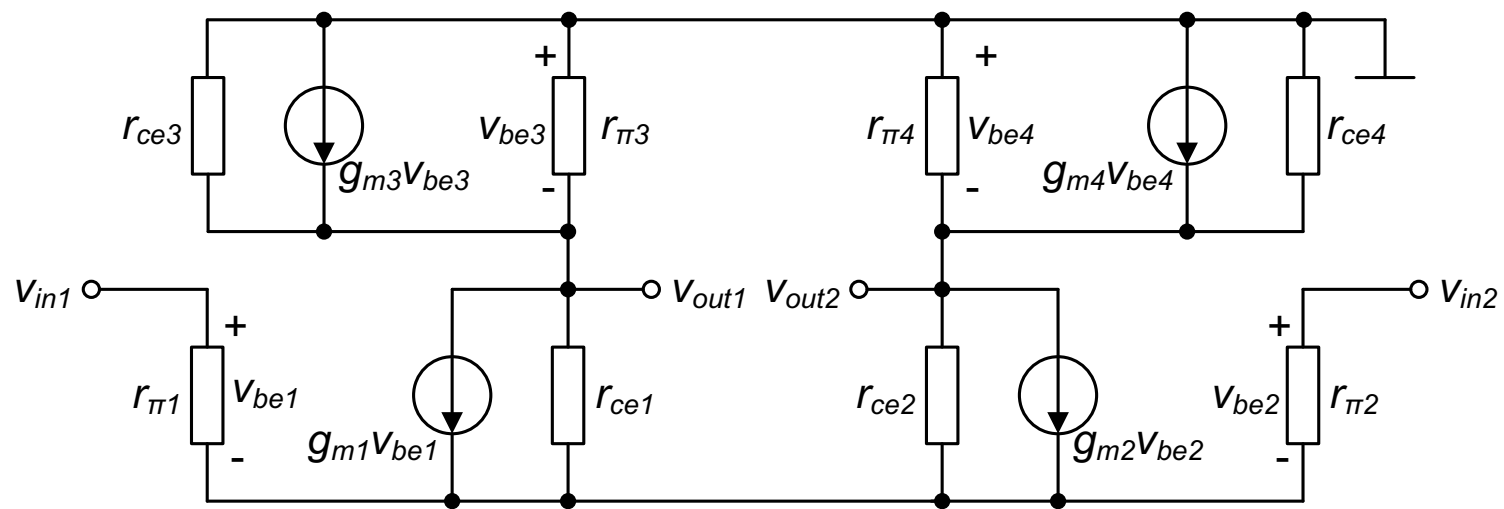
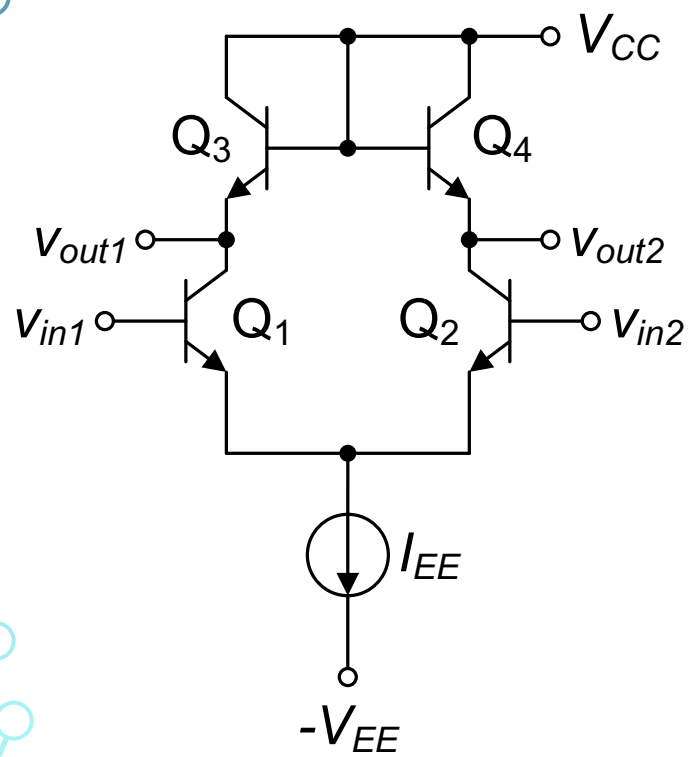


$$V_{CE3} = V_{BE3}$$

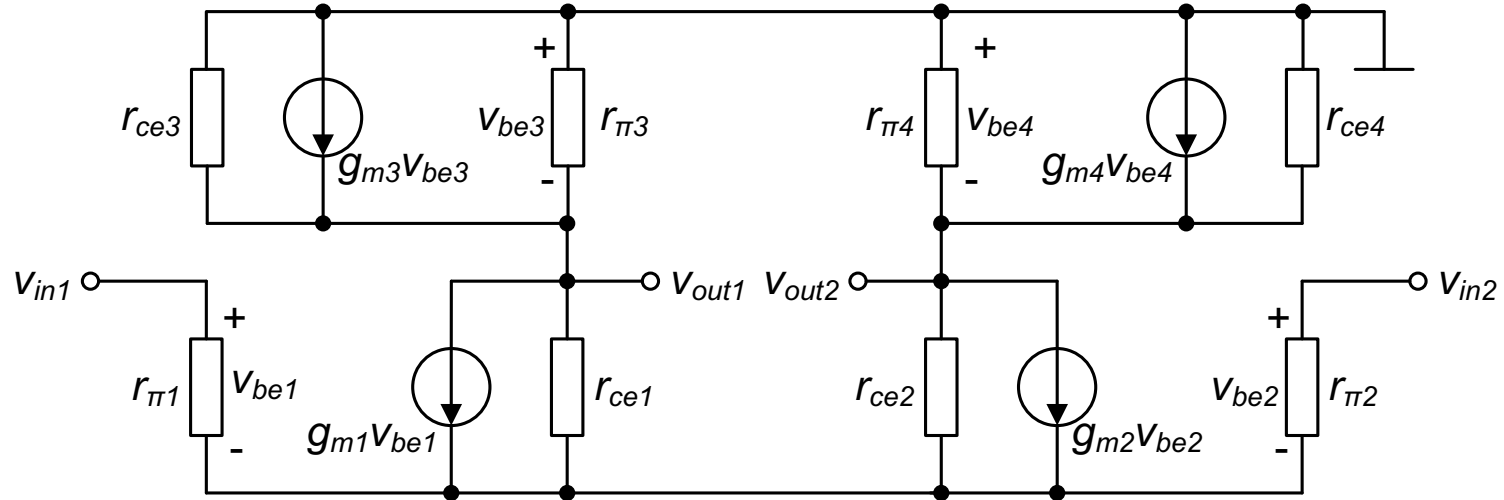
$$V_{CE4} = V_{BE4}$$

Slijedi da su i BJT-ovi Q_3 i Q_4 u direktnom aktivnom režimu.

ZADATAK 1



ZADATAK 1



$$v_{out1} = -v_{be3}$$

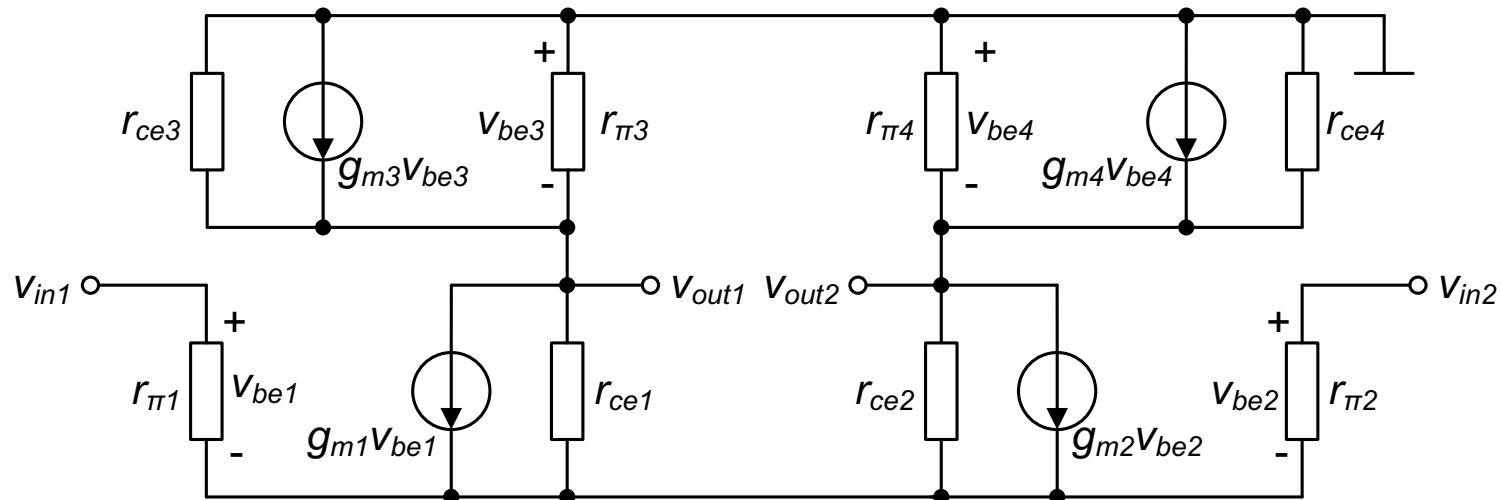
$$v_{out2} = -v_{be4}$$

$$g_{m3}v_{be3} + \frac{v_{be3}}{r_{ce3}} + \frac{v_{be3}}{r_{\pi3}} = g_{m1}v_{be1} + \frac{v_{out1} + v_{be1} - v_{in1}}{r_{ce1}}$$

$g_m r_{ce} \gg 1$ i $g_m r_{\pi} \gg 1$:

$$v_{be1} = \frac{g_{m3}}{g_{m1}} v_{be3} - \frac{v_{out1} - v_{in1}}{g_{m1} r_{ce1}} = \frac{v_{in1}}{g_{m1} r_{ce1}} - \frac{1}{g_{m1}} \left(g_{m3} + \frac{1}{r_{ce1}} \right) v_{out1}$$

ZADATAK 1

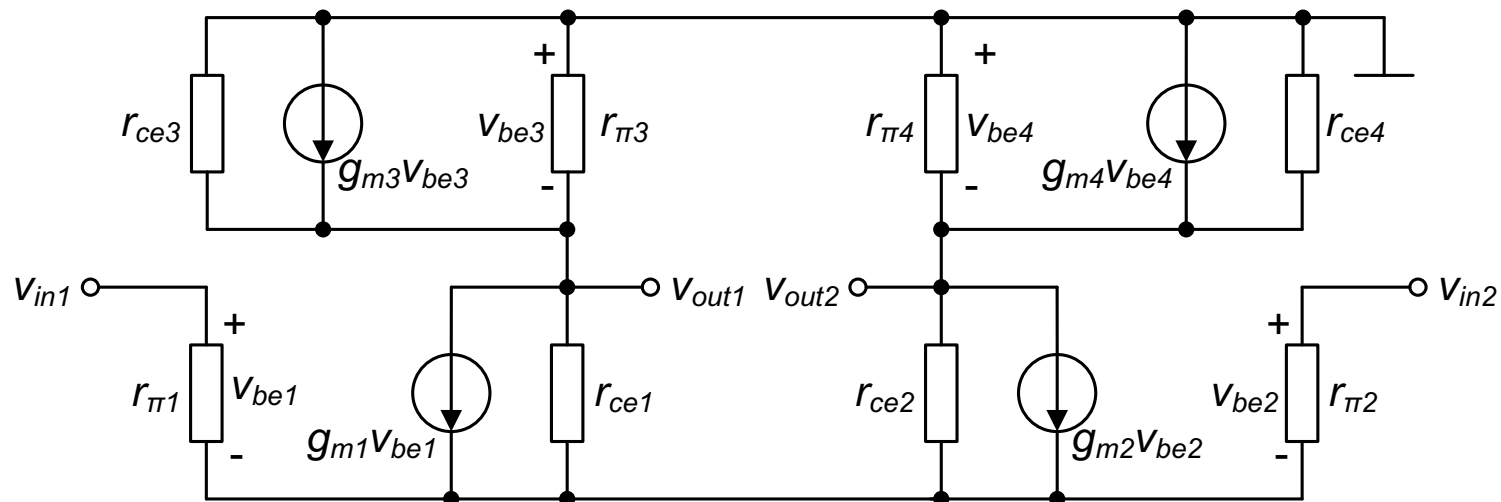


$$g_{m4}v_{be4} + \frac{v_{be4}}{r_{ce4}} + \frac{v_{be4}}{r_{\pi4}} = g_{m2}v_{be2} + \frac{v_{out2} + v_{be2} - v_{in2}}{r_{ce2}}$$

$g_m r_{ce} \gg 1$ i $g_m r_{\pi} \gg 1$:

$$v_{be2} = \frac{g_{m4}}{g_{m2}} v_{be4} - \frac{v_{out2} - v_{in2}}{g_{m2} r_{ce2}} = \frac{v_{in2}}{g_{m2} r_{ce2}} - \frac{1}{g_{m2}} \left(g_{m4} + \frac{1}{r_{ce2}} \right) v_{out2}$$

ZADATAK 1



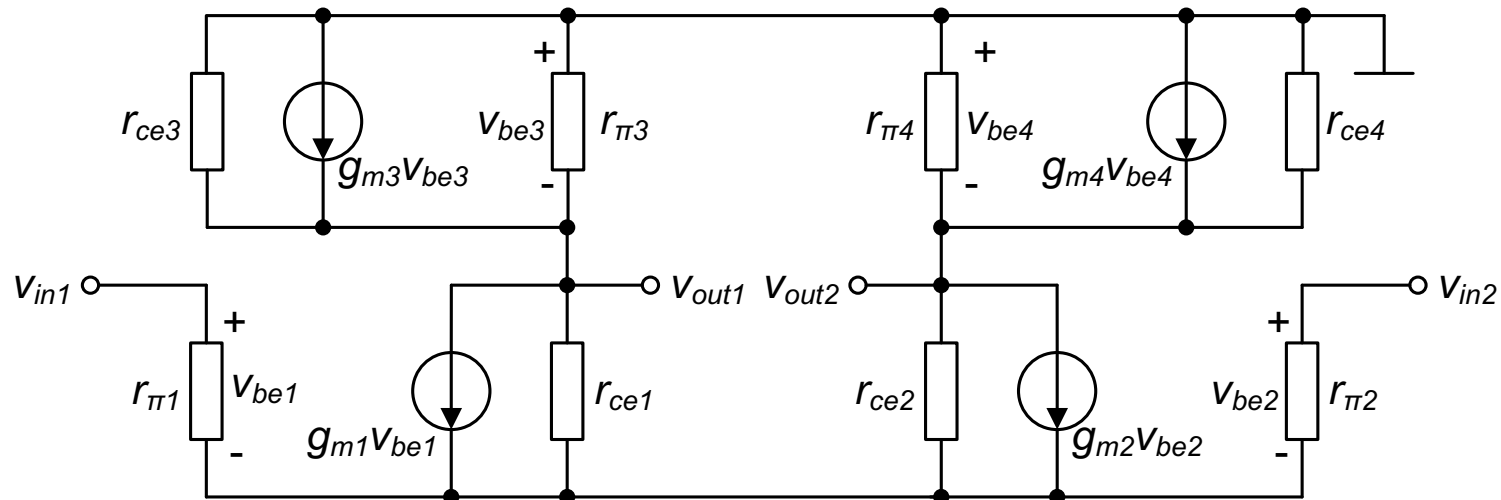
$$v_{in1} - v_{be1} + v_{be2} - v_{in2} = 0$$

$$v_{be1} = \frac{v_{in1}}{g_{m1}r_{ce1}} - \frac{1}{g_{m1}} \left(g_{m3} + \frac{1}{r_{ce1}} \right) v_{out1}$$

$$v_{be2} = \frac{v_{in2}}{g_{m2}r_{ce2}} - \frac{1}{g_{m2}} \left(g_{m4} + \frac{1}{r_{ce2}} \right) v_{out2}$$

$$v_{be2} - v_{be1} \approx \frac{1}{g_{m1}r_{ce1}} (v_{in2} - v_{in1}) - \frac{1}{g_{m1}} \left(g_{m3} + \frac{1}{r_{ce1}} \right) (v_{out2} - v_{out1})$$

ZADATAK 1



$$v_{in1} - v_{be1} + v_{be2} - v_{in2} = 0$$

$$v_{be2} - v_{be1} \approx \frac{1}{g_{m1}r_{ce1}}(v_{in2} - v_{in1}) - \frac{1}{g_{m1}}\left(g_{m3} + \frac{1}{r_{ce1}}\right)(v_{out2} - v_{out1})$$

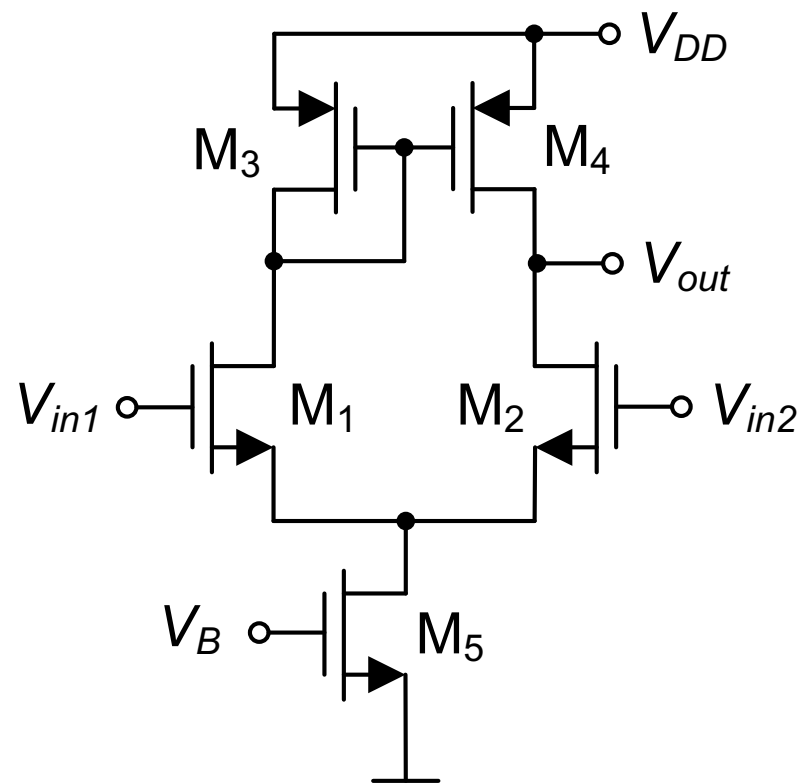
$g_m r_{ce} \gg 1$:

$$v_{in1} - v_{in2} = \frac{1}{g_{m1}}\left(g_{m3} + \frac{1}{r_{ce1}}\right)(v_{out2} - v_{out1})$$

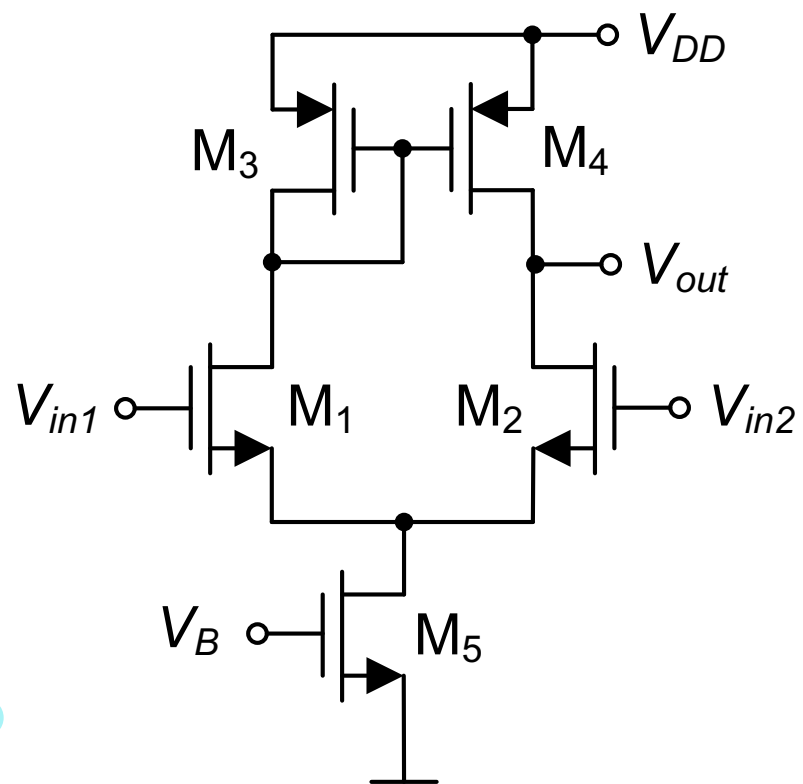
$$A_d = \frac{v_{out1} - v_{out2}}{v_{in1} - v_{in2}} \approx -\frac{g_{m1}}{g_{m3} + \frac{1}{r_{ce1}}} \approx -1$$

ZADATAK 2

Za kolo prikazano na slici, izračunati napon V_B tako da je diferencijalno pojačanje $A_d = v_{out}/(v_{in1} - v_{in2}) = 40$. MOSFET-ovi M_1 i M_2 su identičnih karakteristika. MOSFET-ovi M_3 i M_4 su identičnih karakteristika. Svi MOSFET-ovi rade u zasićenju. Poznato je $\beta_1 = \beta_2 = 0.5\beta_5$, $V_{tn} = 0.5$ V, $\lambda_1 = \lambda_2 = 0.04$ V⁻¹, $\lambda_3 = \lambda_4 = 0.06$ V⁻¹, $\lambda_5 = 0$. Smatrati da su struje strujnog ogledala približno jednake. Pretpostaviti da je $g_m r_{ds} \gg 1$.



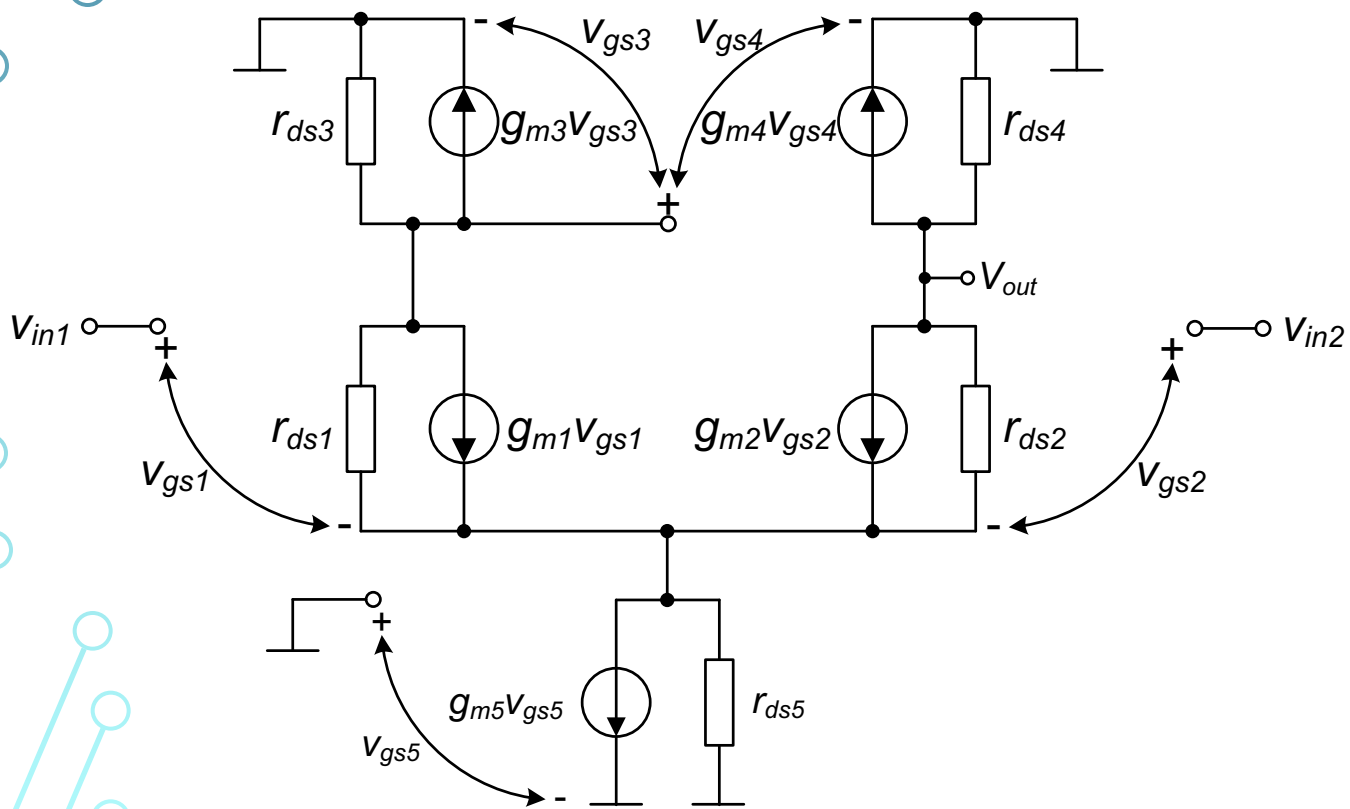
ZADATAK 2



$$I_{D1} = I_{D2} = I_{D3} = I_{D4} = \frac{I_{D5}}{2}$$

$$V_B = V_{GS5} = \sqrt{\frac{2I_{D5}}{\beta_5}} + V_{tn}$$

ZADATAK 2



$$\lambda_5 \rightarrow 0 \Rightarrow r_{ds5} \rightarrow \infty$$

$$v_{gs5} = 0$$

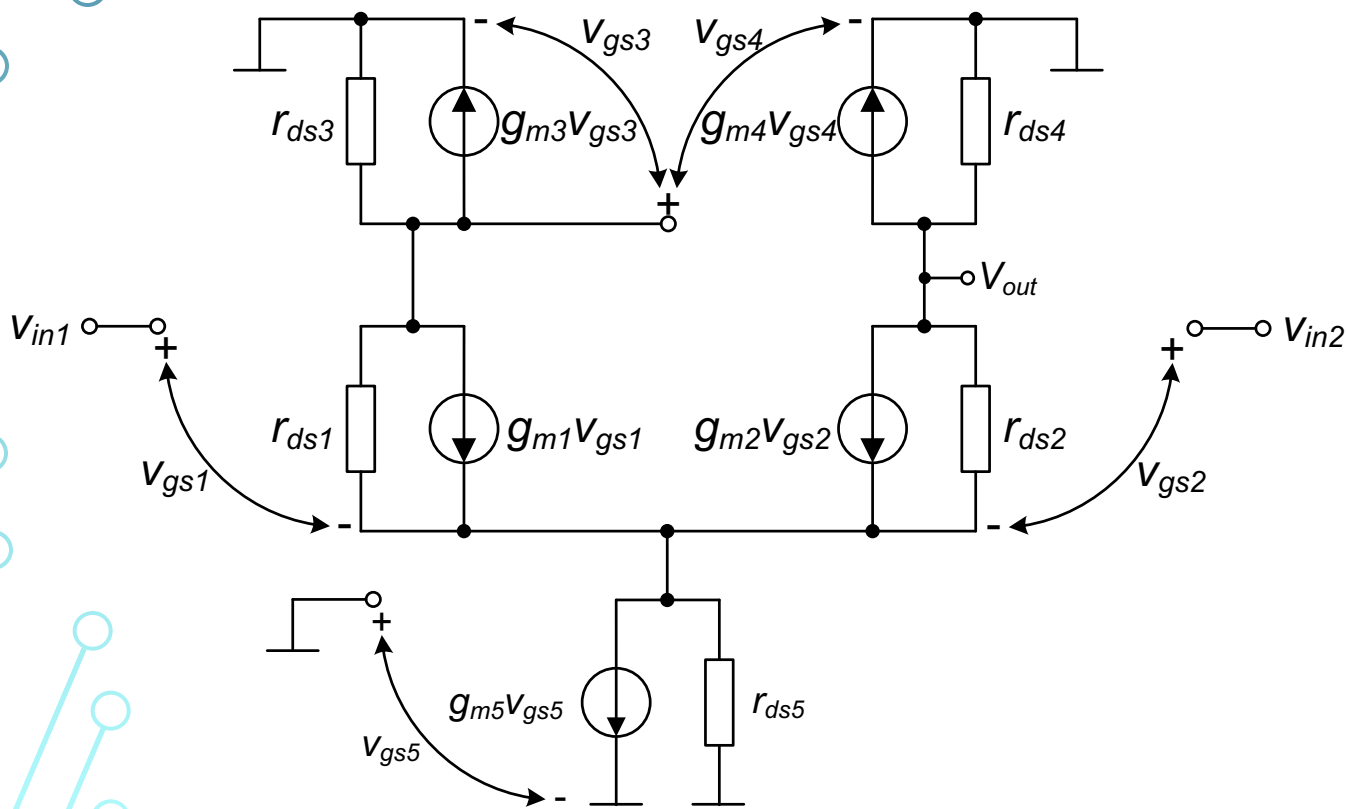
$$v_{gs3} = v_{gs4}$$

$$g_{m1}v_{gs1} + \frac{v_{gs3} + v_{gs1} - v_{in1}}{r_{ds1}} + g_{m3}v_{gs3} + \frac{v_{gs3}}{r_{ds3}} = 0$$

$$g_m r_{ds} \gg 1:$$

$$v_{gs1} = \frac{v_{in1}}{g_{m1}r_{ds1}} - \frac{1}{g_{m1}} \left(g_{m3} + \frac{1}{r_{ds1}} \right) v_{gs3}$$

ZADATAK 2



$$g_{m2}v_{gs2} + \frac{v_{out} + v_{gs2} - v_{in2}}{r_{ds2}} + g_{m4}v_{gs4} + \frac{v_{out}}{r_{ds4}} = 0$$

$g_m r_{ds} \gg 1$:

$$v_{gs2} = \frac{v_{in2}}{g_{m2}r_{ds2}} - \frac{1}{g_{m2}} \left(\frac{1}{r_{ds2}} + \frac{1}{r_{ds4}} \right) v_{out} - \frac{g_{m4}}{g_{m2}} v_{gs3}$$

$$g_{m1}v_{gs1} + \frac{v_{gs3} + v_{gs1} - v_{in1}}{r_{ds1}} + g_{m2}v_{gs2} + \frac{v_{out} + v_{gs2} - v_{in2}}{r_{ds2}} = 0$$

ZADATAK 2

$$g_{m1}v_{gs1} + \frac{v_{gs3} + v_{gs1} - v_{in1}}{r_{ds1}} + g_{m2}v_{gs2} + \frac{v_{out} + v_{gs2} - v_{in2}}{r_{ds2}} = 0$$

$$v_{gs1} = \frac{v_{in1}}{g_{m1}r_{ds1}} - \frac{1}{g_{m1}} \left(g_{m3} + \frac{1}{r_{ds1}} \right) v_{gs3}$$

$$v_{gs2} = \frac{v_{in2}}{g_{m2}r_{ds2}} - \frac{1}{g_{m2}} \left(\frac{1}{r_{ds2}} + \frac{1}{r_{ds4}} \right) v_{out} - \frac{g_{m4}}{g_{m2}} v_{gs3}$$

$g_m r_{ds} \gg 1$:

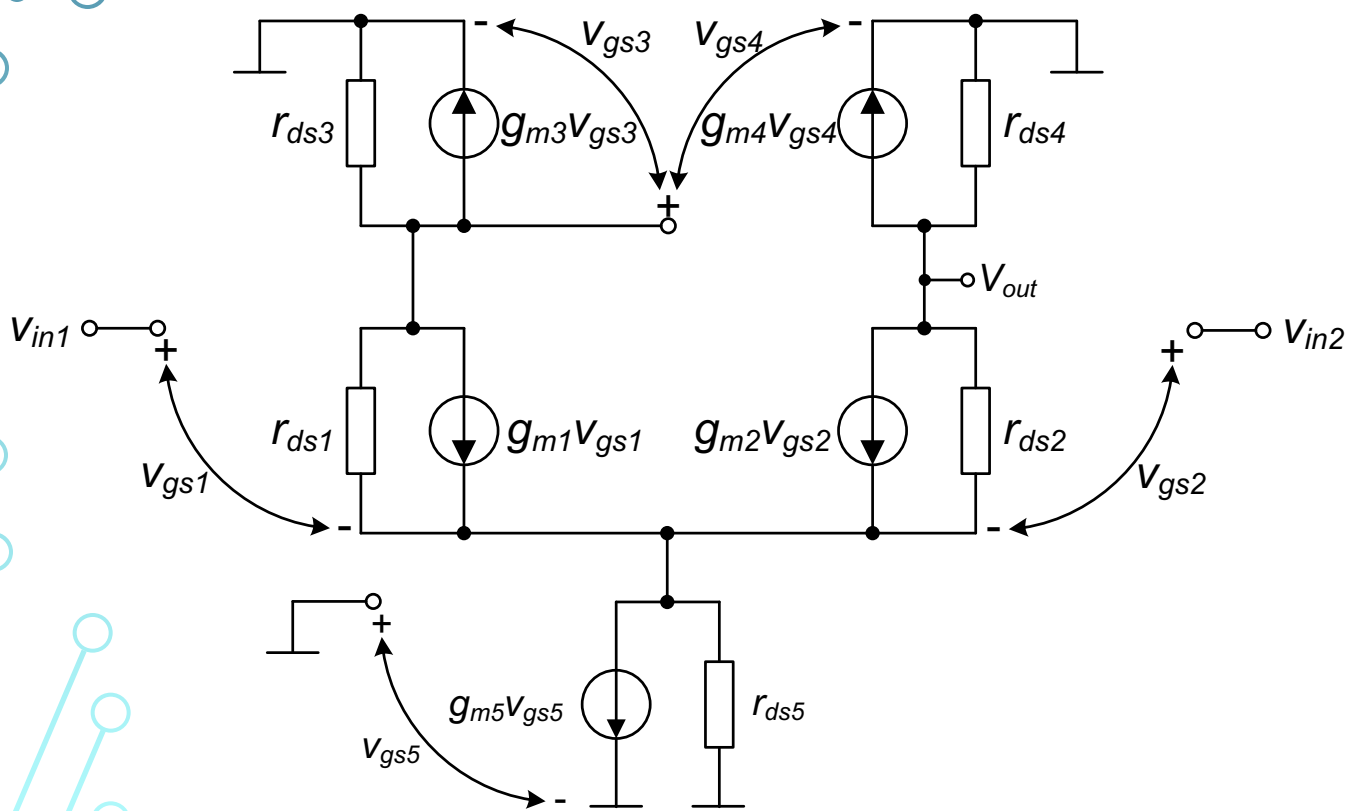
$$g_{m1}v_{gs1} + \frac{v_{gs3} - v_{in1}}{r_{ds1}} + g_{m2}v_{gs2} + \frac{v_{out} - v_{in2}}{r_{ds2}} = 0$$

$$\frac{v_{in1}}{r_{ds1}} - \left(g_{m3} + \frac{1}{r_{ds1}} \right) v_{gs3} + \frac{v_{gs3} - v_{in1}}{r_{ds1}} + \frac{v_{in2}}{r_{ds2}} - \left(\frac{1}{r_{ds2}} + \frac{1}{r_{ds4}} \right) v_{out} - g_{m4}v_{gs3} + \frac{v_{out} - v_{in2}}{r_{ds2}} = 0$$

$$-g_{m3}v_{gs3} - g_{m4}v_{gs3} - \frac{v_{out}}{r_{ds4}} = 0$$

$$v_{gs3} = -\frac{v_{out}}{2g_{m3}r_{ds4}}$$

ZADATAK 2



$$v_{in1} - v_{gs1} + v_{gs2} - v_{in2} = 0$$

ZADATAK 2

$$v_{in1} - v_{gs1} + v_{gs2} - v_{in2} = 0$$

$$v_{gs1} = \frac{v_{in1}}{g_{m1}r_{ds1}} - \frac{1}{g_{m1}} \left(g_{m3} + \frac{1}{r_{ds1}} \right) v_{gs3}$$

$$v_{gs2} = \frac{v_{in2}}{g_{m2}r_{ds2}} - \frac{1}{g_{m2}} \left(\frac{1}{r_{ds2}} + \frac{1}{r_{ds4}} \right) v_{out} - \frac{g_{m4}}{g_{m2}} v_{gs3}$$

$$v_{gs2} - v_{gs1} \approx \frac{1}{g_{m1}r_{ds1}} (v_{in2} - v_{in1}) - \frac{1}{g_{m2}} \left(\frac{1}{r_{ds2}} + \frac{1}{r_{ds4}} \right) v_{out} + \frac{v_{gs3}}{g_{m1}r_{ds1}}$$

$g_m r_{ds} \gg 1$:

$$v_{in1} - v_{in2} \approx \frac{1}{g_{m2}} \left(\frac{1}{r_{ds2}} + \frac{1}{r_{ds4}} \right) v_{out}$$

$$A_d = \frac{v_{out}}{v_{in1} - v_{in2}} \approx \frac{g_{m2}}{\frac{1}{r_{ds2}} + \frac{1}{r_{ds4}}}$$

ZADATAK 2

$$A_d \approx \frac{g_{m2}}{\frac{1}{r_{ds2}} + \frac{1}{r_{ds4}}}$$

$$A_d = \frac{\sqrt{2\beta_2 I_{D2}}}{\lambda_2 I_{D2} + \lambda_4 I_{D4}} = 40$$

$$\frac{\sqrt{\frac{\beta_5 I_{D5}}{2}}}{\frac{I_{D5}}{2} (\lambda_2 + \lambda_4)} = 40$$

$$\sqrt{\frac{2\beta_5}{I_{D5}}} = 40(\lambda_2 + \lambda_4)$$

$$V_B = \sqrt{\frac{2I_{D5}}{\beta_5}} + V_{tn}$$

$$\sqrt{\frac{\beta_5}{2I_{D5}}} = 20(\lambda_2 + \lambda_4)$$

$$\sqrt{\frac{2I_{D5}}{\beta_5}} = \frac{1}{20(\lambda_2 + \lambda_4)}$$

$$V_B = \frac{1}{20(\lambda_2 + \lambda_4)} + V_{tn} = 1 \text{ V}$$