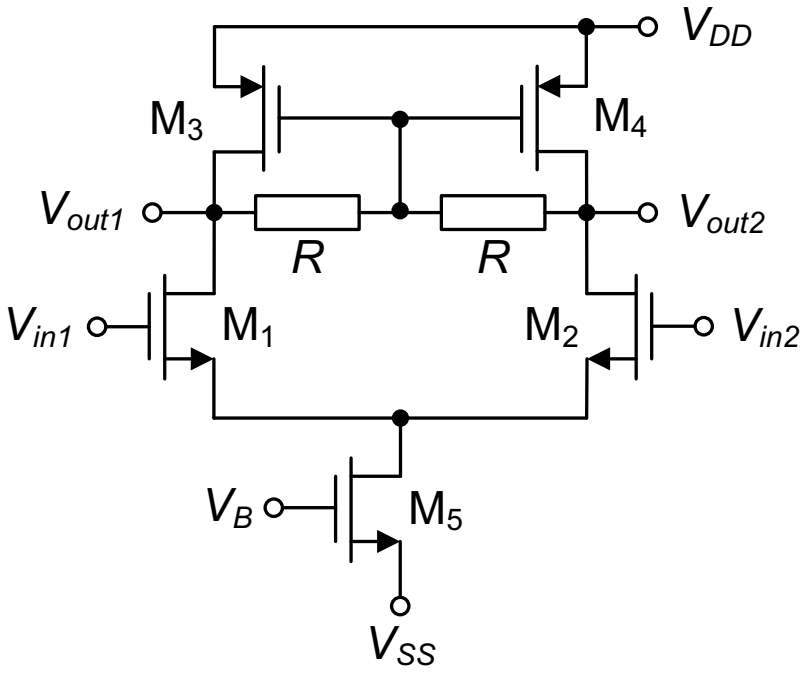
VJEŽBE 11

OSNOVE ELEKTRONIKE, ETR, IV SEMESTAR

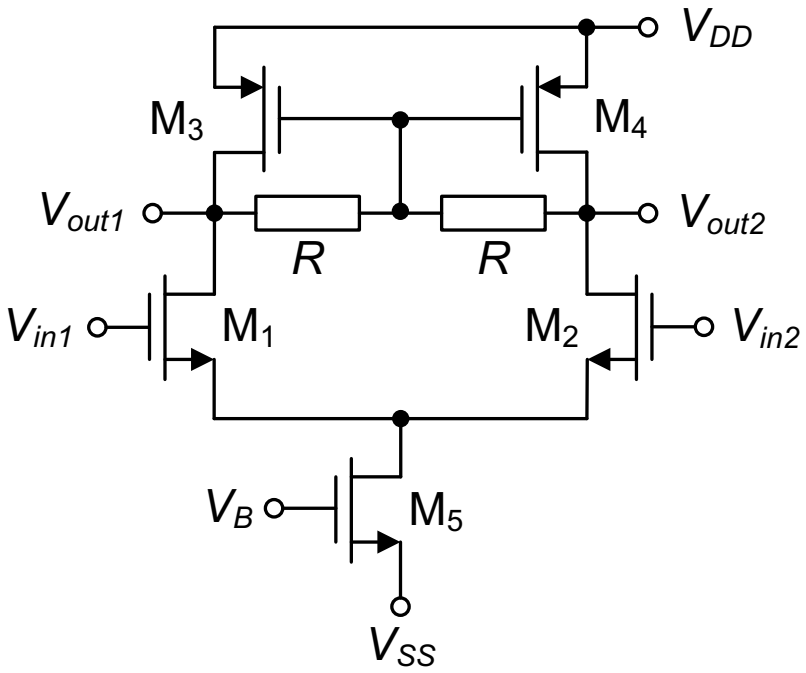
DOC. DR MILENA ERCEG

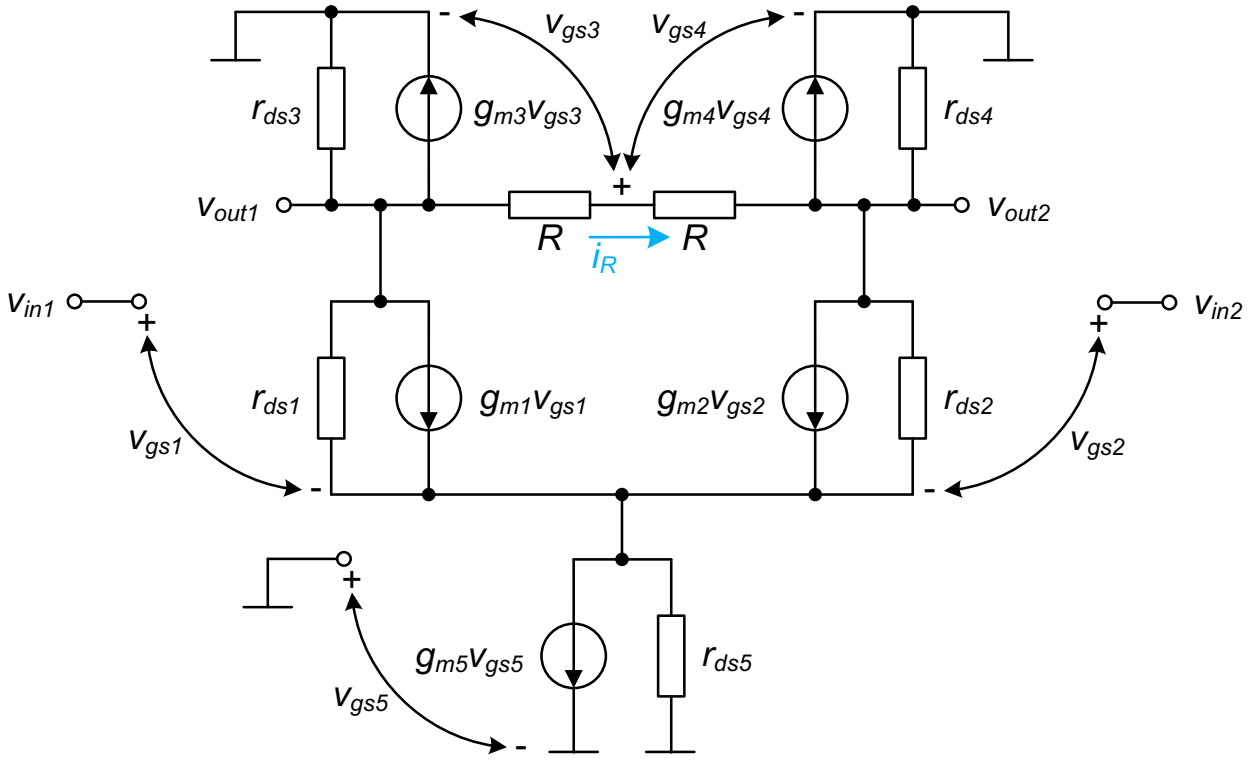
ZADATAK 1

Za kolo prikazano na slici, odrediti diferencijalno naponsko pojačanje $A_d = (v_{out1} - v_{out2})/(v_{in1} - v_{in2})$. 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. Pretpostaviti da je $g_m r_{ds} \gg 1$ i da $\lambda_5 \longrightarrow 0$.

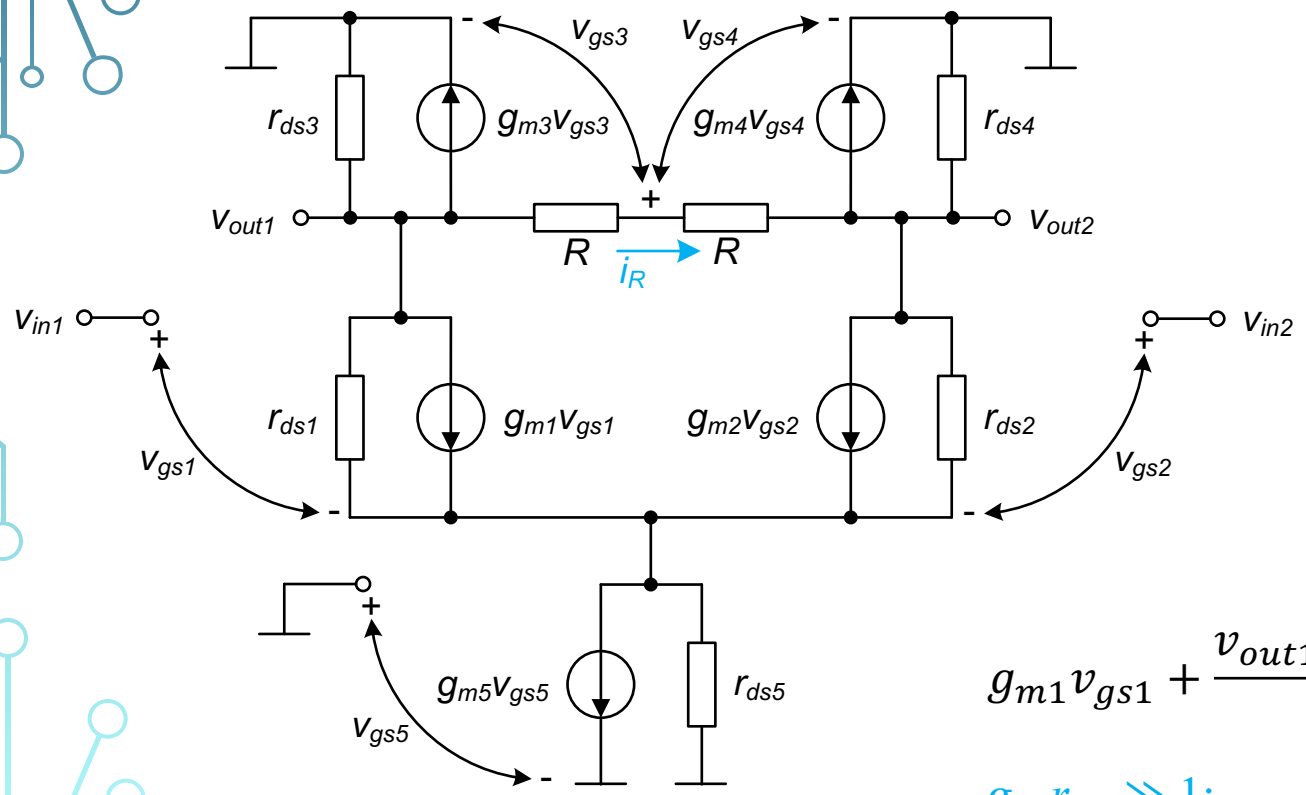


ZADATAK 1


V_{DD}
M_3
M_4
V_{out1}
V_{out2}
R
R
V_{in1}
M_1
M_2
V_{in2}
V_B
M_5
V_{SS}


v_{gs3}
v_{gs4}
r_{ds3}
$g_{m3}v_{gs3}$
$g_{m4}v_{gs4}$
r_{ds4}
v_{out1}
v_{out2}
R
i_R
R
v_{in1}
v_{in2}
r_{ds1}
$g_{m1}v_{gs1}$
$g_{m2}v_{gs2}$
r_{ds2}
v_{gs1}
v_{gs2}
$g_{m5}v_{gs5}$
r_{ds5}
v_{gs5}

ZADATAK 1



$\lambda_5 \longrightarrow 0 \Longrightarrow r_{ds5} \longrightarrow \infty$

$$v_{gs5} = 0$$

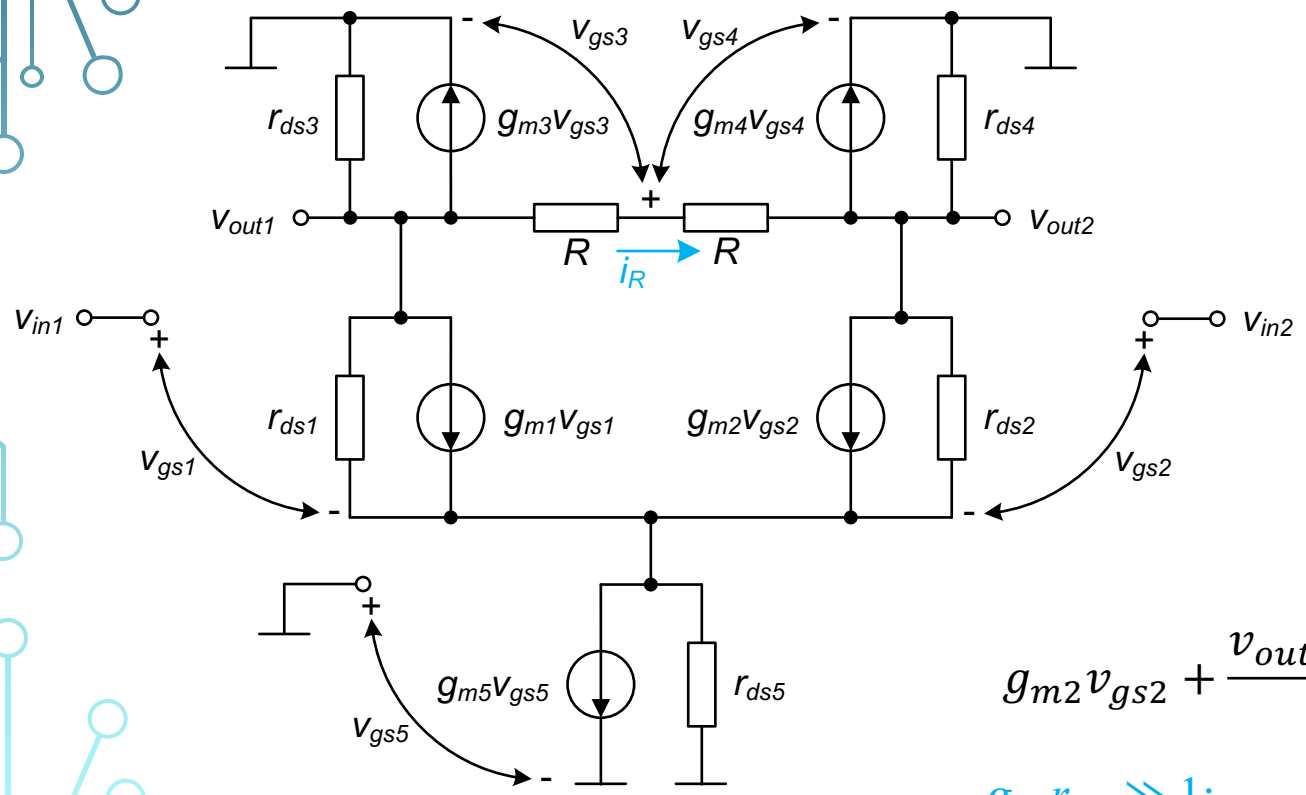
$$i_R = \frac{v_{out1} - v_{gs3}}{R} = \frac{v_{gs4} - v_{out2}}{R}$$

$$g_{m1}v_{gs1} + \frac{v_{out1} + v_{gs1} - v_{in1}}{r_{ds1}} + g_{m3}v_{gs3} + \frac{v_{out1}}{r_{ds3}} + \frac{v_{out1} - v_{gs3}}{R} = 0$$

$g_{m1}r_{ds1} \gg 1$:

$$v_{gs1} = -\frac{1}{g_{m1}}\left(\frac{1}{r_{ds1}} + \frac{1}{r_{ds3}} + \frac{1}{R}\right)v_{out1} + \frac{v_{in1}}{g_{m1}r_{ds1}} - \frac{1}{g_{m1}}\left(g_{m3} - \frac{1}{R}\right)v_{gs3}$$

ZADATAK 1



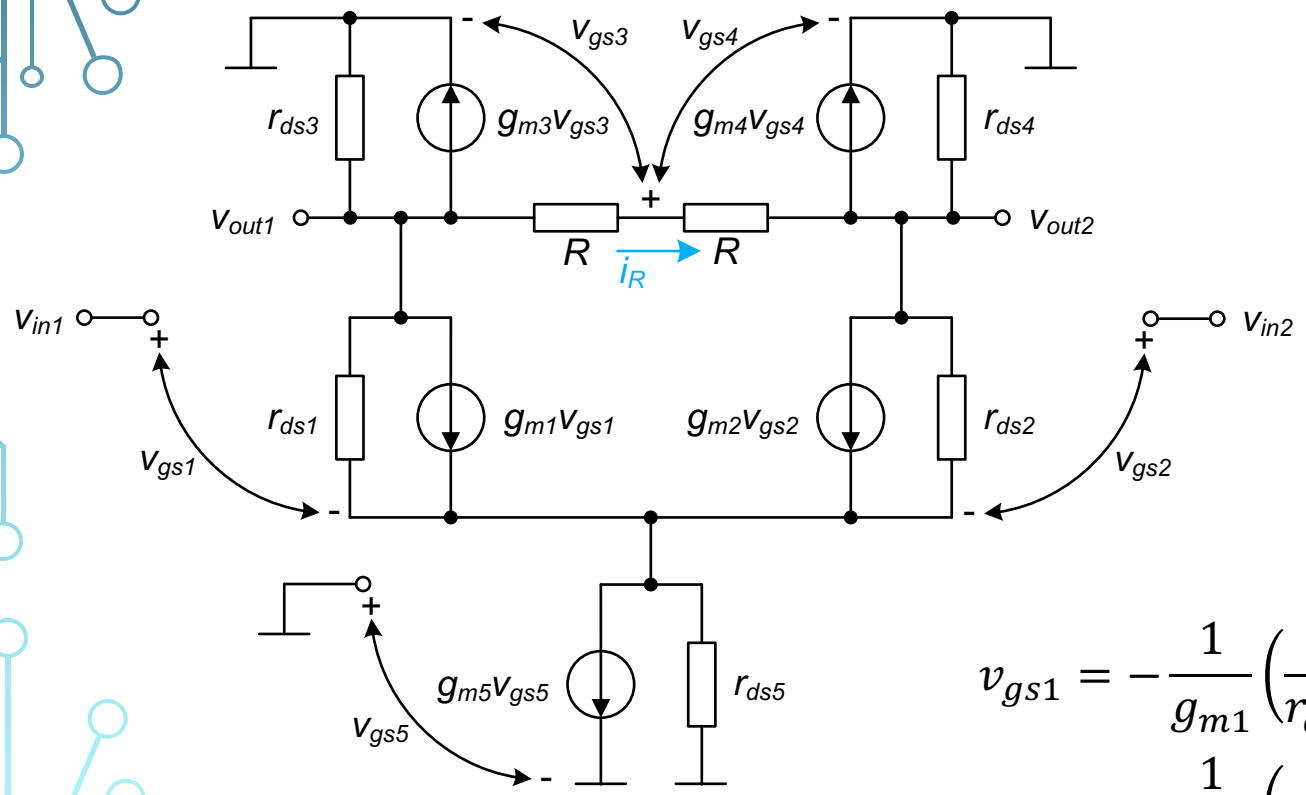
$$i_R = \frac{v_{out1} - v_{gs3}}{R} = \frac{v_{gs4} - v_{out2}}{R}$$

$$g_{m2}v_{gs2} + \frac{v_{out2} + v_{gs2} - v_{in2}}{r_{ds2}} + g_{m4}v_{gs4} + \frac{v_{out2}}{r_{ds4}} - \frac{v_{gs4} - v_{out2}}{R} = 0$$

$g_{m2}r_{ds2} \gg 1$:

$$v_{gs2} = -\frac{1}{g_{m2}}\left(\frac{1}{r_{ds2}} + \frac{1}{r_{ds4}} + \frac{1}{R}\right)v_{out2} + \frac{v_{in2}}{g_{m2}r_{ds2}} - \frac{1}{g_{m2}}\left(g_{m4} - \frac{1}{R}\right)v_{gs4}$$

ZADATAK 1



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

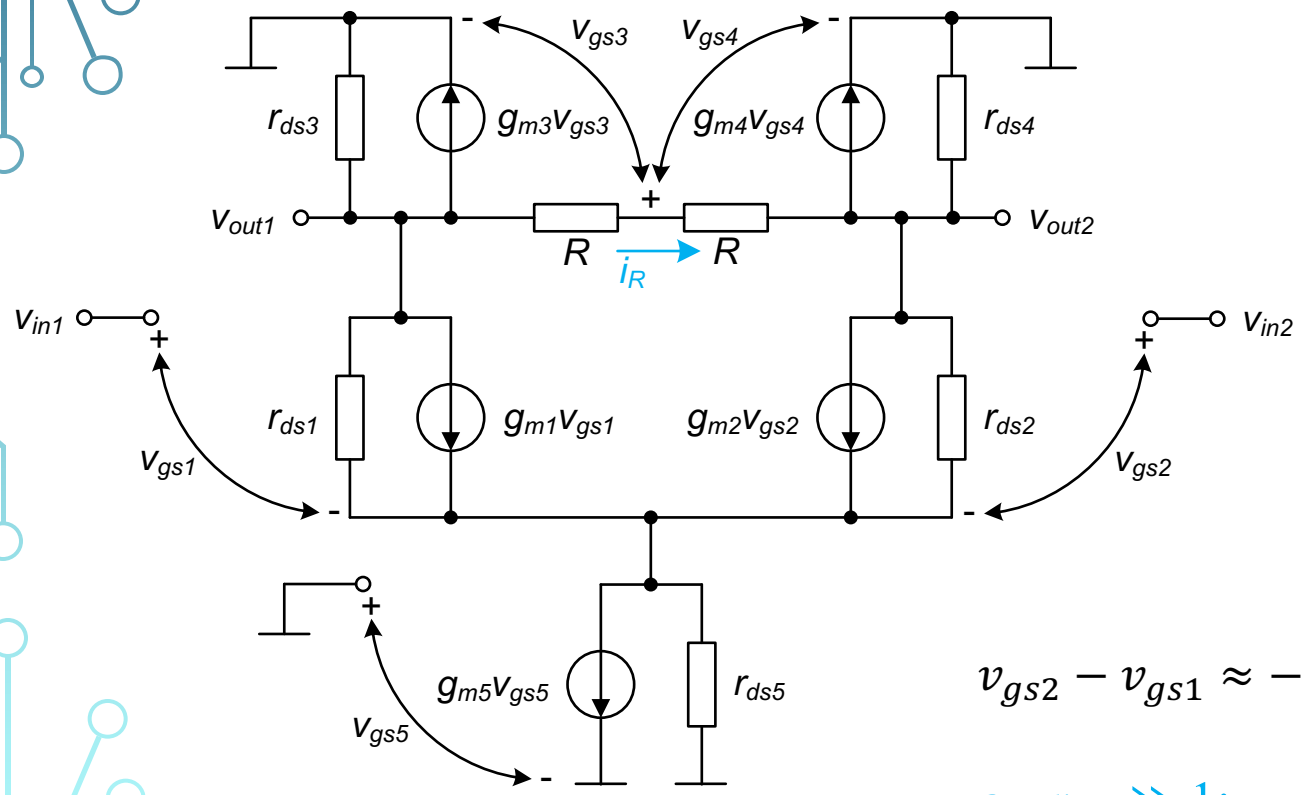
$$v_{gs3} = v_{gs4}$$

$$v_{gs1} = -\frac{1}{g_{m1}}\left(\frac{1}{r_{ds1}} + \frac{1}{r_{ds3}} + \frac{1}{R}\right) v_{out1} + \frac{v_{in1}}{g_{m1} r_{ds1}} - \frac{1}{g_{m1}}\left(g_{m3} - \frac{1}{R}\right) v_{gs3}$$

$$v_{gs2} = -\frac{1}{g_{m2}}\left(\frac{1}{r_{ds2}} + \frac{1}{r_{ds4}} + \frac{1}{R}\right) v_{out2} + \frac{v_{in2}}{g_{m2} r_{ds2}} - \frac{1}{g_{m2}}\left(g_{m4} - \frac{1}{R}\right) v_{gs4}$$

$$v_{gs2} - v_{gs1} \approx -\frac{1}{g_{m2}}\left(\frac{1}{r_{ds2}} + \frac{1}{r_{ds4}} + \frac{1}{R}\right)(v_{out2} - v_{out1}) + \frac{v_{in2} - v_{in1}}{g_{m2} r_{ds2}}$$

ZADATAK 1



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

$$v_{gs2} - v_{gs1} \approx -\frac{1}{g_{m2}}\left(\frac{1}{r_{ds2}} + \frac{1}{r_{ds4}} + \frac{1}{R}\right)(v_{out2} - v_{out1}) + \frac{v_{in2} - v_{in1}}{g_{m2} r_{ds2}}$$

$g_{m2} r_{ds2} \gg 1$:

$$v_{in2} - v_{in1} = -\frac{1}{g_{m2}}\left(\frac{1}{r_{ds2}} + \frac{1}{r_{ds4}} + \frac{1}{R}\right)(v_{out2} - v_{out1})$$

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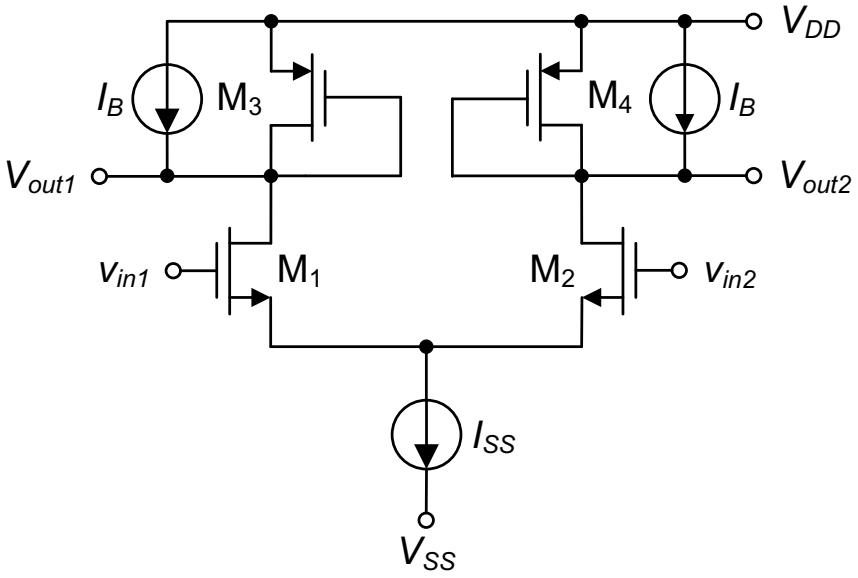
$$v_{in2} - v_{in1} = -\frac{1}{g_{m2}}\left(\frac{1}{r_{ds2}} + \frac{1}{r_{ds4}} + \frac{1}{R}\right)(v_{out2} - v_{out1})$$

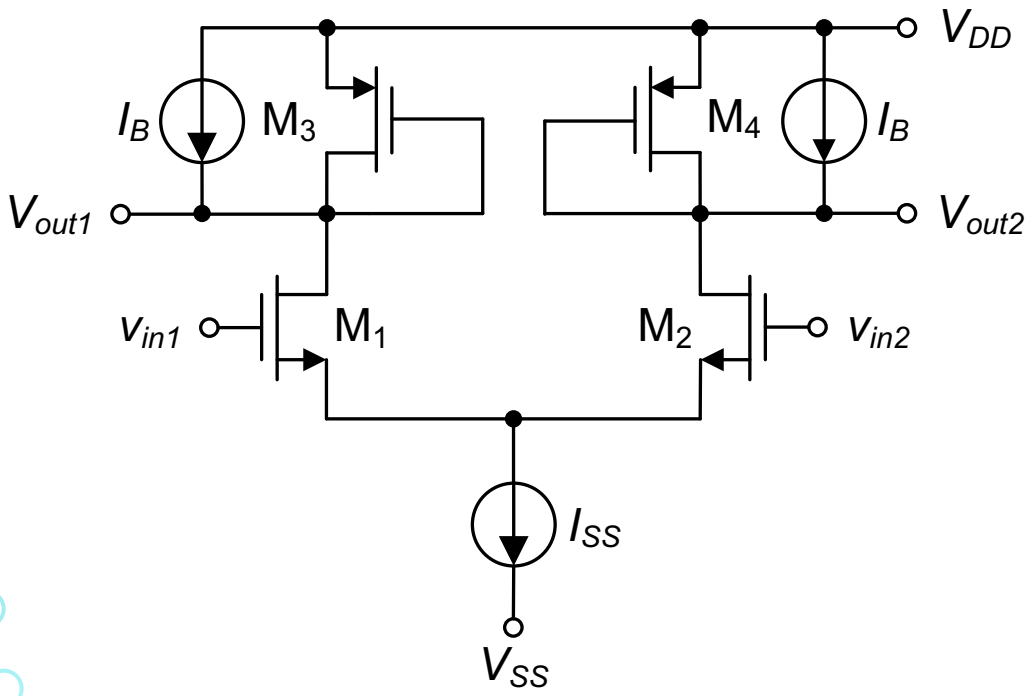
$$A_d = \frac{v_{out1} - v_{out2}}{v_{in1} - v_{in2}} \approx -\frac{g_{m2}}{\frac{1}{r_{ds2}} + \frac{1}{r_{ds4}} + \frac{1}{R}}$$

ZADATAK 1

Za kolo prikazano na slici, izračunati odnos struja I_B i I_{SS} tako da diferencijalna pojačanja budu $A_{v1} = v_{out1}/(v_{in1} - v_{in2}) = -40$ i $A_{v2} = v_{out2}/(v_{in1} - v_{in2}) = 40$. MOSFET-ovi M_1 i M_2 su identičnih karakteristika i rade u zasićenju. MOSFET-ovi M_3 i M_4 su identičnih karakteristika. Poznato je $\beta_1 = \beta_2 = 16\beta_3 = 16\beta_4$. Pretpostaviti da je $g_m r_{ds} \gg 1$.



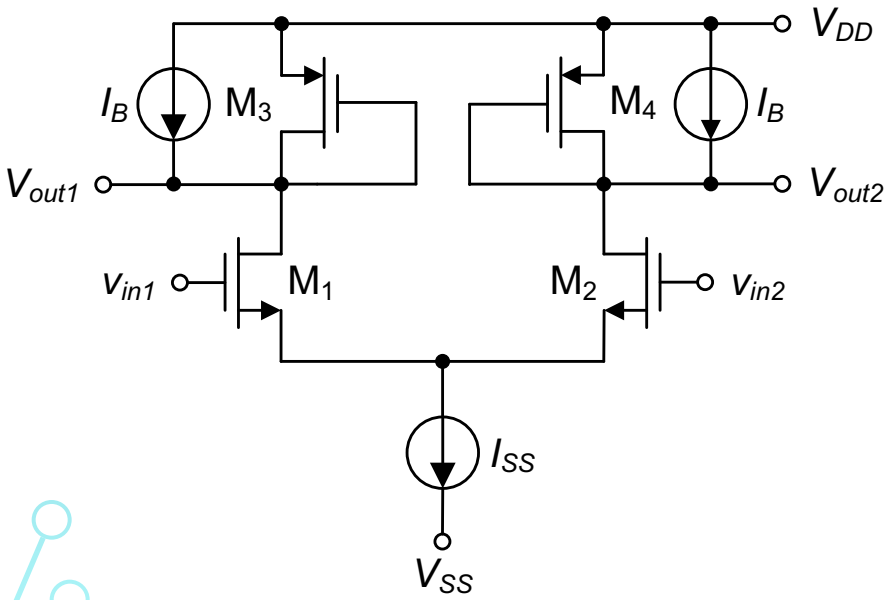
ZADATAK 1

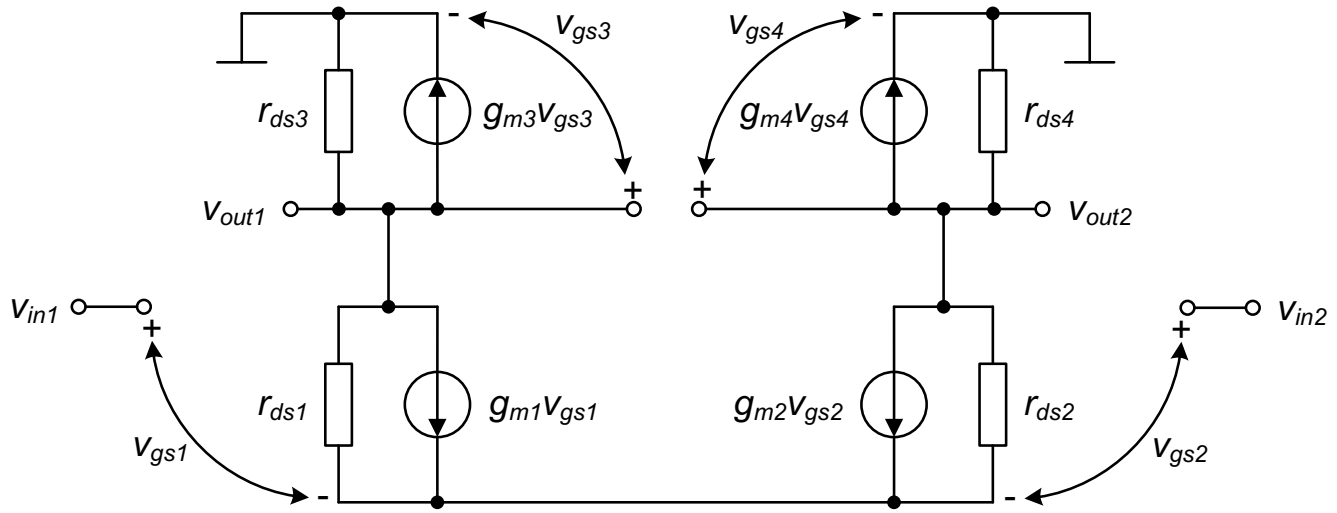


$$I_{D1} = I_{D2} = \frac{I_{SS}}{2}$$

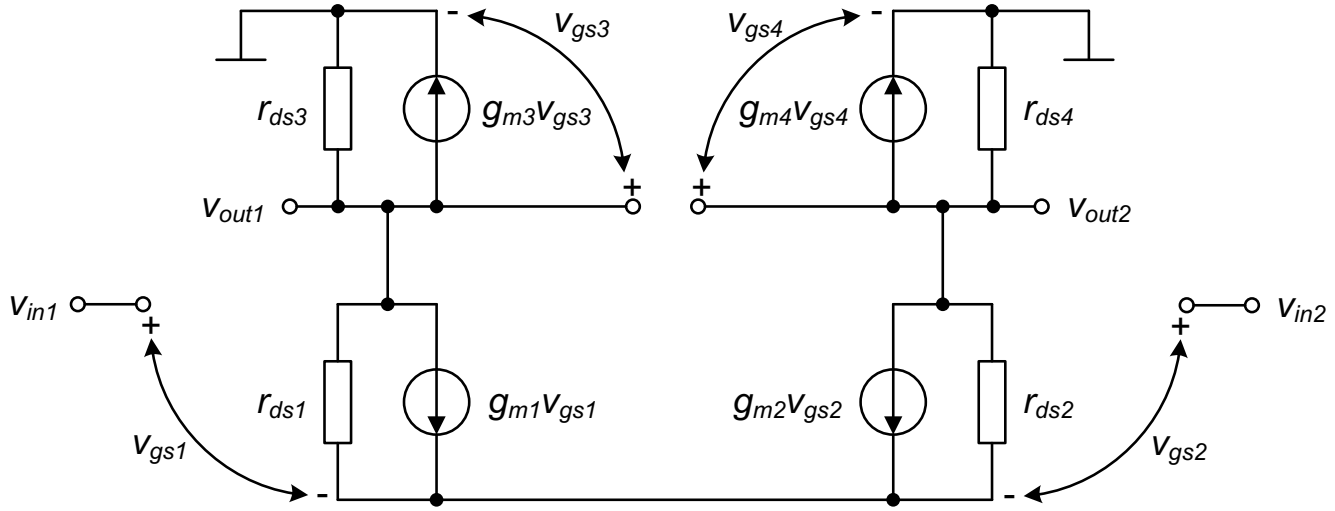
$$I_{D3} = I_{D4} = \frac{I_{SS}}{2} - I_B$$

ZADATAK 1


V_{DD}
I_B
M_3
M_4
I_B
V_{out1}
V_{out2}
v_{in1}
M_1
M_2
v_{in2}
I_{SS}
V_{SS}


v_{gs3}
v_{gs4}
r_{ds3}
$g_{m3}v_{gs3}$
$g_{m4}v_{gs4}$
r_{ds4}
v_{out1}
v_{out2}
v_{in1}
v_{in2}
r_{ds1}
$g_{m1}v_{gs1}$
$g_{m2}v_{gs2}$
r_{ds2}
v_{gs1}
v_{gs2}

ZADATAK 1



$$v_{gs3} = v_{out1}$$

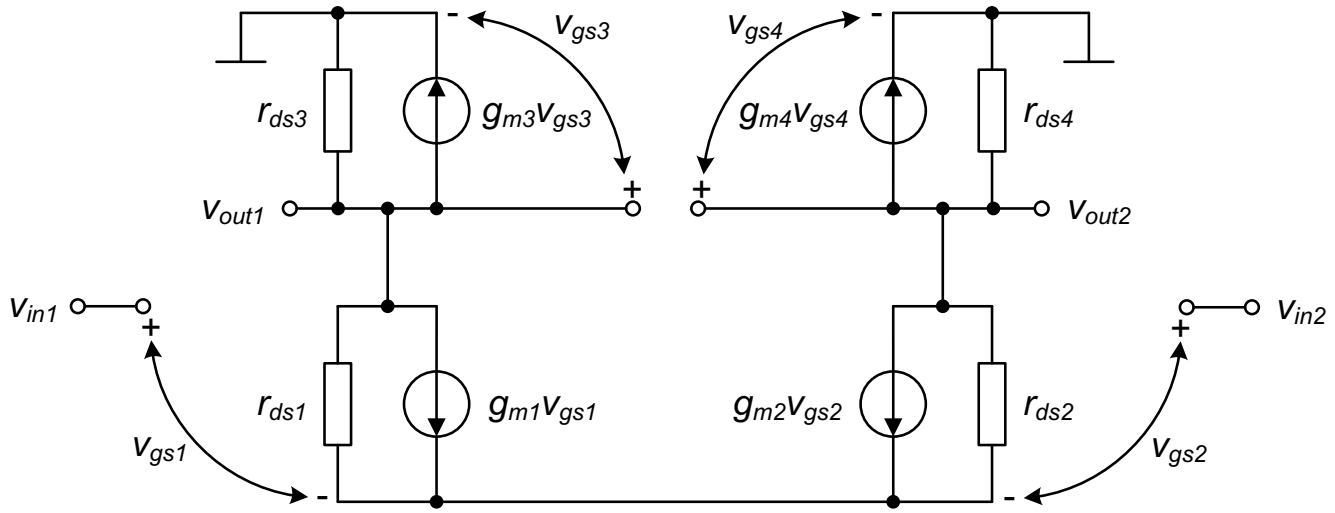
$$v_{gs4} = v_{out2}$$

$$g_{m1}v_{gs1} + \frac{v_{out1} + v_{gs1} - v_{in1}}{r_{ds1}} + g_{m3}v_{out1} + \frac{v_{out1}}{r_{ds3}} = 0$$

$g_{m1}r_{ds1} \gg 1$, $g_{m3}r_{ds3} \gg 1$:

$$v_{gs1} = -\frac{1}{g_{m1}}\left(g_{m3} + \frac{1}{r_{ds1}}\right)v_{out1} + \frac{v_{in1}}{g_{m1}r_{ds1}}$$

ZADATAK 1



$$v_{gs3} = v_{out1}$$

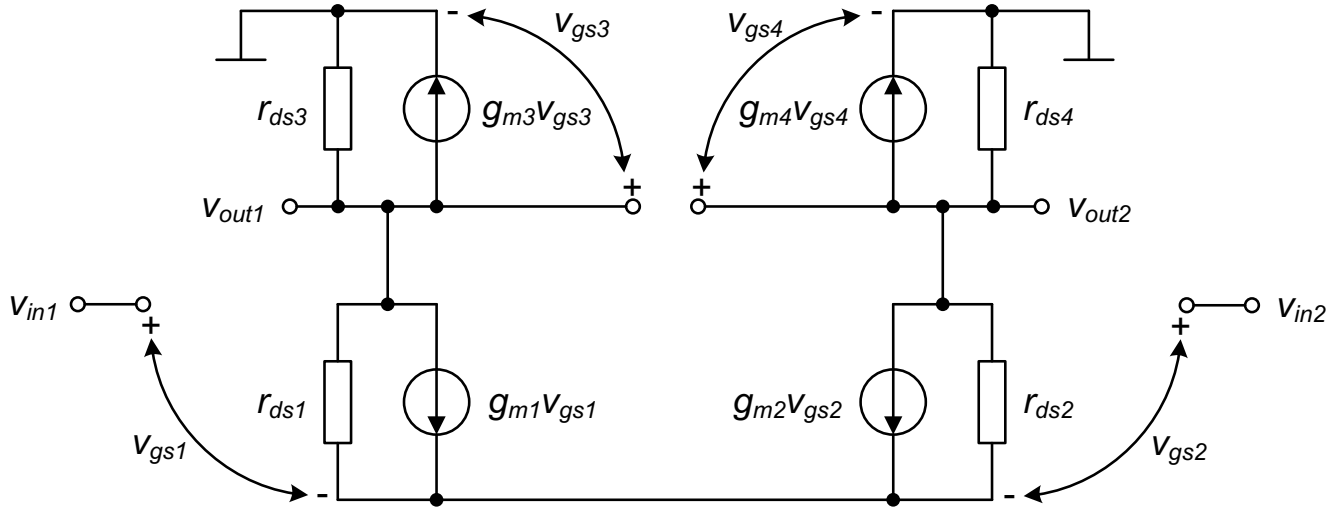
$$v_{gs4} = v_{out2}$$

$$g_{m2}v_{gs2} + \frac{v_{out2} + v_{gs2} - v_{in2}}{r_{ds2}} + g_{m4}v_{out2} + \frac{v_{out2}}{r_{ds4}} = 0$$

$g_{m2}r_{ds2} \gg 1$, $g_{m4}r_{ds4} \gg 1$:

$$v_{gs2} = -\frac{1}{g_{m2}}\left(g_{m4} + \frac{1}{r_{ds2}}\right)v_{out2} + \frac{v_{in2}}{g_{m2}r_{ds2}}$$

ZADATAK 1



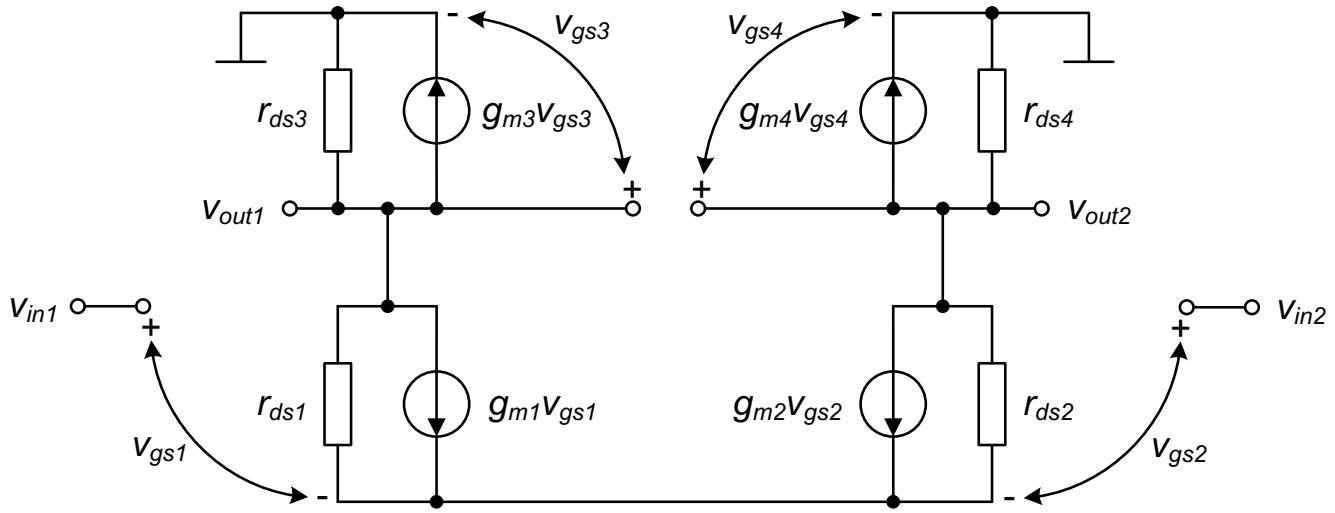
$$v_{in1} - v_{gs1} + v_{gs2} - v_{in2} = 0$$

$$v_{gs1} = -\frac{1}{g_{m1}}\left(g_{m3} + \frac{1}{r_{ds1}}\right)v_{out1} + \frac{v_{in1}}{g_{m1}r_{ds1}}$$

$$v_{gs2} = -\frac{1}{g_{m2}}\left(g_{m4} + \frac{1}{r_{ds2}}\right)v_{out2} + \frac{v_{in2}}{g_{m2}r_{ds2}}$$

$$v_{gs2} - v_{gs1} \approx -\frac{1}{g_{m2}}\left(g_{m4} + \frac{1}{r_{ds2}}\right)(v_{out2} - v_{out1}) + \frac{v_{in2} - v_{in1}}{g_{m2}r_{ds2}}$$

ZADATAK 1



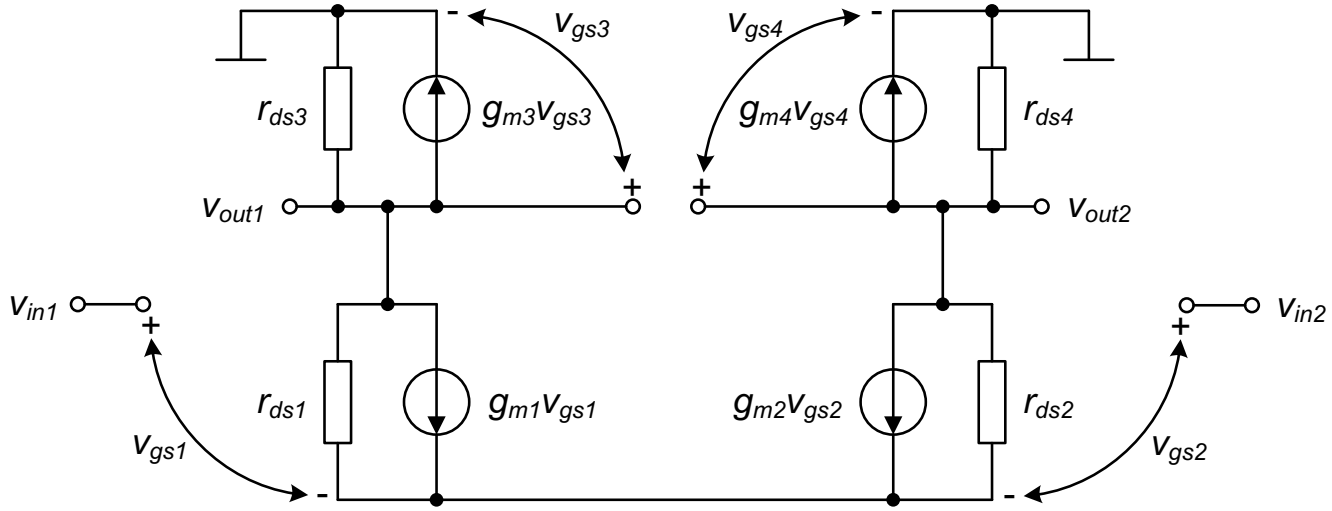
$$v_{in1} - v_{gs1} + v_{gs2} - v_{in2} = 0$$

$$v_{gs2} - v_{gs1} \approx -\frac{1}{g_{m2}}\left(g_{m4} + \frac{1}{r_{ds2}}\right)(v_{out2} - v_{out1}) + \frac{v_{in2} - v_{in1}}{g_{m2} r_{ds2}}$$

$$v_{in2} - v_{in1} \approx -\frac{1}{g_{m2}}\left(g_{m4} + \frac{1}{r_{ds2}}\right)(v_{out2} - v_{out1})$$

$$A_d = \frac{v_{out1} - v_{out2}}{v_{in1} - v_{in2}} \approx -\frac{g_{m2}}{g_{m4} + \frac{1}{r_{ds2}}}$$

ZADATAK 1



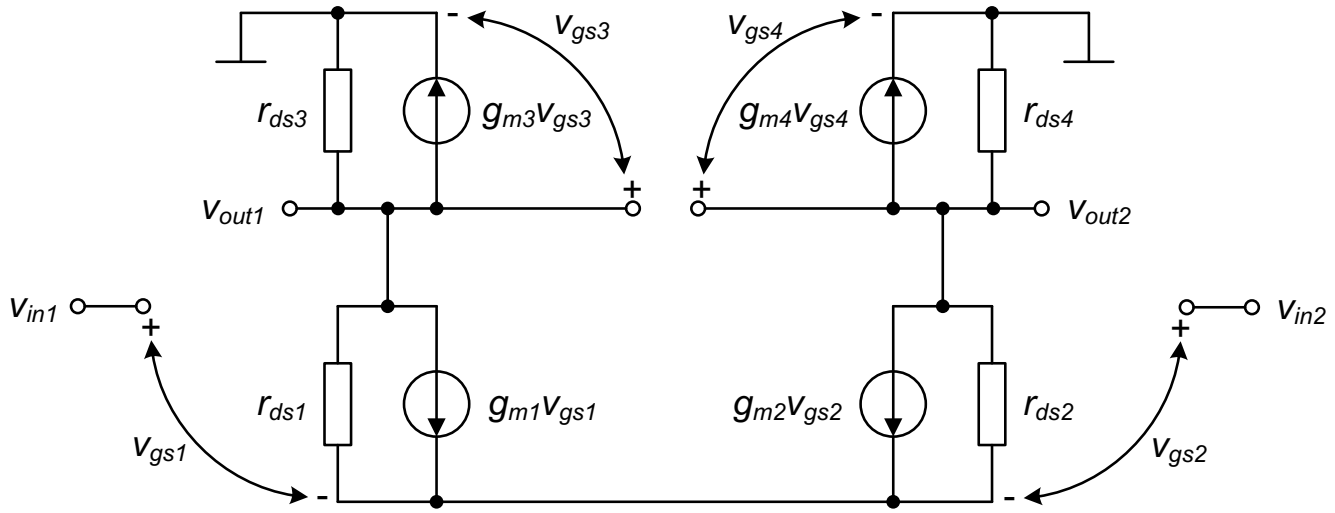
$$g_{m1}v_{gs1} + \frac{v_{out1} + v_{gs1} - v_{in1}}{r_{ds1}} + g_{m2}\, v_{gs2} + \frac{v_{out2} + v_{gs2} - v_{in2}}{r_{ds2}} = 0$$

$$g_{m1}\left(v_{gs1} + v_{gs2}\right) + \frac{v_{out1} + v_{out2}}{r_{ds1}} - \frac{v_{in1} + v_{in2}}{r_{ds1}} = 0$$

$$v_{gs1} = -\frac{1}{g_{m1}}\left(g_{m3} + \frac{1}{r_{ds1}}\right)v_{out1} + \frac{v_{in1}}{g_{m1}r_{ds1}}$$

$$v_{gs2} = -\frac{1}{g_{m2}}\left(g_{m4} + \frac{1}{r_{ds2}}\right)v_{out2} + \frac{v_{in2}}{g_{m2}r_{ds2}}$$

ZADATAK 1

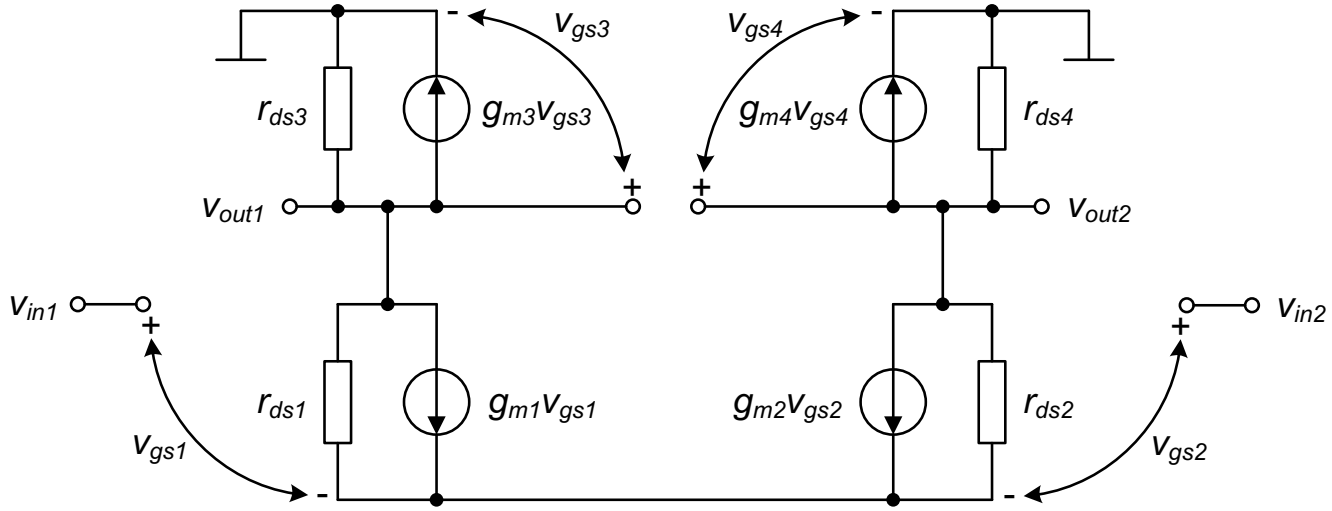


$$v_{gs1} = -\frac{1}{g_{m1}}\left(g_{m3} + \frac{1}{r_{ds1}}\right)v_{out1} + \frac{v_{in1}}{g_{m1}r_{ds1}}$$

$$v_{gs2} = -\frac{1}{g_{m2}}\left(g_{m4} + \frac{1}{r_{ds2}}\right)v_{out2} + \frac{v_{in2}}{g_{m2}r_{ds2}}$$

$$v_{gs1} + v_{gs2} \approx -\frac{1}{g_{m2}}\left(g_{m4} + \frac{1}{r_{ds2}}\right)(v_{out2} + v_{out1}) + \frac{v_{in2} + v_{in1}}{g_{m2}r_{ds2}}$$

ZADATAK 1



$$g_{m1}(v_{gs1} + v_{gs2}) + \frac{v_{out1} + v_{out2}}{r_{ds1}} - \frac{v_{in1} + v_{in2}}{r_{ds1}} = 0$$

$$v_{gs1} + v_{gs2} \approx -\frac{1}{g_{m2}}\left(g_{m4} + \frac{1}{r_{ds2}}\right)(v_{out2} + v_{out1}) + \frac{v_{in2} + v_{in1}}{g_{m2}r_{ds2}}$$

$$-\left(g_{m4} + \frac{1}{r_{ds2}}\right)(v_{out2} + v_{out1}) + \frac{v_{out1} + v_{out2}}{r_{ds1}} = 0$$

$$v_{out1} = -v_{out2}$$

ZADATAK 1

$$v_{out1} = -v_{out2}$$

$$A_d = \frac{v_{out1} - v_{out2}}{v_{in1} - v_{in2}} \approx -\frac{g_{m2}}{g_{m4} + \frac{1}{r_{ds2}}}$$

$$A_{v1} \approx -\frac{1}{2}\frac{g_{m2}}{g_{m4} + \frac{1}{r_{ds2}}}$$

$$A_{v2} \approx \frac{1}{2}\frac{g_{m2}}{g_{m4} + \frac{1}{r_{ds2}}} \approx \frac{1}{2}\frac{g_{m2}}{g_{m4}}$$

$$\frac{1}{2}\frac{\sqrt{2\beta_2 I_{D2}}}{\sqrt{2\beta_4 I_{D4}}} = 40$$

$$\frac{2\sqrt{\beta_4 I_{D2}}}{\sqrt{\beta_4 I_{D4}}} = 40$$

$$\sqrt{I_{D2}} = 20\sqrt{I_{D4}}$$

$$\sqrt{\frac{I_{SS}}{2}} = 20\sqrt{\frac{I_{SS}}{2} - I_B}$$

$$\frac{I_{SS}}{2} = 400\left(\frac{I_{SS}}{2} - I_B\right)$$

$$I_{SS} = 800\left(\frac{I_{SS}}{2} - I_B\right)$$

$$399 I_{SS} = 800 I_B$$

$$\frac{I_B}{I_{SS}} \approx \frac{1}{2}$$