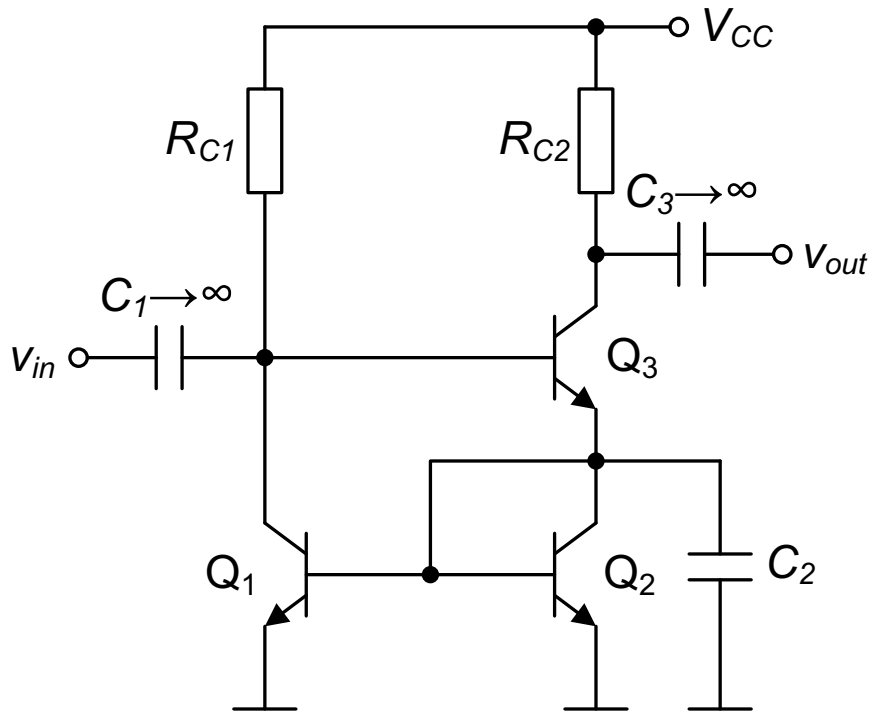
VJEŽBE 7

OSNOVE ELEKTRONIKE, ETR, IV SEMESTAR

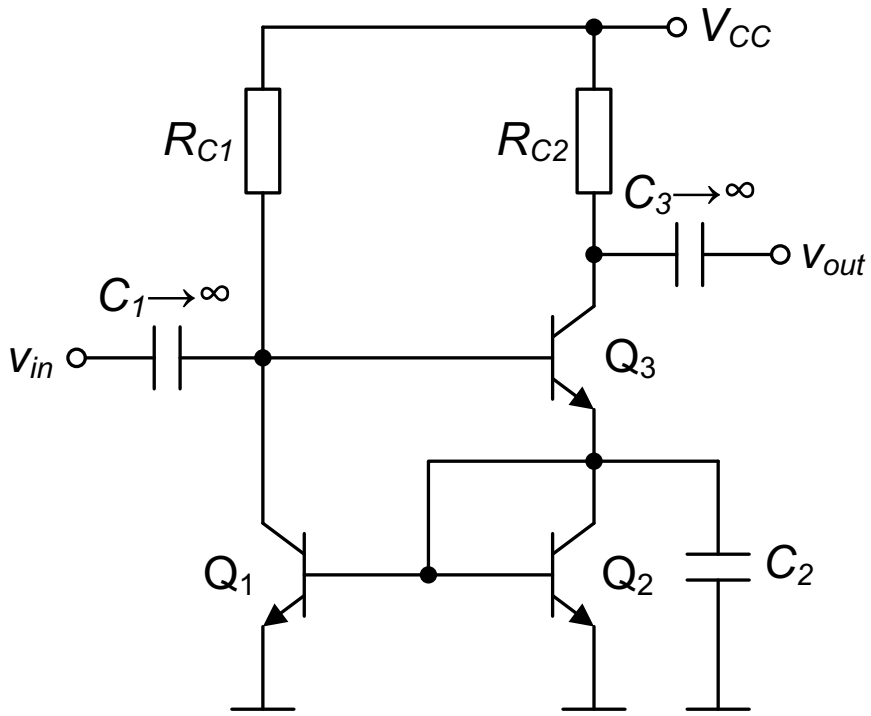
DOC. DR MILENA ERCEG

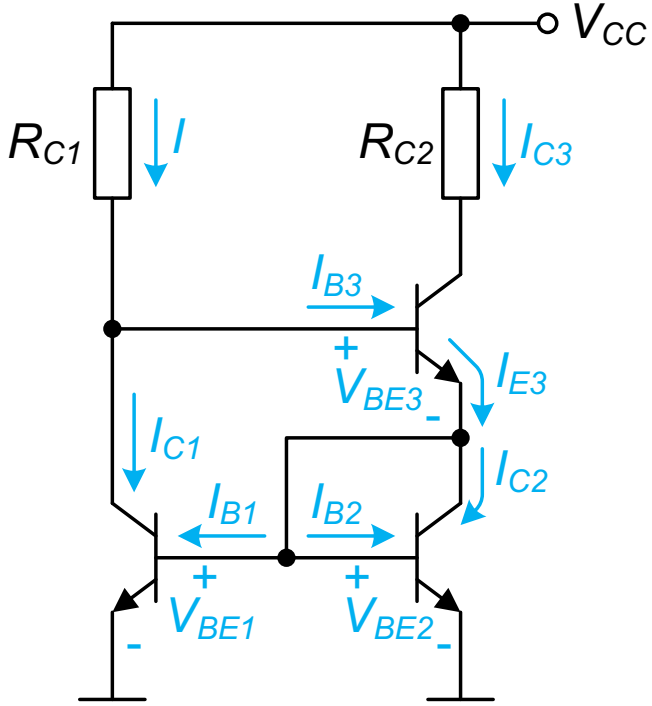
ZADATAK 1

Za kolo prikazano na slici izračunati naponsko pojačanje A_v i ulaznu otpornost R_{in}. Poznato je: napon napajanja kola V_{CC}=11.4 V, otpornosti R_{C1}=10 kΩ i R_{C2}=5 kΩ, napon baza-emitor BJT-a kada provodi V_{BE}=0.7 V, napon kolektor-emitor BJT-a u zasićenju V_{CES}=0.2 V, strujno pojačanje BJT-a β= 100, *Early*-jev napon $V_A \longrightarrow \infty$, termički napon V_T = 25 mV i kapacitivnost C_2: a) $C_2 = 0$, b) $C_2 \longrightarrow \infty$.

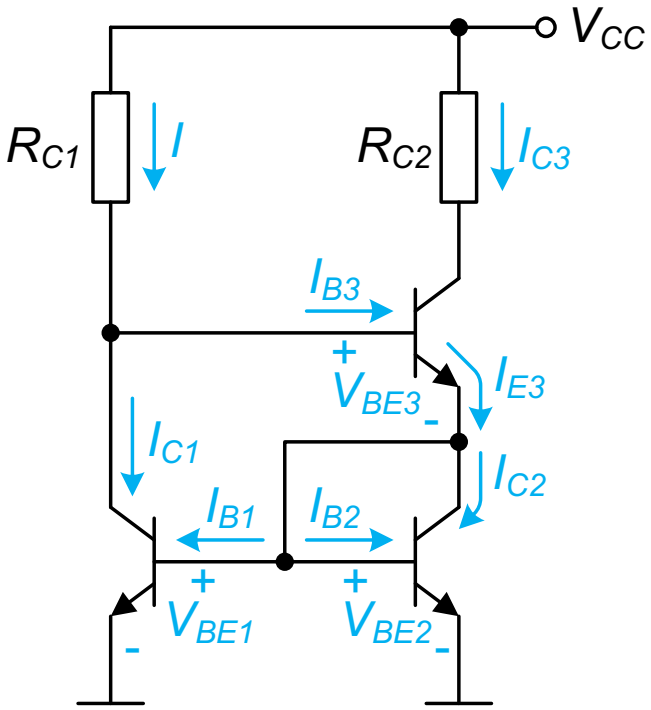


ZADATAK 1 – DC ANALIZA





ZADATAK 1 – DC ANALIZA



$$I = \frac{V_{CC} - V_{BE2} - V_{BE3}}{R_{C1}} = 1\ \text{mA}$$

$$V_{CE1} = V_{CC} - R_{C1}I = 1.4\ V > V_{CES}$$

Slijedi da je BJT Q_1 u DAR-u.

$$V_{CE2} = V_{BE2} = 0.7\ V > V_{CES}$$

Slijedi da je BJT Q_2 također u DAR-u.

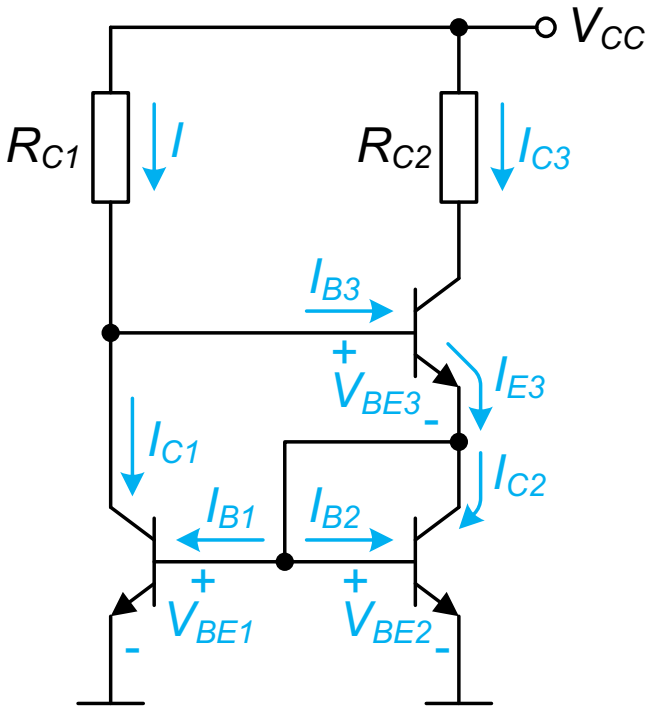
Kako je $V_{BE1} = V_{BE2}$ slijedi da je $I_{C1} = I_{C2}$.

Uvodi se pretpostavka da je i Q_3 u DAR-u.

$$I_{C2} = I_{E3} - I_{B1} - I_{B2} \Rightarrow I_{B3} = \frac{\beta + 2}{\beta + 1} I_{B2}$$

$$I_{C1} = I - I_{B3} \Rightarrow I_{B1} = \frac{\beta + 1}{\beta^2 + 2\beta + 2} I = 9.9\ \mu\text{A}$$

ZADATAK 1 – DC ANALIZA



$$I_{C1} = \beta I_{B1} = 0.99\ \text{mA}$$

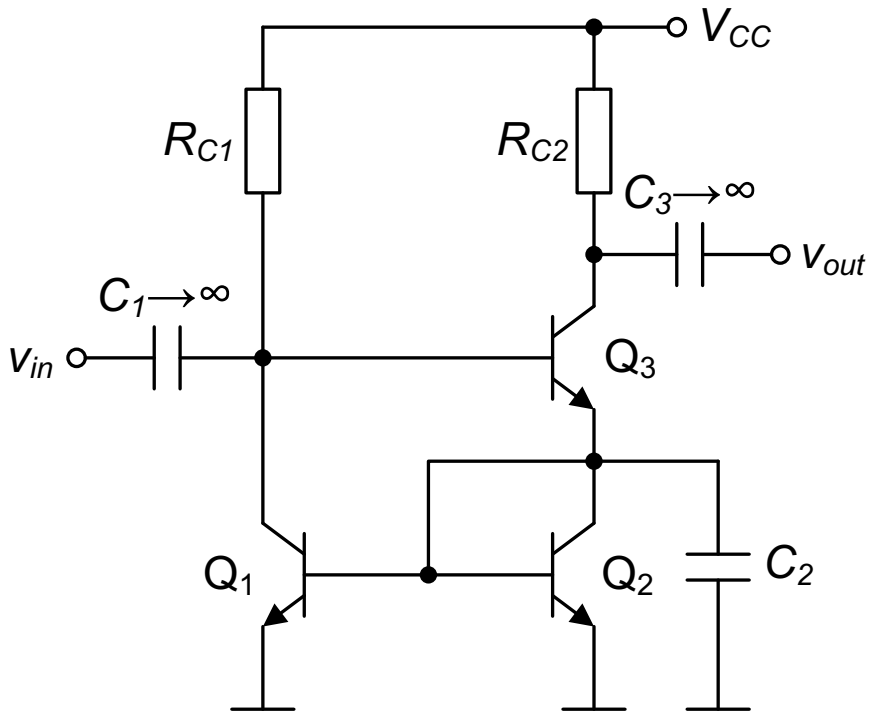
$$I_{C2} = I_{C1} = 0.99\ \text{mA}$$

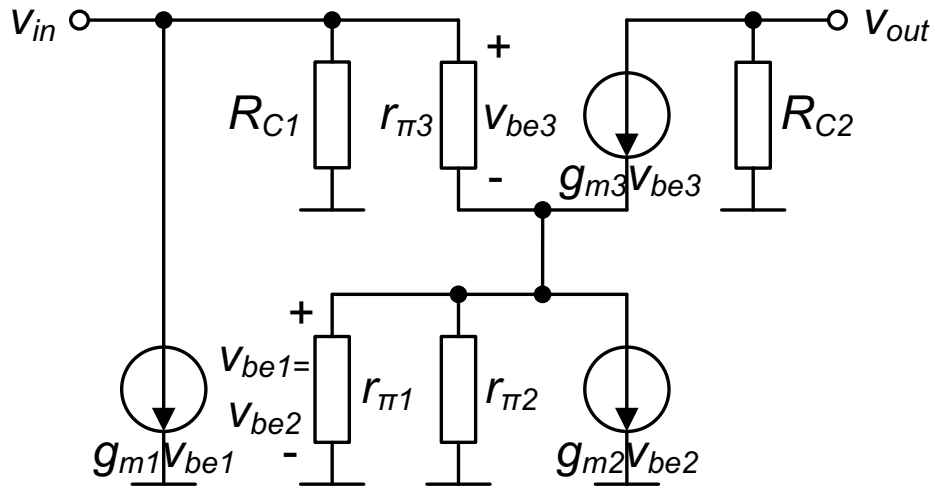
$$I_{C3} = \beta I_{B3} = \beta \frac{\beta + 2}{\beta + 1} I_{B2} = \frac{\beta + 2}{\beta + 1} I_{C2} = 1\ \text{mA}$$

$$V_{CE3} = V_{CC} - R_{C2} I_{C3} - V_{BE2} = 5.7\ \text{V} > V_{CES}$$

Slijedi da je BJT Q_3 u DAR-u.

ZADATAK 1 – AC ANALIZA





$$g_{m1} = g_{m2} = \frac{I_{C1}}{V_T} = 39.6\ mS$$

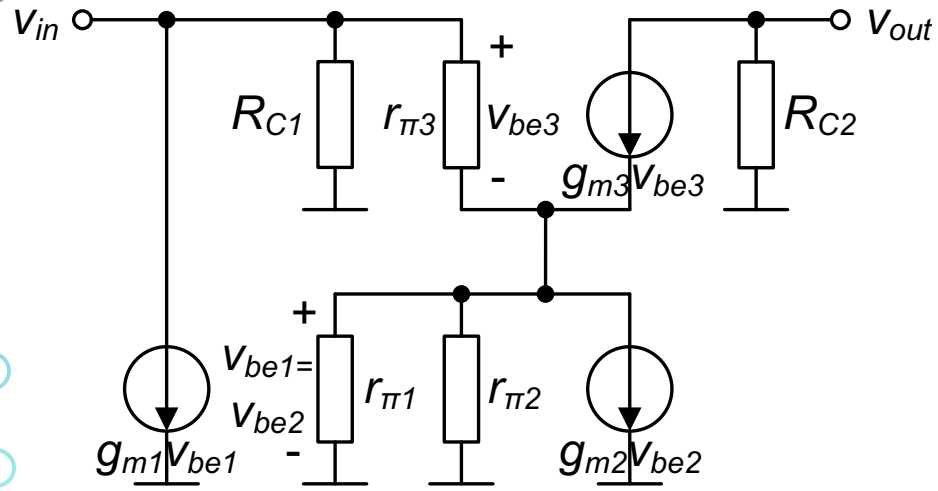
$$g_{m3} = \frac{I_{C3}}{V_T} = 40\ mS$$

$$r_{\pi 1} = r_{\pi 2} = \frac{\beta}{g_{m1}} = 2.525\ k\Omega$$

$$r_{\pi 3} = \frac{\beta}{g_{m3}} = 2.5\ k\Omega$$

$$r_{ce1}, r_{ce2}, r_{ce3} \rightarrow \infty$$

ZADATAK 1 – AC ANALIZA



$$v_{out} = -g_{m3}R_{C2}v_{be3}$$

$$v_{be3} = v_{in} - v_{be1}$$

$$g_{m2}v_{be2} + v_{be2}\left(\frac{1}{r_{\pi1}} + \frac{1}{r_{\pi2}}\right) = g_{m3}v_{be3} + \frac{v_{be3}}{r_{\pi3}} \Longrightarrow v_{be1} = \frac{\beta+1}{\beta+2}\frac{r_{\pi1}}{r_{\pi3}}v_{be3}$$

$$v_{be3} = v_{in} - \frac{\beta+1}{\beta+2}\frac{r_{\pi1}}{r_{\pi3}}v_{be3} \Longrightarrow v_{be3} = \frac{(\beta+2)r_{\pi3}}{(\beta+2)r_{\pi3} + (\beta+1)r_{\pi1}}v_{in}$$

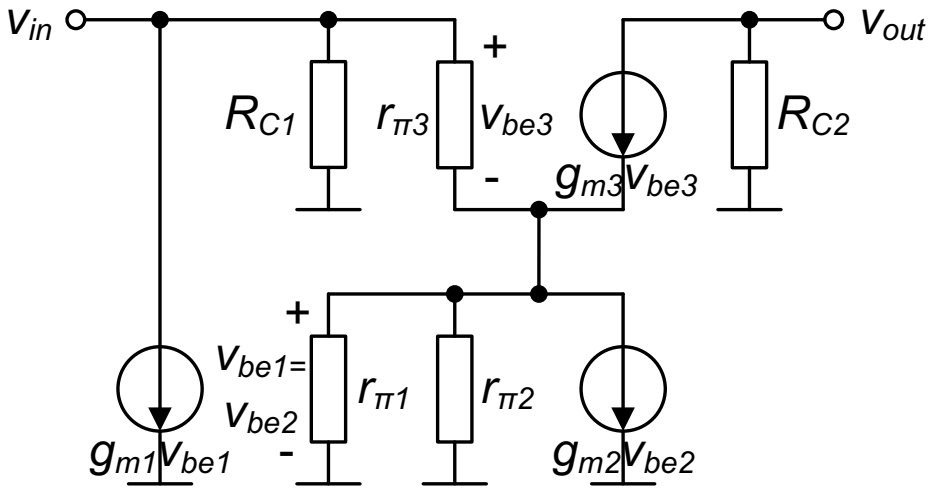
$$v_{out} = -g_{m3}R_{C2}\frac{(\beta+2)r_{\pi3}}{(\beta+2)r_{\pi3} + (\beta+1)r_{\pi1}}v_{in}$$

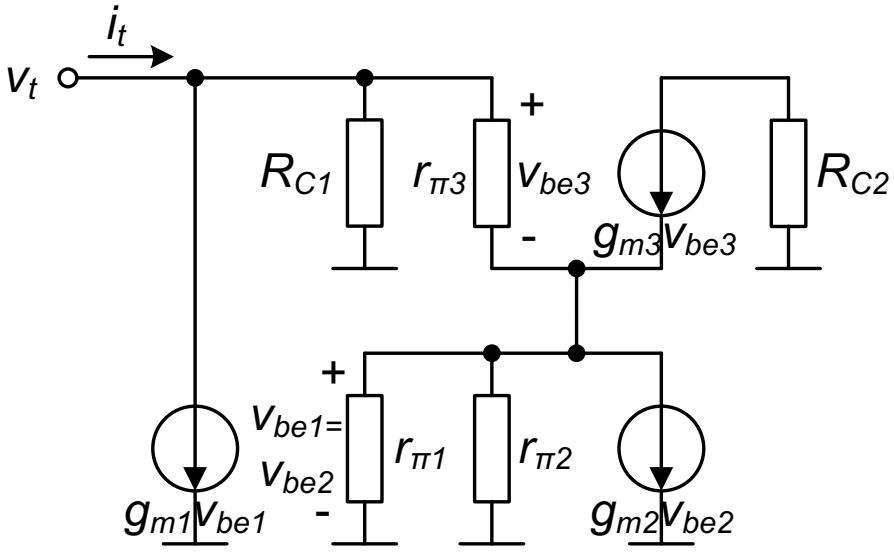
$$A_v = \frac{v_{out}}{v_{in}} = -\frac{(\beta+2)\beta R_{C2}}{(\beta+2)r_{\pi3} + (\beta+1)r_{\pi1}} = -100.5$$

$r_{\pi3} \approx r_{\pi1}$ i $\beta \gg 1$:

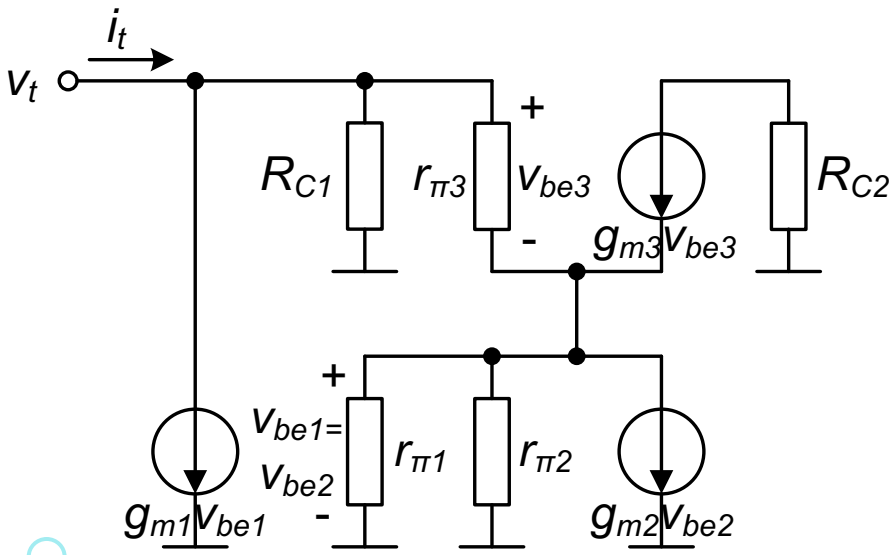
$$A_v \approx -\frac{g_{m3}R_{C2}}{2} = -100$$

ZADATAK 1 – AC ANALIZA





ZADATAK 1 – AC ANALIZA



$$i_t = \frac{v_t}{R_{C1}} + \frac{v_t - v_{be1}}{r_{\pi 3}} + g_{m1}v_{be1} = \left(\frac{1}{R_{C1}} + \frac{1}{r_{\pi 3}}\right)v_t + \left(g_{m1} - \frac{1}{r_{\pi 3}}\right)v_{be1}$$

$$g_{m2}v_{be1} + 2\frac{v_{be1}}{r_{\pi 1}} = \left(g_{m3} + \frac{1}{r_{\pi 3}}\right)(v_t - v_{be1})$$

$$\Longrightarrow v_{be1} = \frac{g_{m3} + \frac{1}{r_{\pi 3}}}{g_{m1} + g_{m3} + \frac{1}{r_{\pi 3}} + \frac{2}{r_{\pi 1}}}v_t$$

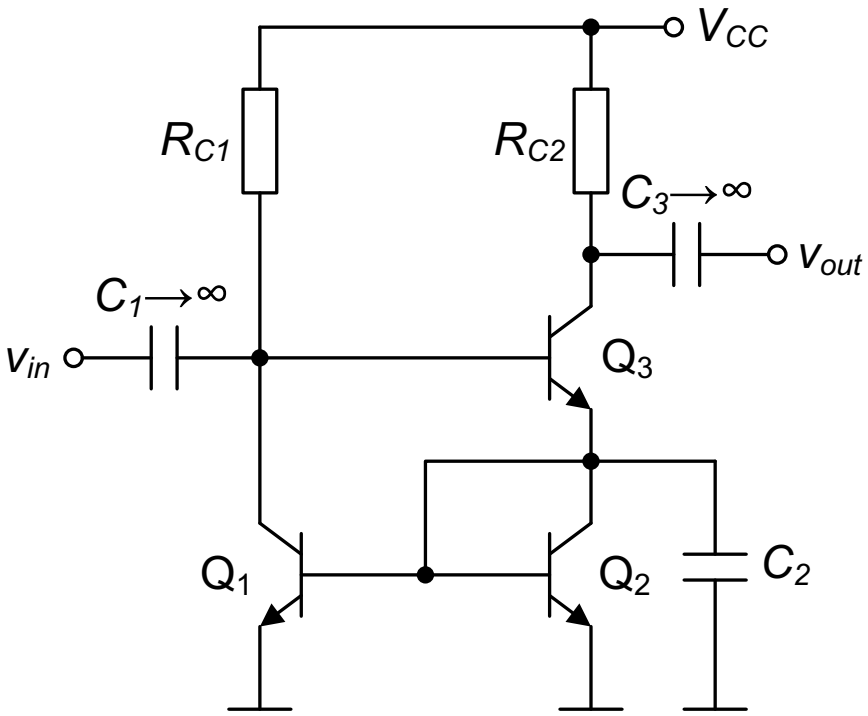
$$i_t = \left[\frac{1}{R_{C1}} + \frac{1}{r_{\pi 3}} + \left(g_{m1} - \frac{1}{r_{\pi 3}}\right)\frac{g_{m3} + \frac{1}{r_{\pi 3}}}{g_{m1} + g_{m3} + \frac{1}{r_{\pi 3}} + \frac{2}{r_{\pi 1}}}\right]v_t$$

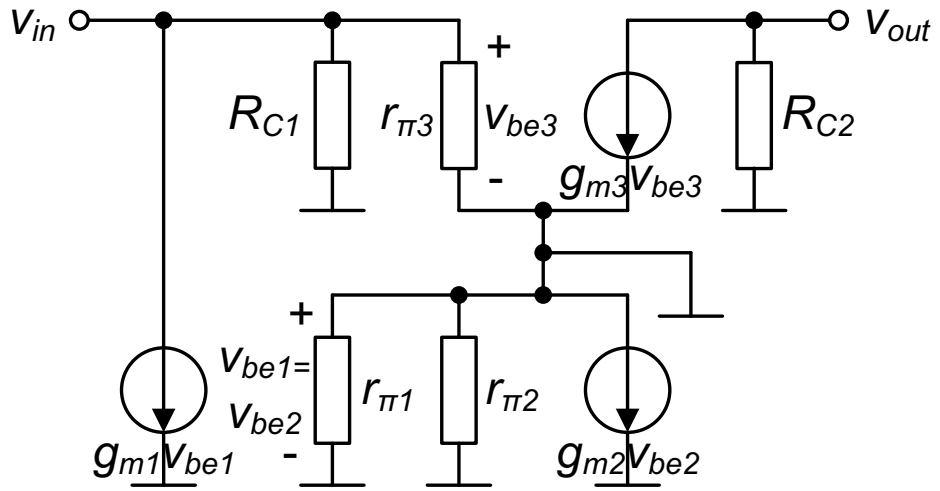
$$R_{in} = \frac{v_t}{i_t} = \frac{1}{\frac{1}{R_{C1}} + \frac{1}{r_{\pi 3}} + \left(g_{m1} - \frac{1}{r_{\pi 3}}\right)\frac{g_{m3} + \frac{1}{r_{\pi 3}}}{g_{m1} + g_{m3} + \frac{1}{r_{\pi 3}} + \frac{2}{r_{\pi 1}}}} = 50.5\ \Omega$$

$\beta \gg 1$ i $g_{m1} \approx g_{m3}$:

$$R_{in} \approx \frac{1}{\frac{1}{R_{C1}} + \frac{g_{m1}}{2}} = 50.25$$

ZADATAK 1 – AC ANALIZA





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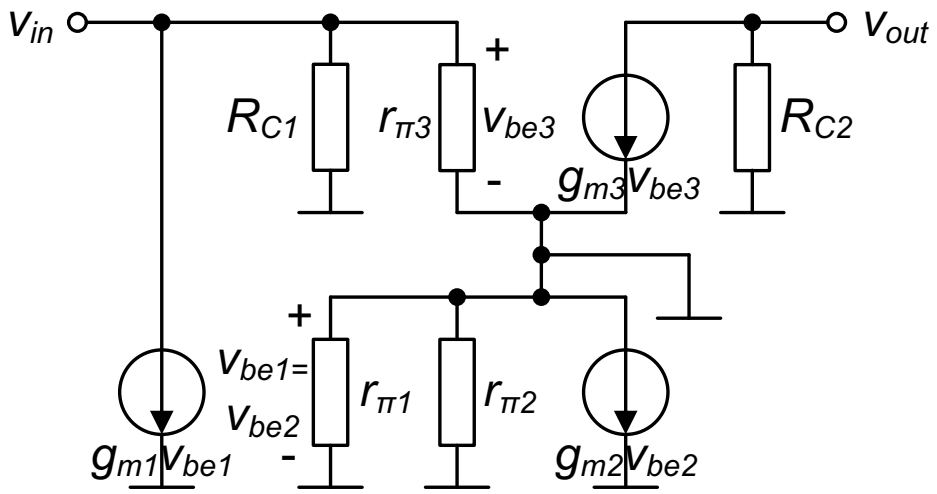
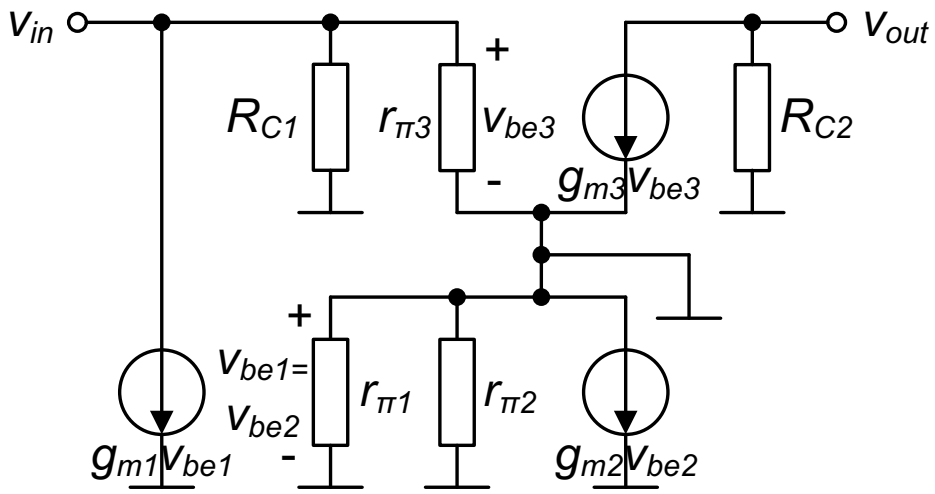
ZADATAK 1 – AC ANALIZA

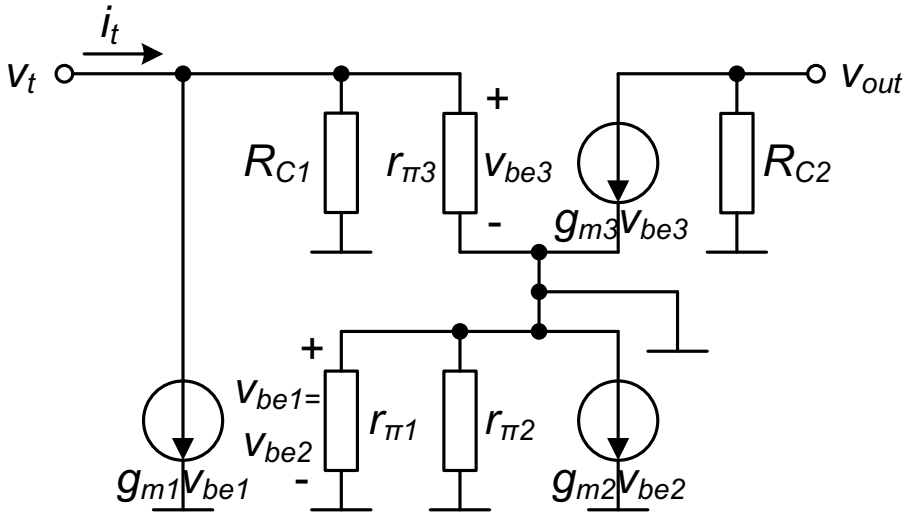


$$v_{out} = -g_{m3}R_{C2}v_{be3} = -g_{m3}R_{C2}v_{in}$$

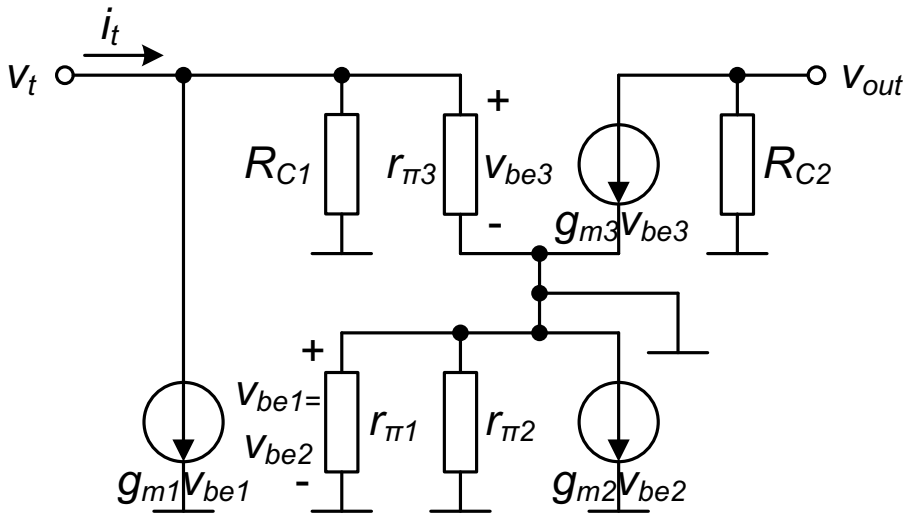
$$A_v \approx -g_{m3}R_{C2} = -200$$

ZADATAK 1 – AC ANALIZA





ZADATAK 1 – AC ANALIZA

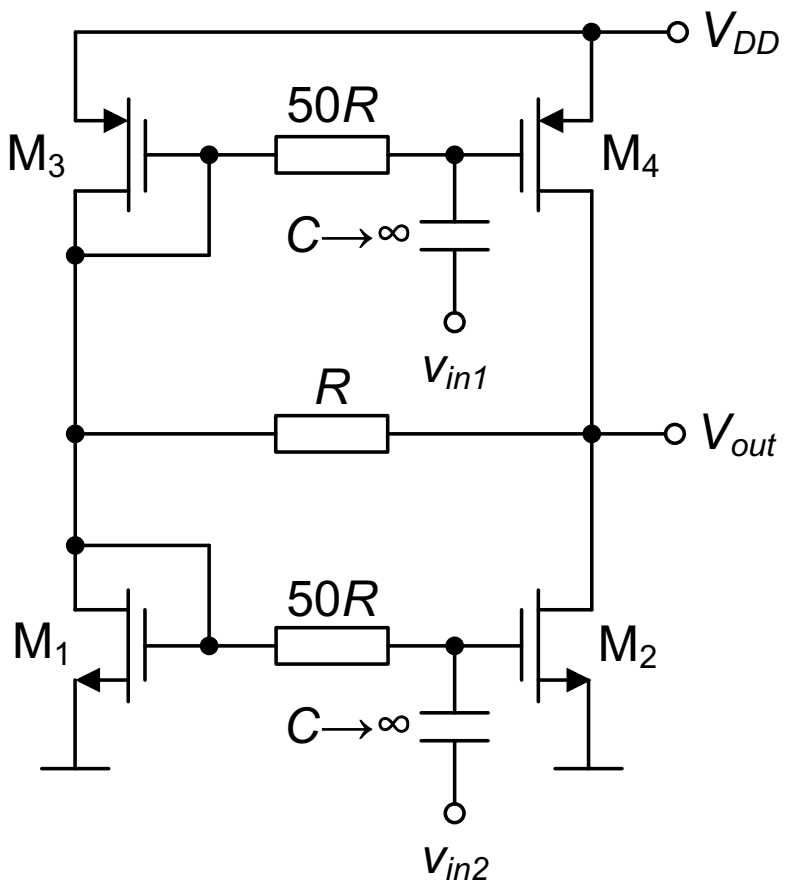


$$v_{be1} = v_{be2} = 0 \Longrightarrow g_{m1}v_{be1} = 0$$

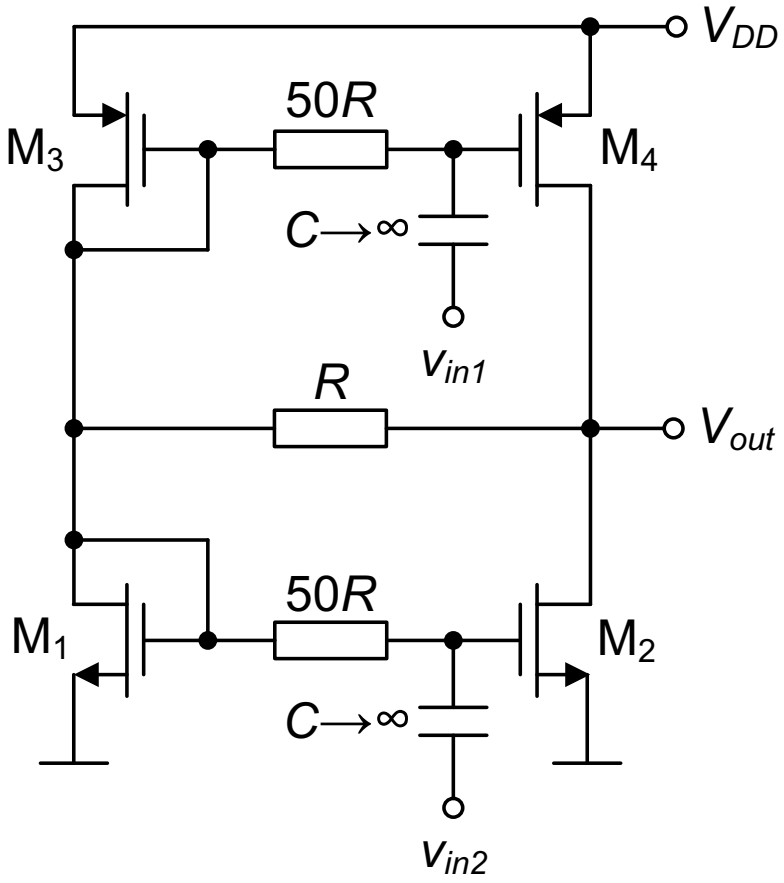
$$R_{in} = \frac{v_t}{i_t} = \frac{R_{C1}r_{\pi 3}}{R_{C1} + r_{\pi 3}} = 2\ \text{k}\Omega$$

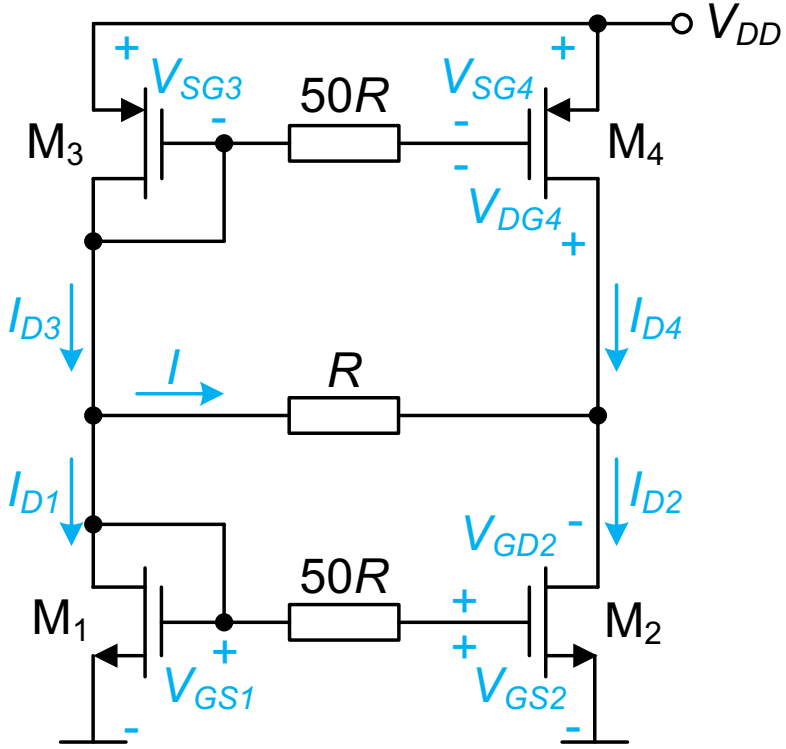
ZADATAK 2

Za kolo prikazano na slici izračunati naponsko pojačanje $A_v = v_{out} / (v_{in1} + v_{in2})$. Poznato je: napon napajanja kola V_{DD}=12 V, otpornost R=50 kΩ, napon praga MOSFET-ova $V_{t1}=V_{t2}$=2 V i $V_{t3}=V_{t4}$=-2 V, faktor β=0.2 mA/V^2, koeficijent modulacije dužine kanala $\lambda \longrightarrow 0$.

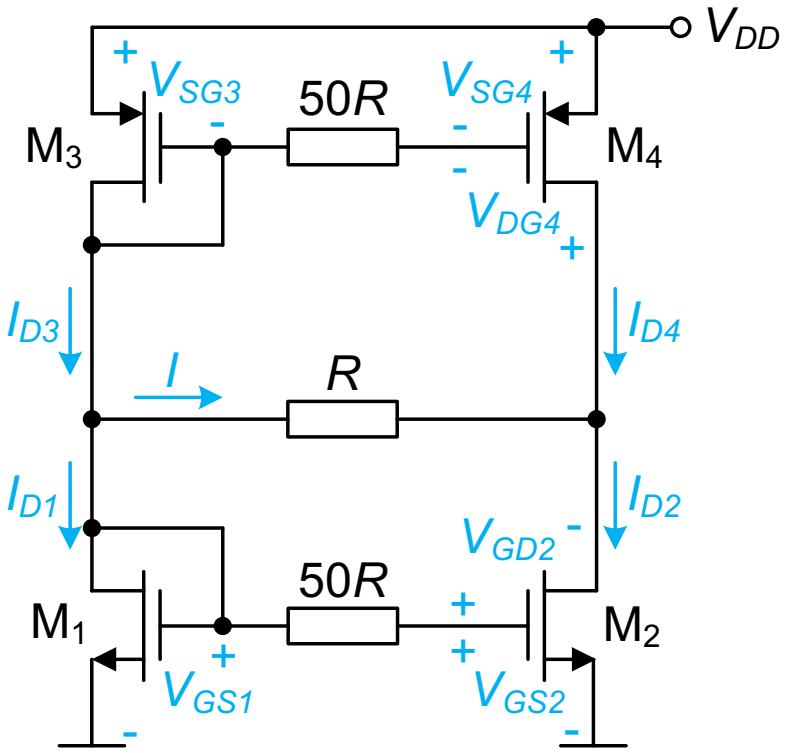


ZADATAK 2 – DC ANALIZA





ZADATAK 2 – DC ANALIZA



$$V_{GS1} = V_{GS2} \Longrightarrow I_{D1} = I_{D2}$$

$$V_{SG3} = V_{SG4} \Longrightarrow I_{D3} = I_{D4}$$

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

$V_{GD1} = 0$ V i $V_{DG3} = 0$ V

Slijedi da su MOSFET-ovi M_1 i M_3 u zasićenju.

$$\left.\begin{matrix} I = I_{D3} - I_{D1} \\ I = I_{D2} - I_{D4} \end{matrix}\right\} \Longrightarrow 2I = I_{D3} - I_{D1} + I_{D2} - I_{D4} = 0$$

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

$V_{GD2} = RI = 0$ V i $V_{DG4} = -RI = 0$ V

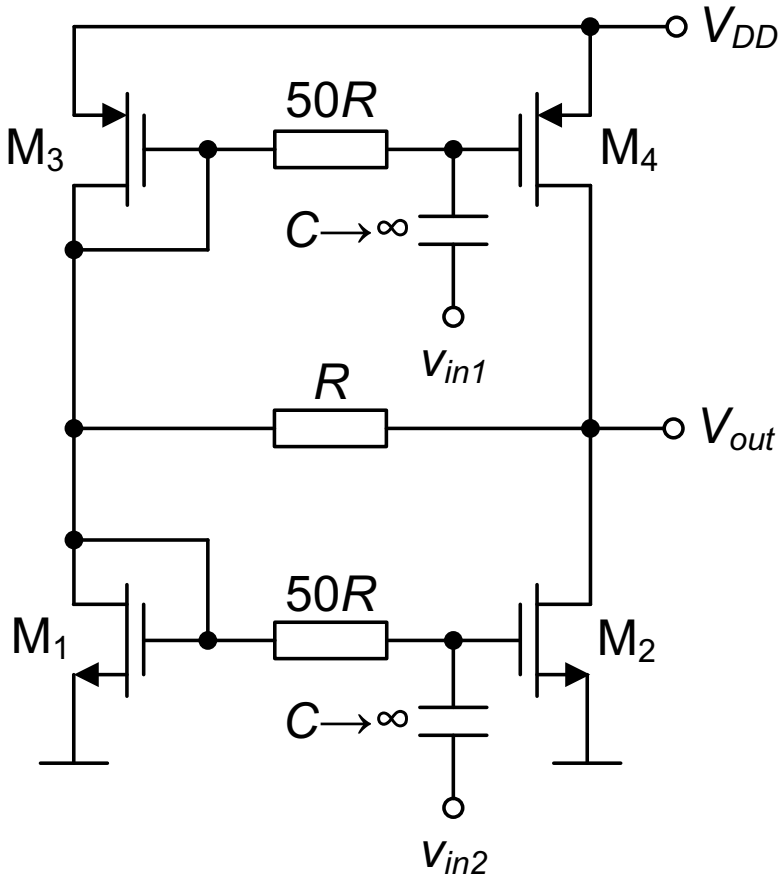
Slijedi da su i MOSFET-ovi M_2 i M_4 u zasićenju.

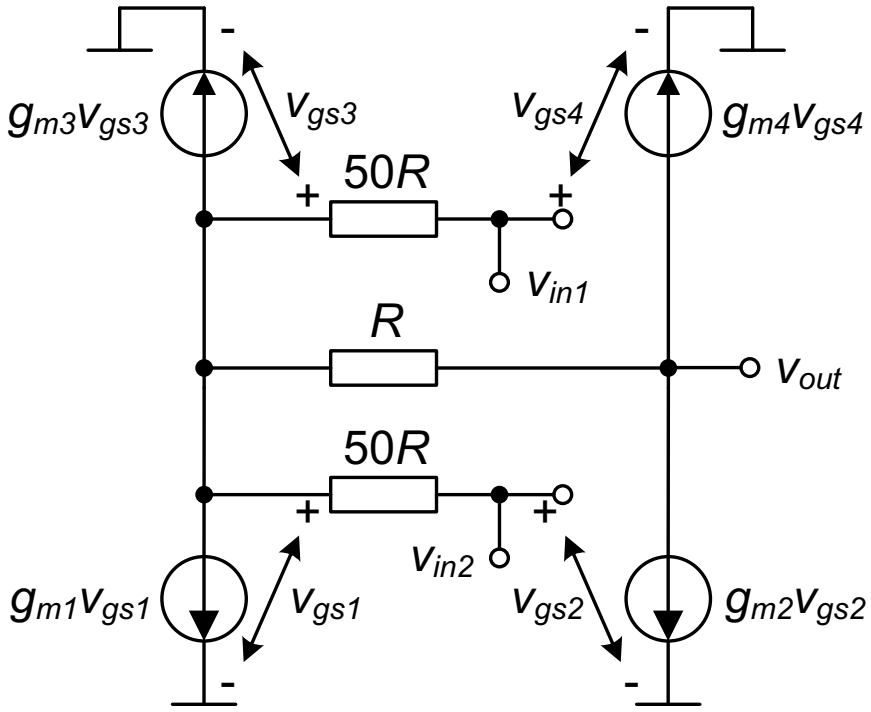
$$V_{GS1} = V_{GS2} = V_{SG3} = V_{SG4} = \frac{V_{DD}}{2} = 6 \text{ V}$$

$$I_{D1} = I_{D2} = I_{D3} = I_{D4} = \frac{\beta}{2}(V_{GS1} - V_t)^2(1 + \lambda V_{DS})$$

$$\approx \frac{\beta}{2}(V_{GS1} - V_t)^2 = 1.6 \text{ mA}$$

ZADATAK 2 – AC ANALIZA

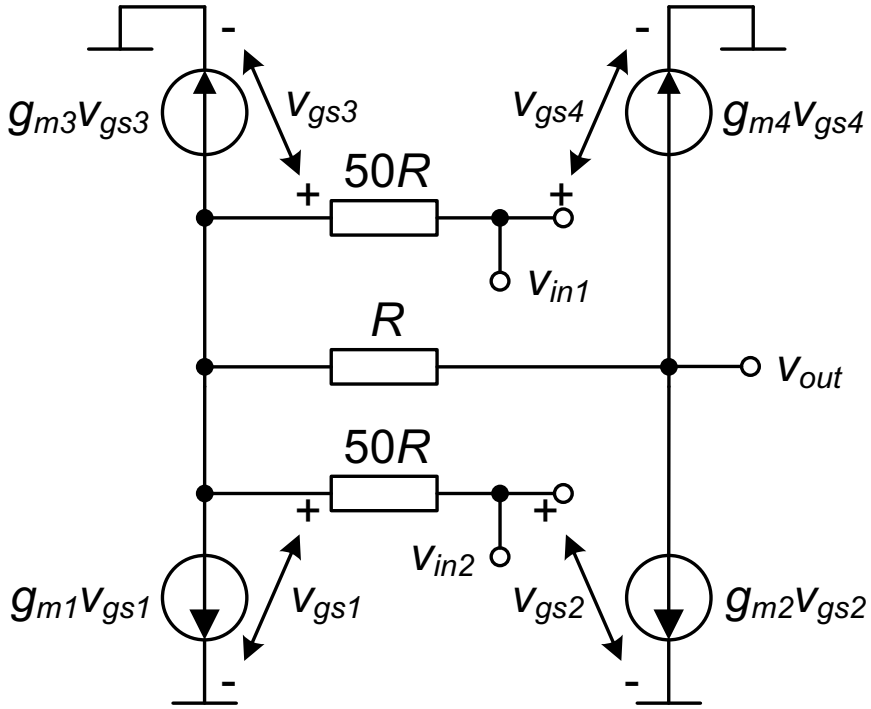


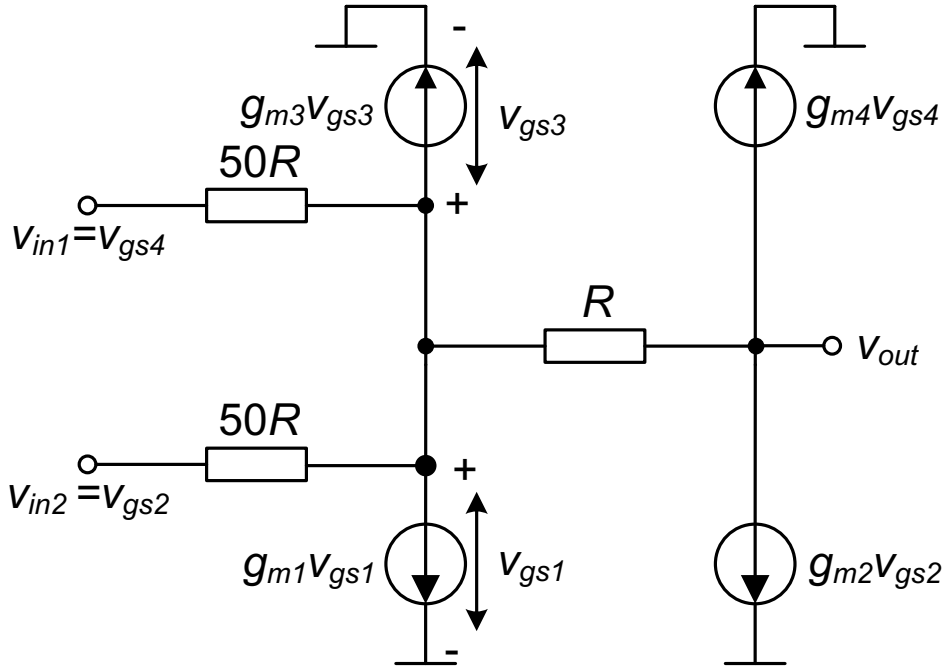


$$g_{m1} = g_{m2} = g_{m3} = g_{m4} = \sqrt{2\beta I_{D1}} = 0.8\ \text{mS}$$

$$r_{ds1} = r_{ds2} = r_{ds3} = r_{ds4} = \frac{1}{\lambda I_{D1}} \to \infty$$

ZADATAK 2 – AC ANALIZA





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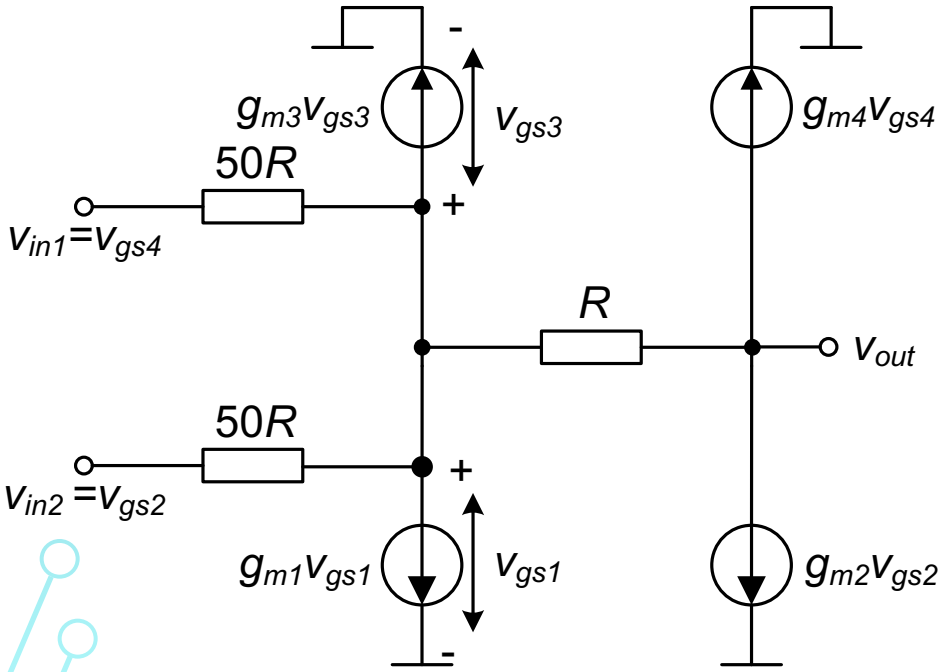

$$v_{gs1} = v_{gs3}$$

$$\frac{v_{in1} - v_{gs1}}{50R} + \frac{v_{in2} - v_{gs1}}{50R} = (g_{m1} + g_{m3})v_{gs1} + g_{m2}v_{gs2} + g_{m4}v_{gs4}$$

$$\frac{v_{in1} + v_{in2}}{50R} = \left(g_{m1} + g_{m3} + \frac{2}{50R}\right)v_{gs1} + g_{m2}v_{in2} + g_{m4}v_{in1}$$

$$v_{gs1} = \frac{1}{2}\frac{1 - 50g_{m1}R}{1 + 50g_{m1}R}(v_{in1} + v_{in2})$$

$$v_{out} = v_{gs1} - R\left(g_{m2}v_{gs2} + g_{m4}v_{gs4}\right) = v_{gs1} - g_{m1}R(v_{in2} + v_{in1})$$

$$v_{out} = \left[\frac{1}{2}\frac{1 - 50g_{m1}R}{1 + 50g_{m1}R} - g_{m1}R\right](v_{in1} + v_{in2})$$

$$A_v = \frac{v_{out}}{v_{in1} + v_{in2}} = \frac{1}{2}\frac{1 - 50g_{m1}R}{1 + 50g_{m1}R} - g_{m1}R = -40.48$$

$$50g_{m1}R \gg 1: A_v \approx -\frac{1}{2} - g_{m1}R = -40.5$$