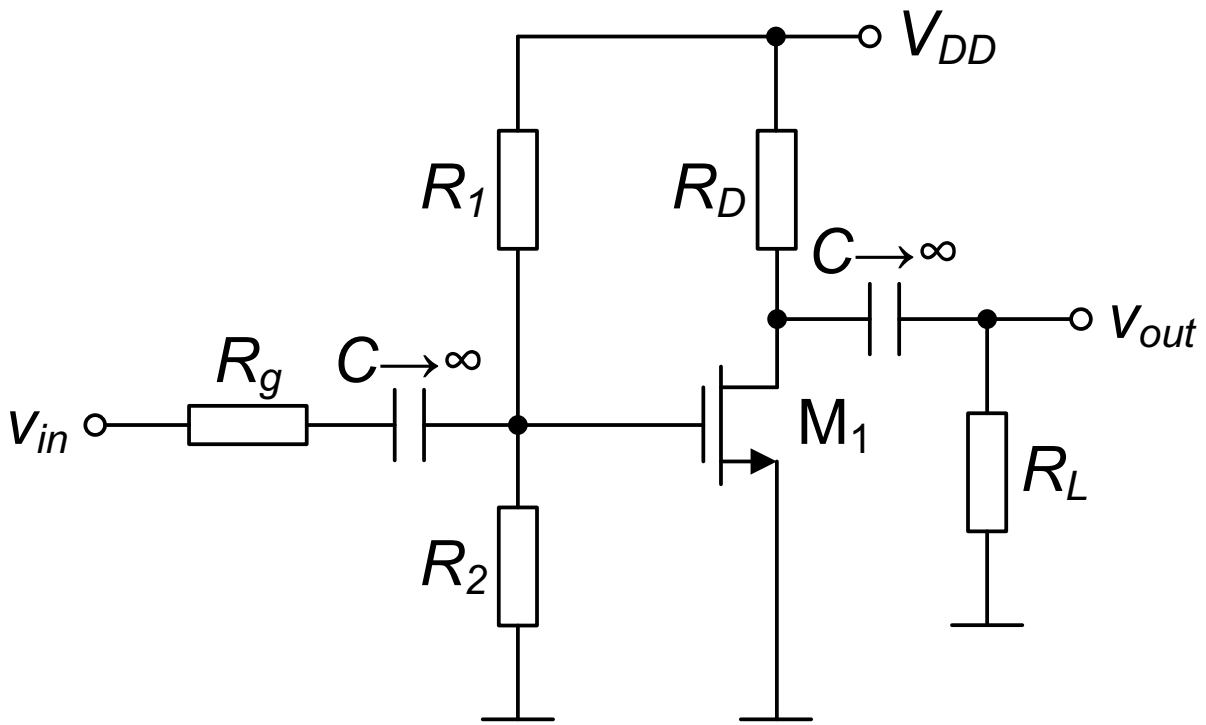
VJEŽBE 6

OSNOVE ELEKTRONIKE, ETR, IV SEMESTAR

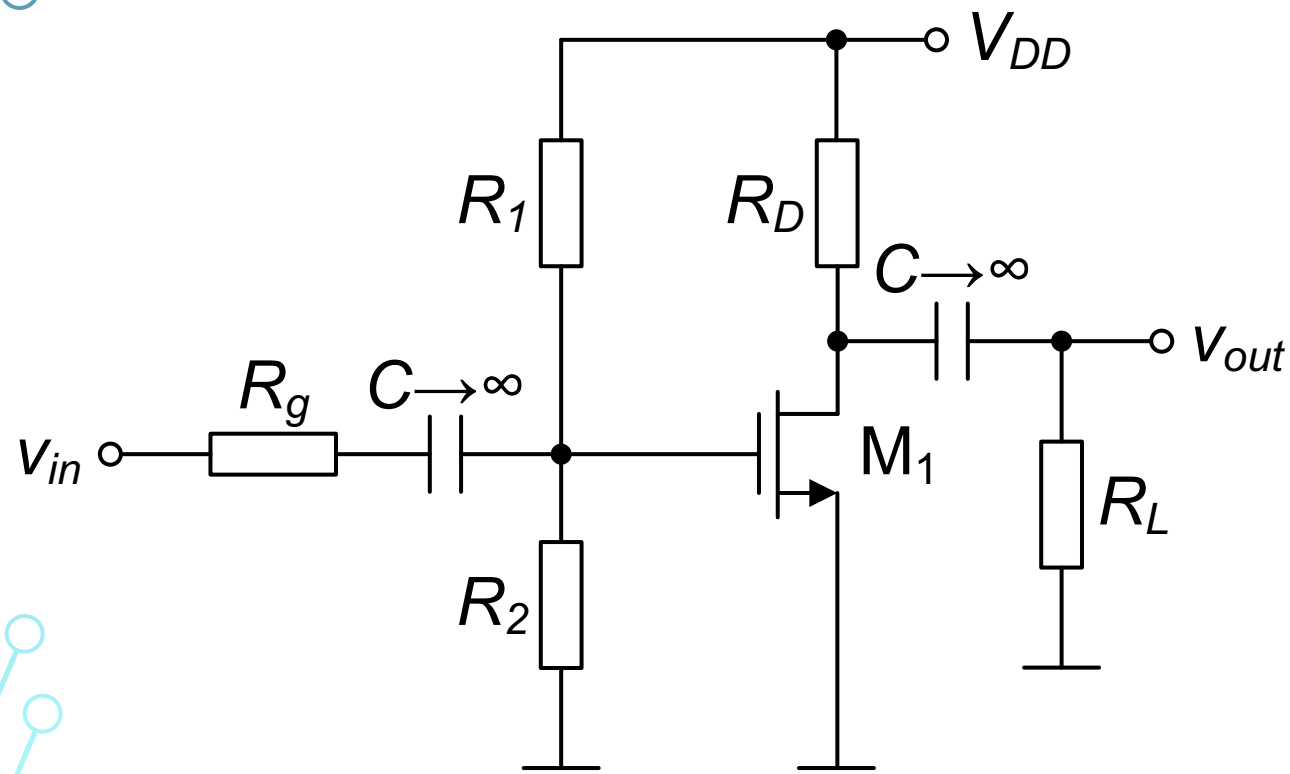
DOC. DR MILENA ERCEG

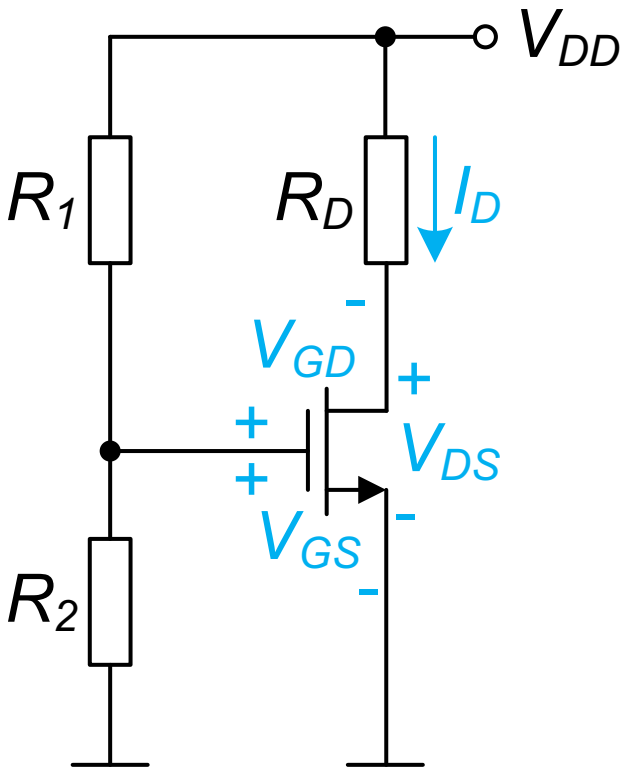
ZADATAK 1

Za kolo prikazano na slici izračunati naponsko pojačanje A_v i izlaznu otpornost R_{out}. Poznato je: napon napajanja kola V_{DD}=5 V, otpornosti R_1=100 kΩ, R_2=47 kΩ, R_D=3.3 kΩ, otpornost potrošača R_L=10 kΩ, unutrašnja otpornost generatora R_g=1 kΩ, napon praga MOSFET-a V_t=1.2 V, β=1 mA/V^2, koeficijent modulacije dužine kanala λ=0.02 V^{-1}.

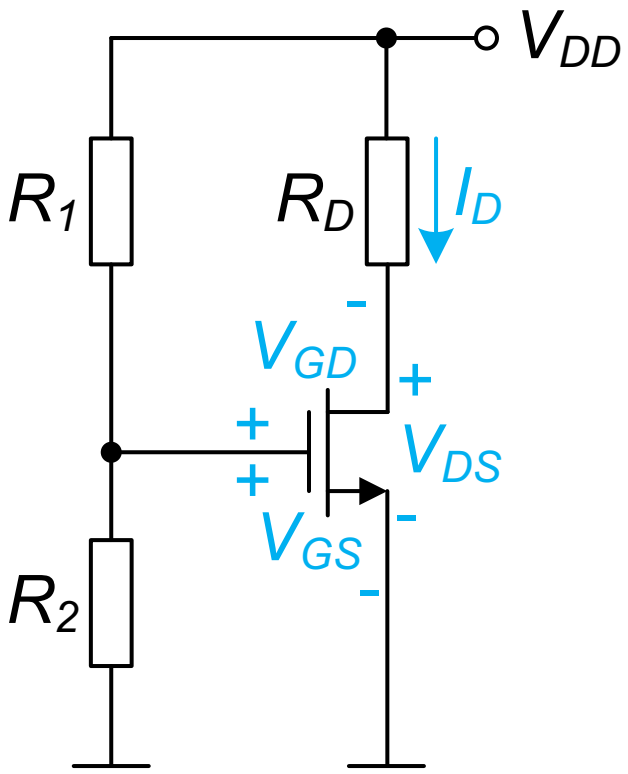


ZADATAK 1


V_{DD}
R_1
R_D
$C \to \infty$
v_{out}
R_g
$C \to \infty$
v_{in}
M_1
R_L
R_2


V_{DD}
R_1
R_D
I_D
V_{GD}
V_{DS}
V_{GS}
R_2

ZADATAK 1- DC ANALIZA



$$V_{GS} = \frac{R_2}{R_1 + R_2} V_{DD} = 1.6\ \text{V} > V_t$$

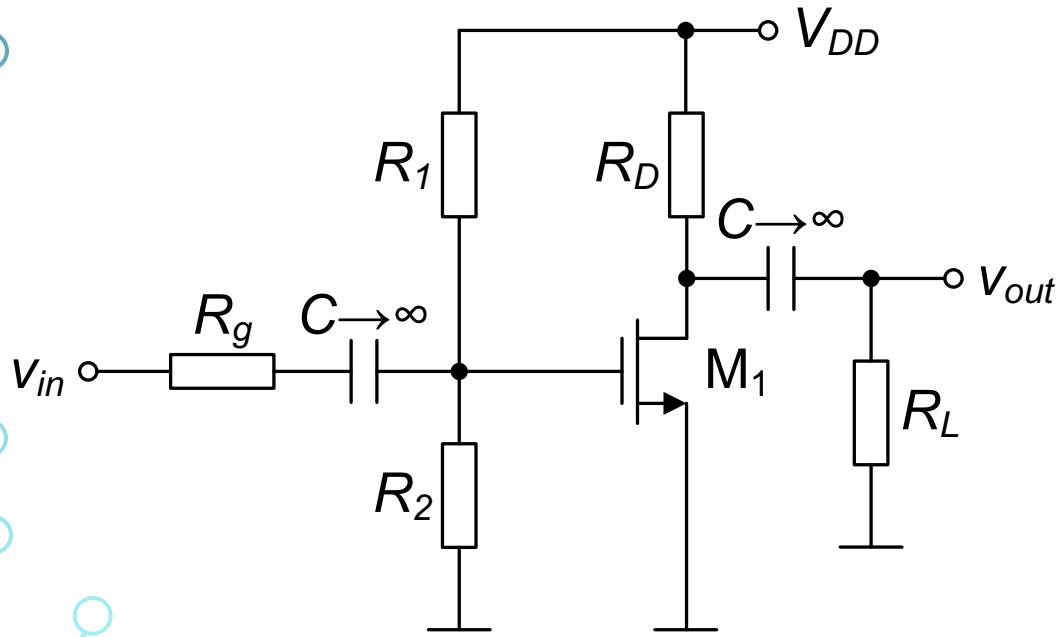
Uvodi se pretpostavka da je MOSFET M_1 u zasićenju.

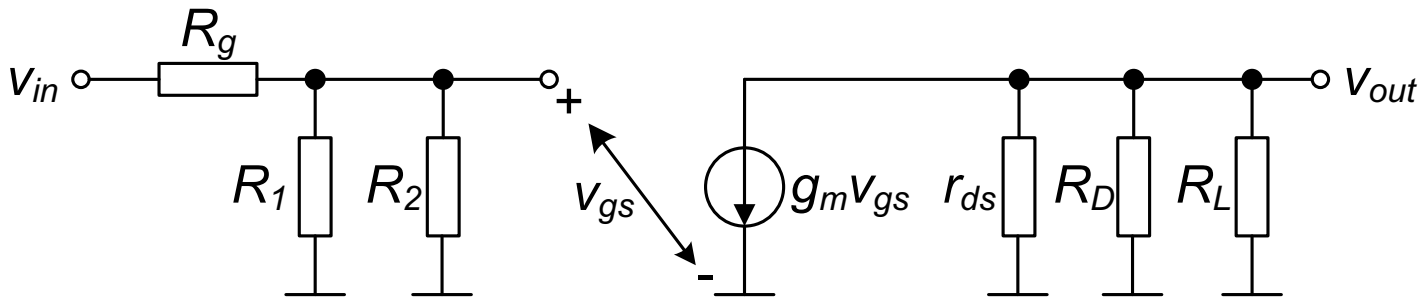
$$I_D = \frac{1}{2}\beta(V_{GS} - V_t)^2(1 + \lambda V_{DS}) \approx \frac{1}{2}\beta(V_{GS} - V_t)^2 = 80\ \mu\text{A}$$

$$V_{GD} = V_{GS} + R_D I_D - V_{DD} = -3.136\ \text{V} < V_t$$

Slijedi da je pretpostavka o zasićenju tačna.

ZADATAK 1 – ODREĐIVANJE NAPONSKOG POJAČANJA

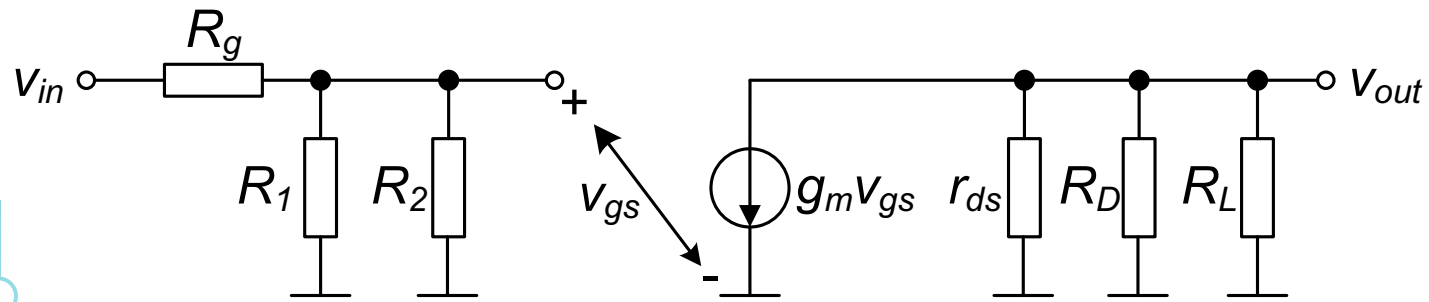




$$g_m = \sqrt{2\beta I_D} = 0.4\ \text{mS}$$

$$r_{ds} = \frac{1}{\lambda I_D} = 625\ \text{k}\Omega$$

ZADATAK 1 - ODREĐIVANJE NAPONSKOG POJAČANJA



$$R_{e1} = \frac{R_1 R_2}{R_1 + R_2} = 31.97\ \text{k}\Omega$$

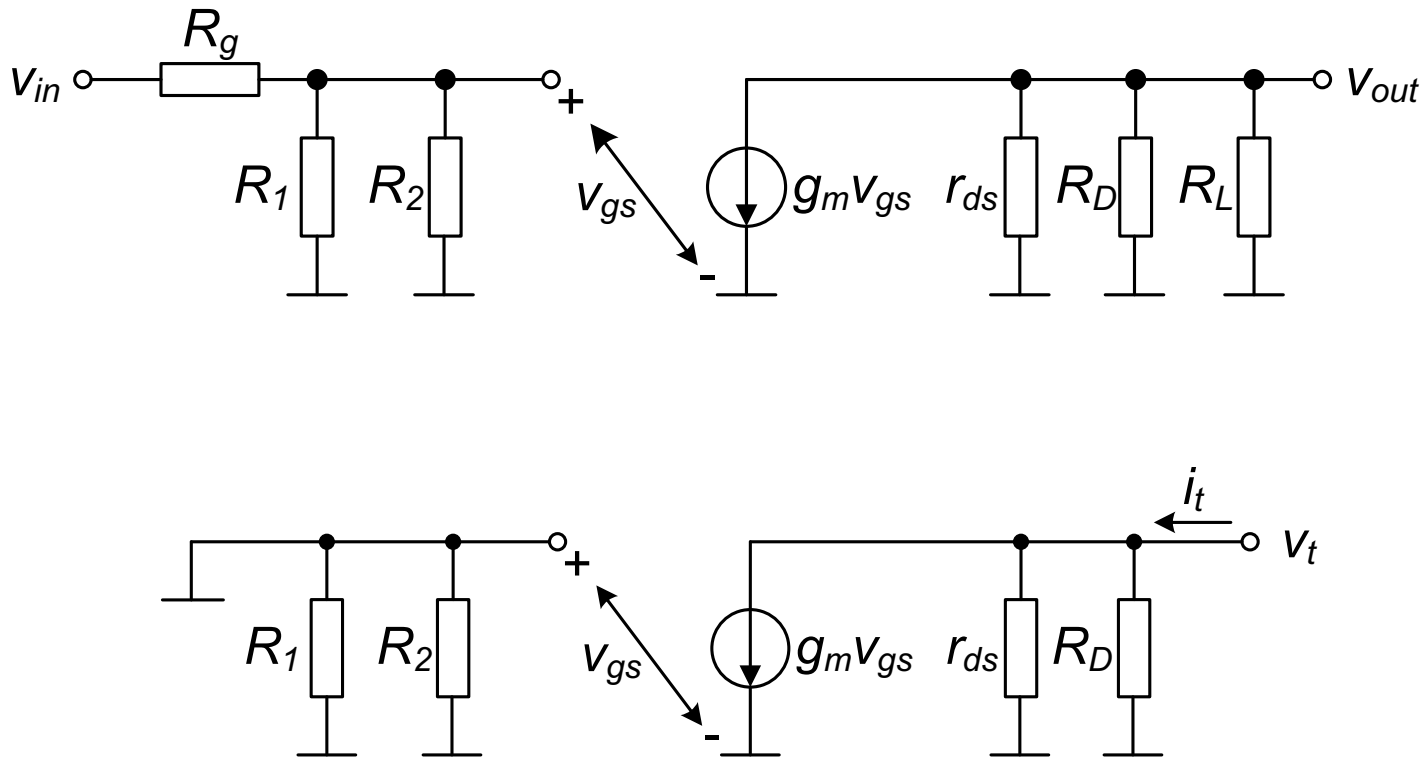
$$R_{e2} = \frac{1}{\frac{1}{r_{ds}} + \frac{1}{R_D} + \frac{1}{R_L}} = 2.47\ \text{k}\Omega$$

$$v_{gs} = \frac{R_{e1}}{R_g + R_{e1}} v_{in}$$

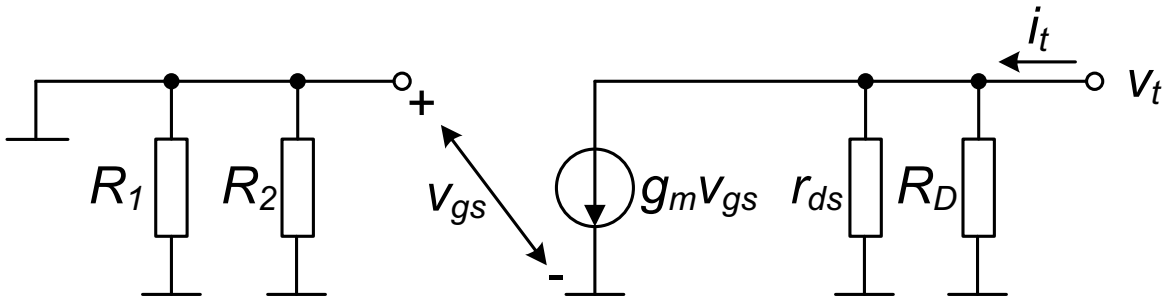
$$g_m v_{gs} + \frac{v_{out}}{R_{e2}} = 0$$

$$A_v = \frac{v_{out}}{v_{in}} = -g_m \frac{R_{e1} R_{e2}}{R_g + R_{e1}} = -0.96$$

ZADATAK 1 – ODREĐIVANJE IZLAZNE OTPORNOSTI



ZADATAK 1 – ODREĐIVANJE IZLAZNE OTPORNOSTI

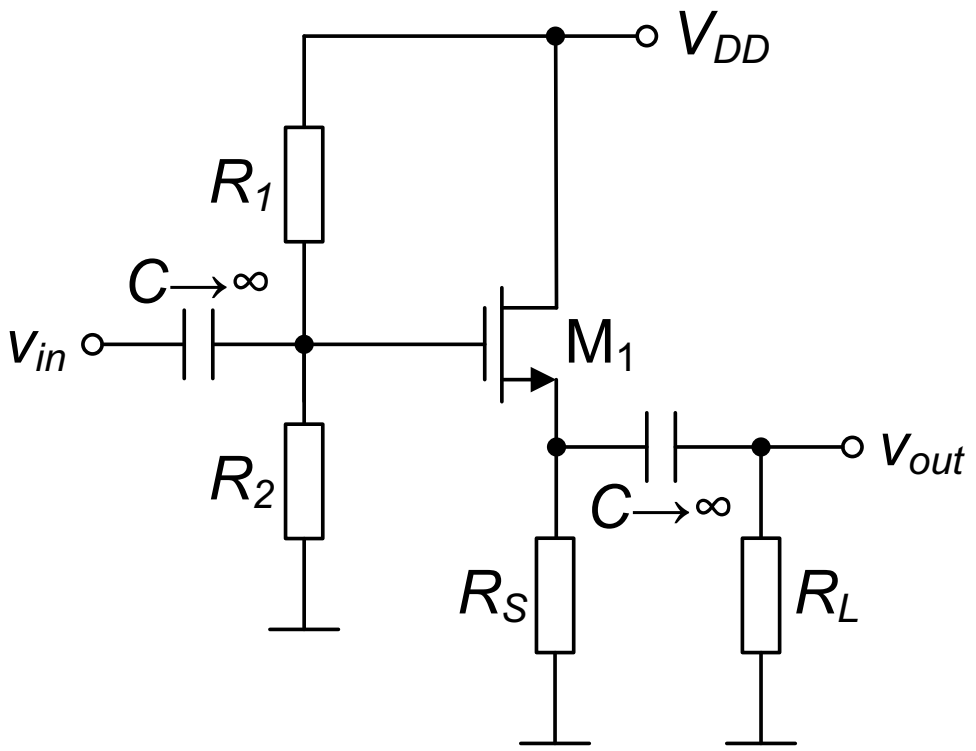


$$v_{gs} = 0$$

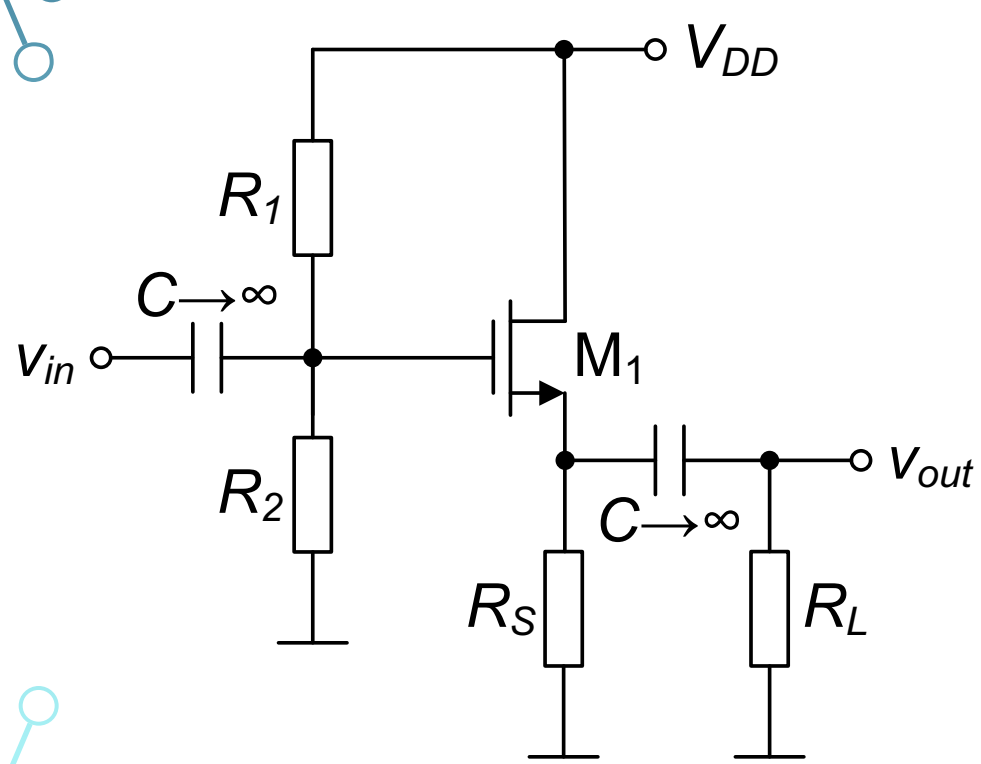
$$R_{out} = \frac{v_t}{i_t} = \frac{r_{ds} R_D}{r_{ds} + R_D} = 3.28\,\text{k}\Omega$$

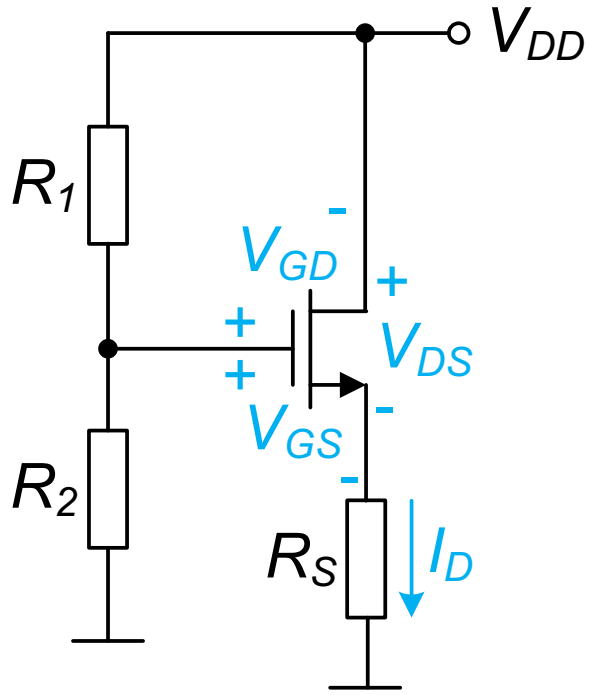
ZADATAK 2

Za kolo prikazano na slici izračunati naponsko pojačanje A_v i izlaznu otpornost R_{out}. Poznato je: napon napajanja kola V_{DD}=10 V, otpornosti R_1=54.4 kΩ, R_2=100 kΩ, R_S=2 kΩ, otpornost potrošača R_L=2 kΩ, napon praga MOSFET-a V_t=2 V, β=2 mA/V^2, koeficijent modulacije dužine kanala λ=0.001 V^{-1}.

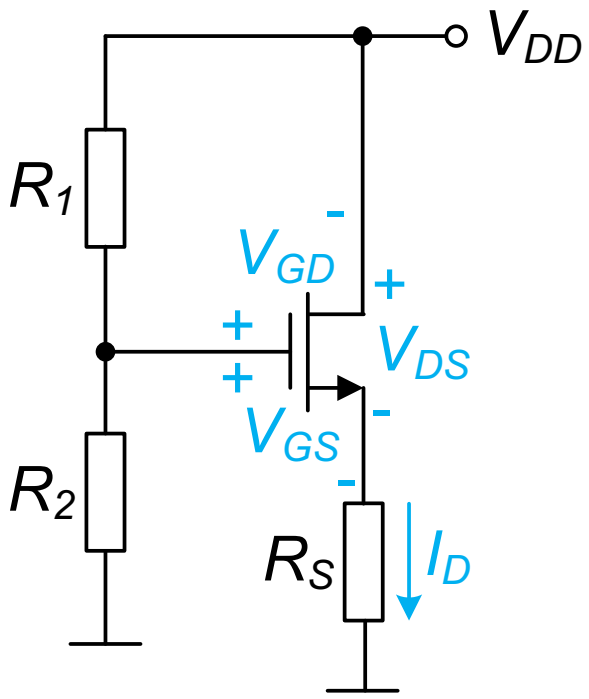


ZADATAK 2


V_{DD}
R_1
$C \to \infty$
v_{in}
M_1
R_2
v_{out}
$C \to \infty$
R_S
R_L


V_{DD}
R_1
V_{GD}
V_{DS}
V_{GS}
R_2
R_S
I_D

ZADATAK 2 – DC ANALIZA



$$V_G = \frac{R_2}{R_1 + R_2} V_{DD} = 6.47\ \text{V}$$

$$V_{GD} = V_G - V_{DD} = -3.53\ \text{V} < V_t$$

Slijedi da je MOSFET M_1 u zasićenju.

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

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

$$I_{D1} = 3.12\ \text{mA i } I_{D2} = 1.6\ \text{mA}$$

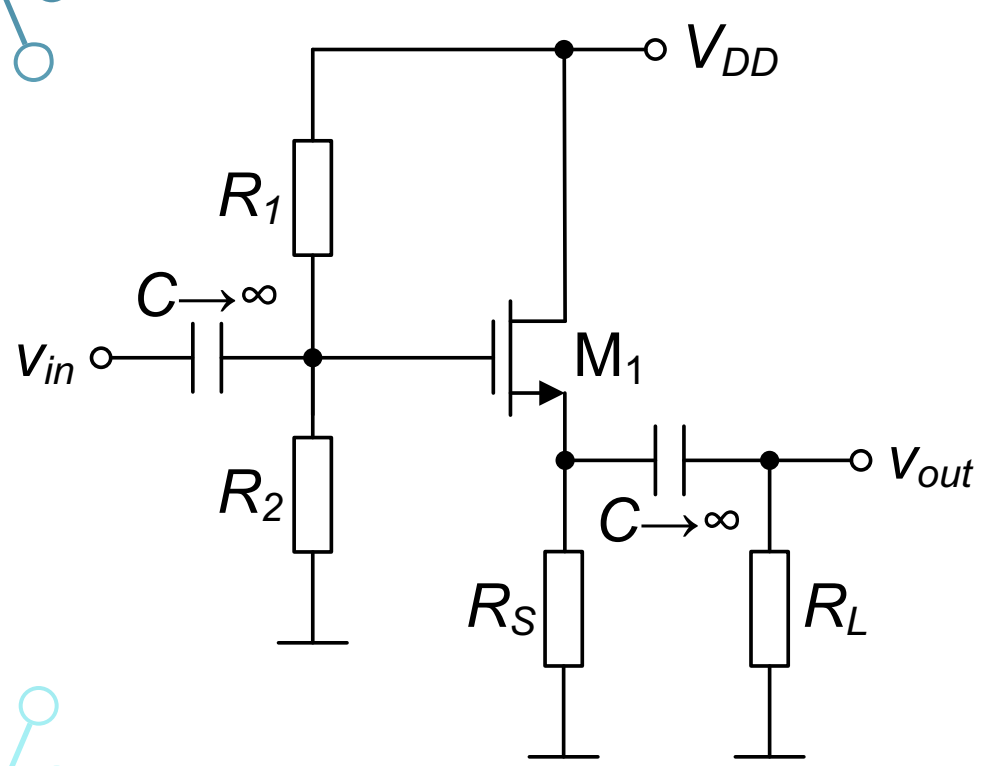
$$V_{GS}(I_D = I_{D1}) = V_G - R_S I_{D1} = 0.23\ \text{V} < V_t$$

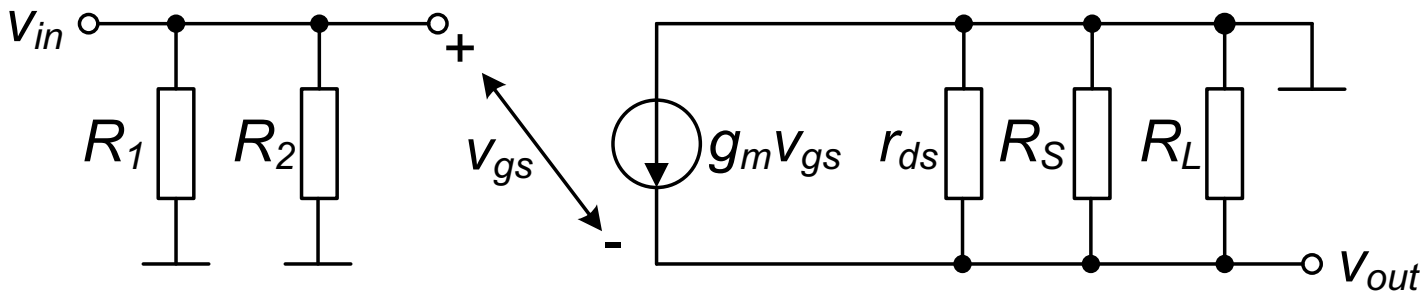
Ovo rješenje nije prihvatljivo.

$$V_{GS}(I_D = I_{D2}) = V_G - R_S I_{D2} = 3.27\ \text{V} > V_t$$

$$\Longrightarrow I_D = 1.6\ \text{mA}$$

ZADATAK 2 – ODREĐIVANJE NAPONSKOG POJAČANJA

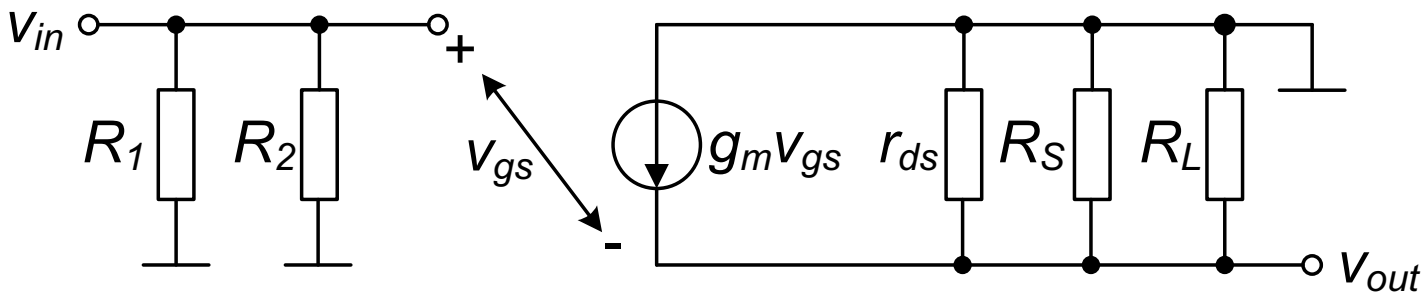




$$g_m = \sqrt{2\beta I_D} = 2.53\ \text{mS}$$

$$r_{ds} = \frac{1}{\lambda I_D} = 62.5\ \text{k}\Omega$$

ZADATAK 2 – ODREĐIVANJE NAPONSKOG POJAČANJA



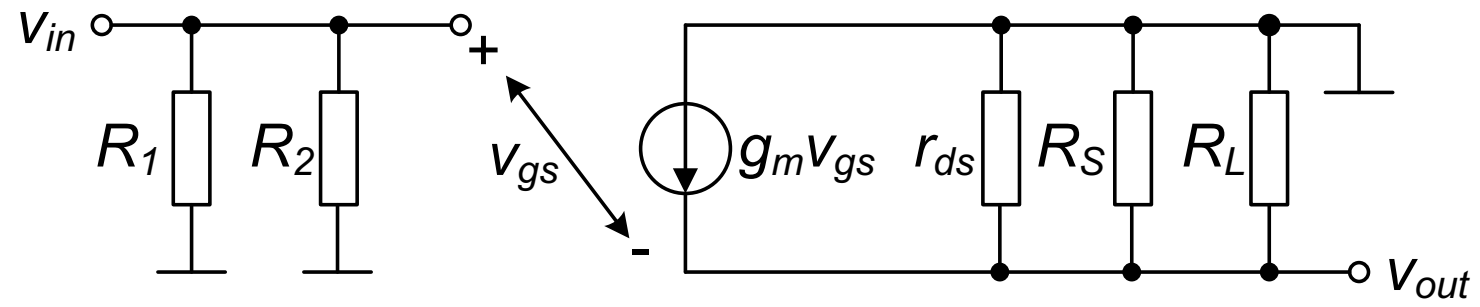
$$R_{e1} = \frac{1}{\frac{1}{r_{ds}} + \frac{1}{R_S} + \frac{1}{R_L}} = 0.98\ \text{k}\Omega$$

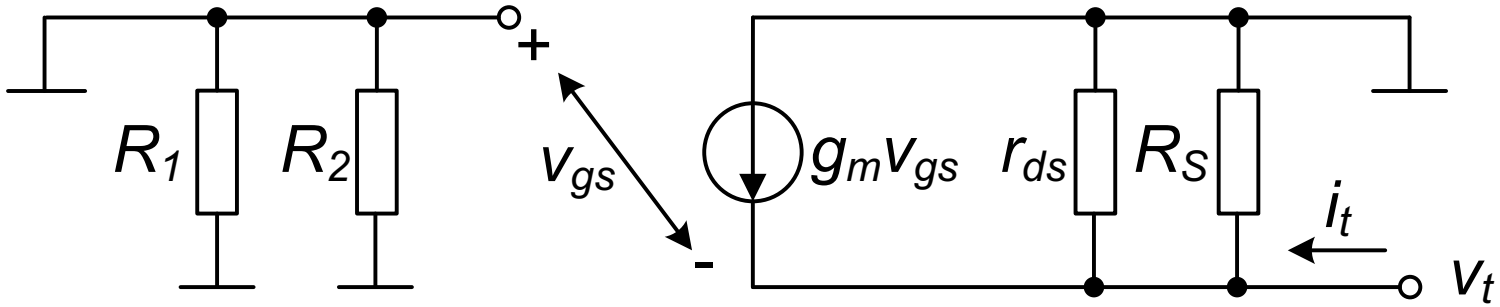
$$v_{gs} = v_{in} - v_{out}$$

$$g_m v_{gs} - \frac{v_{out}}{R_{e1}} = 0$$

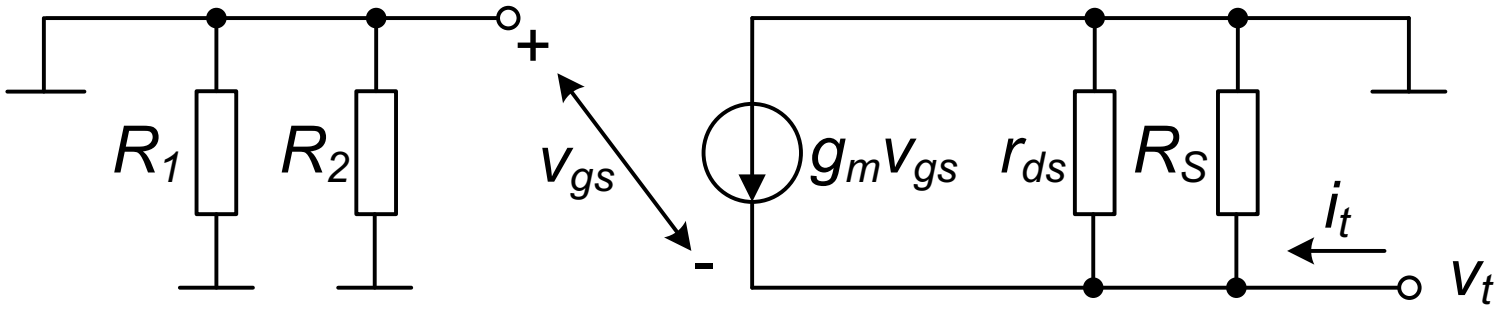
$$A_v = \frac{v_{out}}{v_{in}} = \frac{g_m R_{e1}}{1 + g_m R_{e1}} = 0.71$$

ZADATAK 2 – ODREĐIVANJE IZLAZNE OTPORNOSTI





ZADATAK 2 – ODREĐIVANJE IZLAZNE OTPORNOSTI



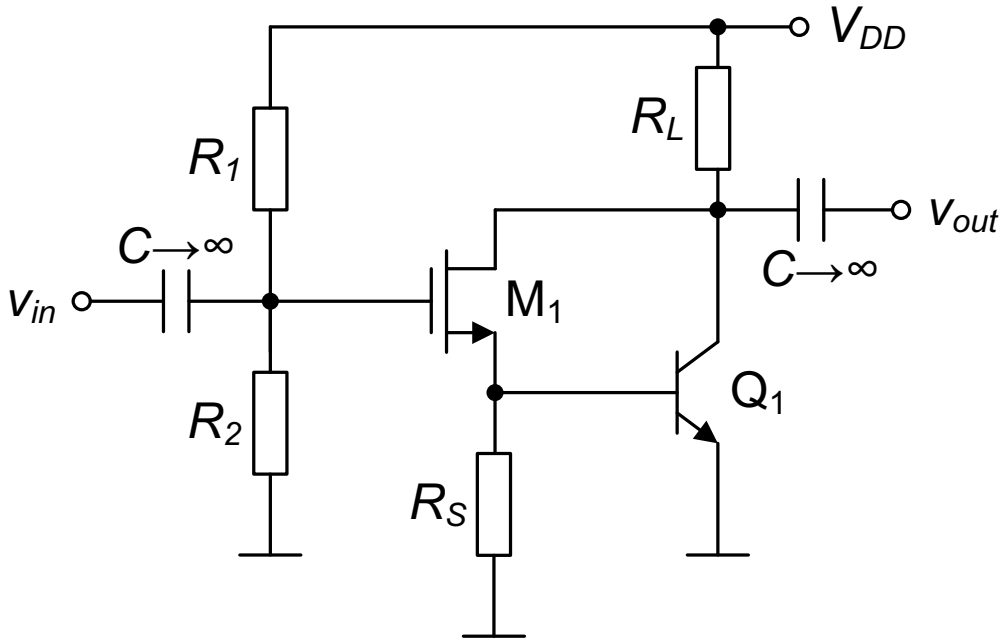
$$v_{gs} = -v_t$$

$$g_m v_{gs} + i_t - v_t\left(\frac{1}{r_{ds}} + \frac{1}{R_S}\right) = 0$$

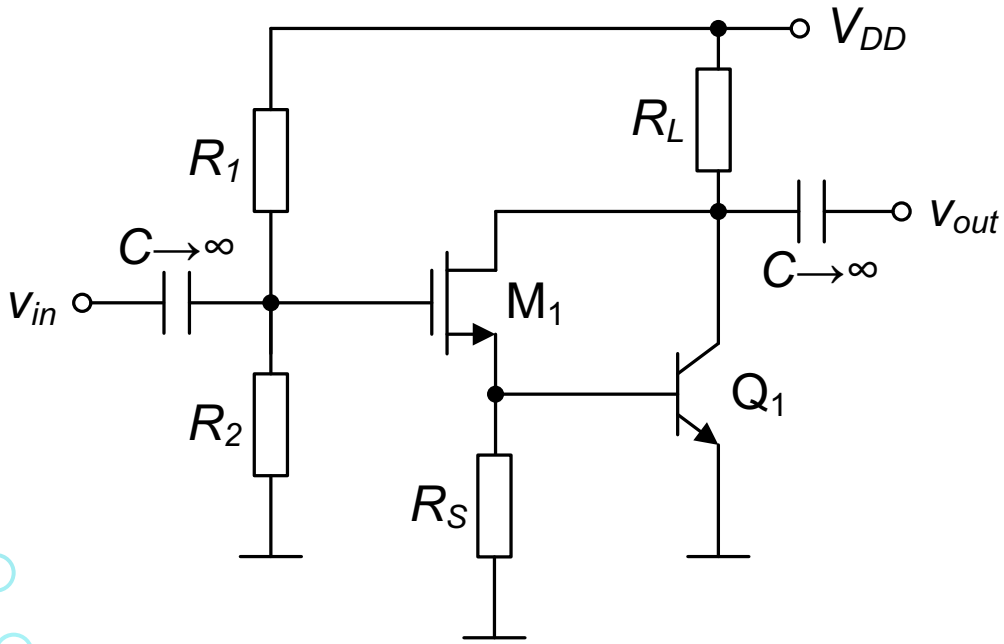
$$R_{out} = \frac{v_t}{i_t} = \frac{r_{ds}R_S}{r_{ds} + (1 + g_m r_{ds})R_S} = 328.3\ \Omega$$

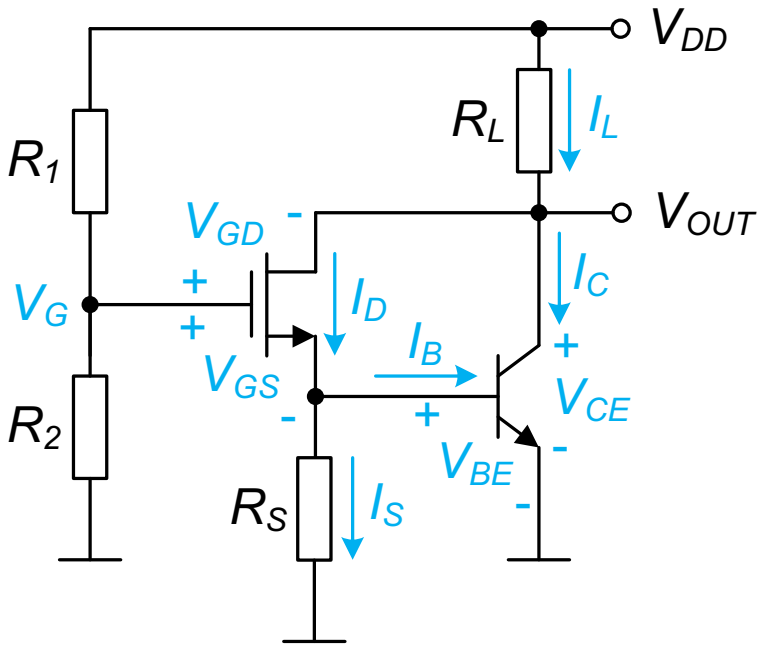
ZADATAK 3

Za kolo prikazano na slici izračunati odnos otpornosti $x=R_1/R_2$ tako da jednosmjerni napon na izlazu kola iznosi V_{OUT}=2.5 V. Poznato je: napon napajanja kola V_{DD}=5 V, otpornosti R_S=1 kΩ i R_L=1 kΩ, napon praga MOSFET-a V_t=0.8 V, faktor β_M=11 mA/V^2 MOSFET-a, koeficijent modulacije dužine kanala MOSFET-a λ_M=0.05 V^{-1}, strujno pojačanje BJT-a β_B=100, napon baza-emitor BJT-a kada provodi V_{BE}=0.7 V, napon kolektor-emitor BJT-a u zasićenju V_{CES}=0.2 V, termički napon V_T=25 mV, *Early*-jev napon V_A=20 V. Izračunati naponsko pojačanje A_v.

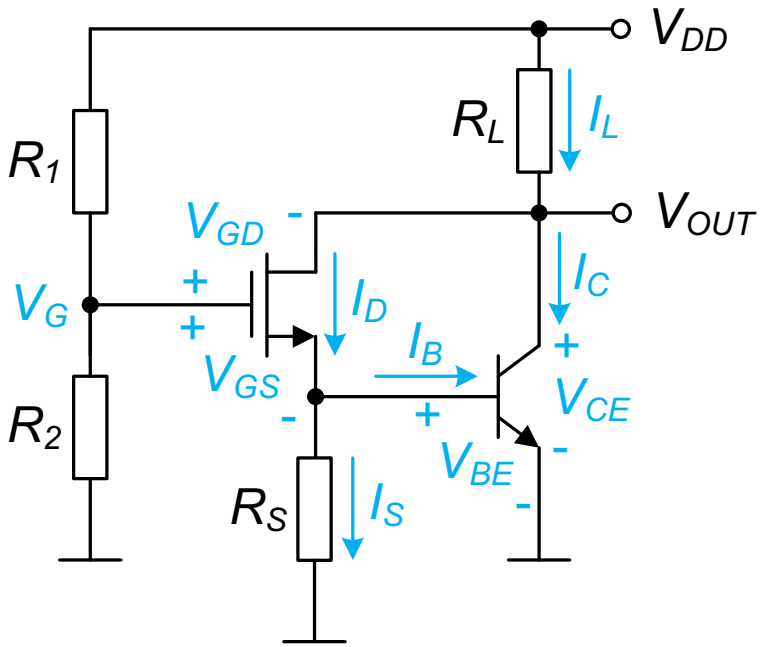


ZADATAK 3 – DC ANALIZA





ZADATAK 3 – DC ANALIZA



Uvodi se pretpostavka da je MOSFET u zasićenju.

$$V_{CE} = V_{OUT} > V_{CES}$$

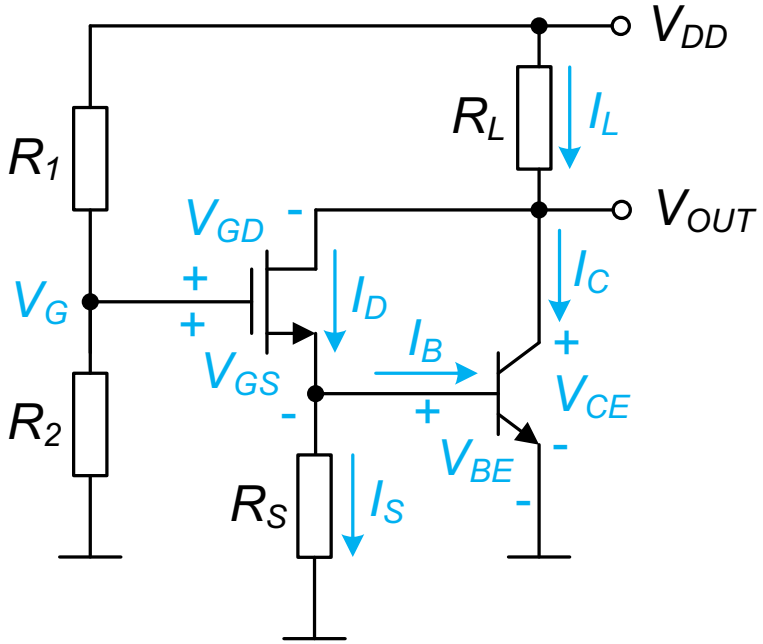
Slijedi da je BJT u DAR-u.

$$I_L = \frac{V_{DD} - V_{OUT}}{R_L} = 2.5\ \text{mA}$$

$$I_S = \frac{V_{BE}}{R_S} = 0.7\ \text{mA}$$

$$\left.\begin{aligned} I_L &= I_D + I_C \\ I_D &= I_S + I_B \\ I_C &= \beta_B I_B \end{aligned}\right\} \Rightarrow I_D = \frac{\beta_B I_S + I_L}{\beta_B + 1}$$

ZADATAK 3 – DC ANALIZA



$$I_D = \frac{1}{2}\beta_M (V_{GS} - V_t)^2 (1 + \lambda_M V_{DS}) \approx \frac{1}{2}\beta_M (V_{GS} - V_t)^2$$

$$V_{GS} = V_G - V_{BE}$$

$$V_G = \frac{R_2}{R_1 + R_2} V_{DD} = \frac{1}{x+1} V_{DD}$$

$$x = \frac{R_1}{R_2} \approx \frac{V_{DD}}{\sqrt{\frac{2}{\beta_M}\frac{I_L + \beta_B I_S}{\beta_B + 1}} + V_{BE} + V_t} - 1 = 1.69$$

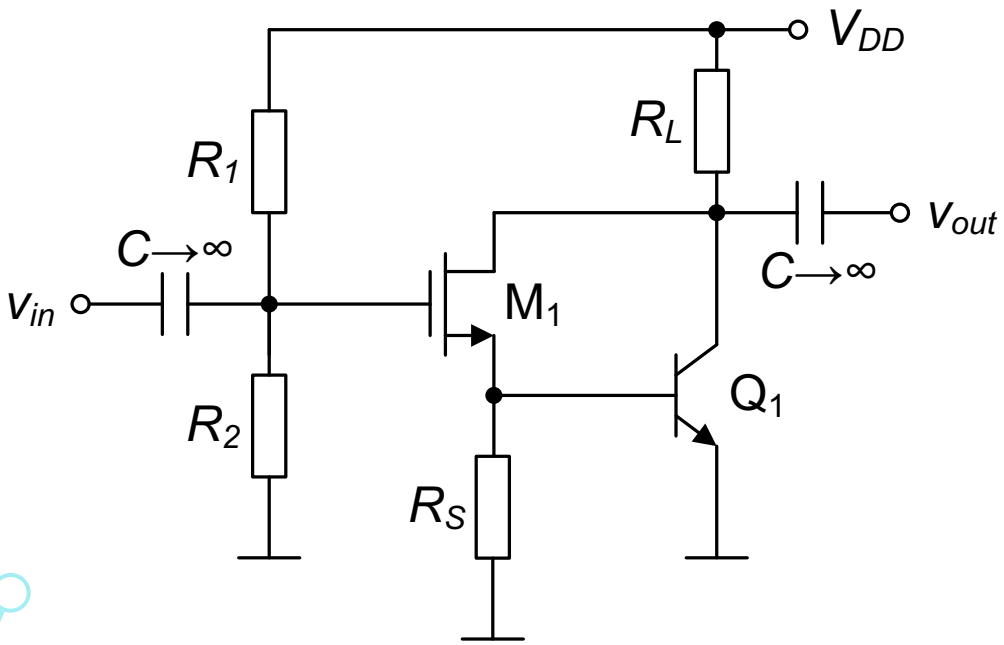
$$V_{GS} = 1.16\ \text{V}$$

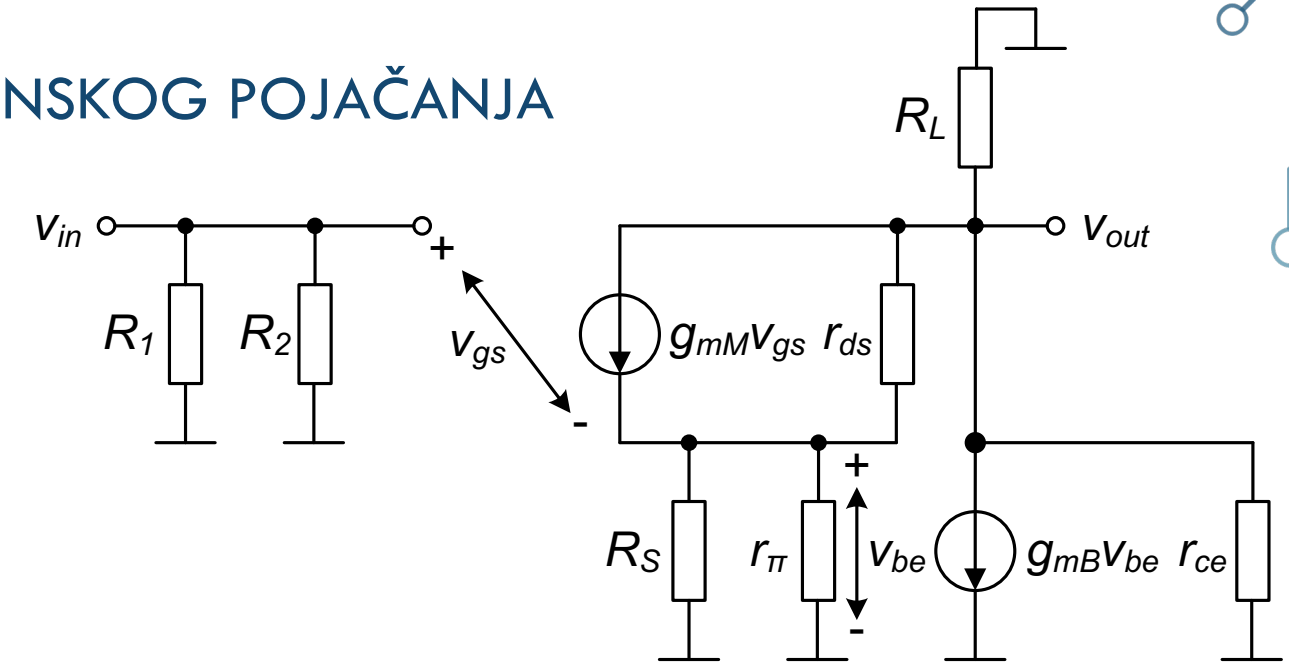
$$I_D = 0.71\ \text{mA}$$

$$V_{GD} = V_G - V_{OUT} = -0.64\ \text{V} < V_t$$

Slijedi da je pretpostavka o zasićenju MOSFET-a tačna.

ZADATAK 3 – ODREĐIVANJE NAPONSKOG POJAČANJA





$$g_{mM} = \sqrt{2\beta_M I_D} = 3.98\ \text{mS}$$

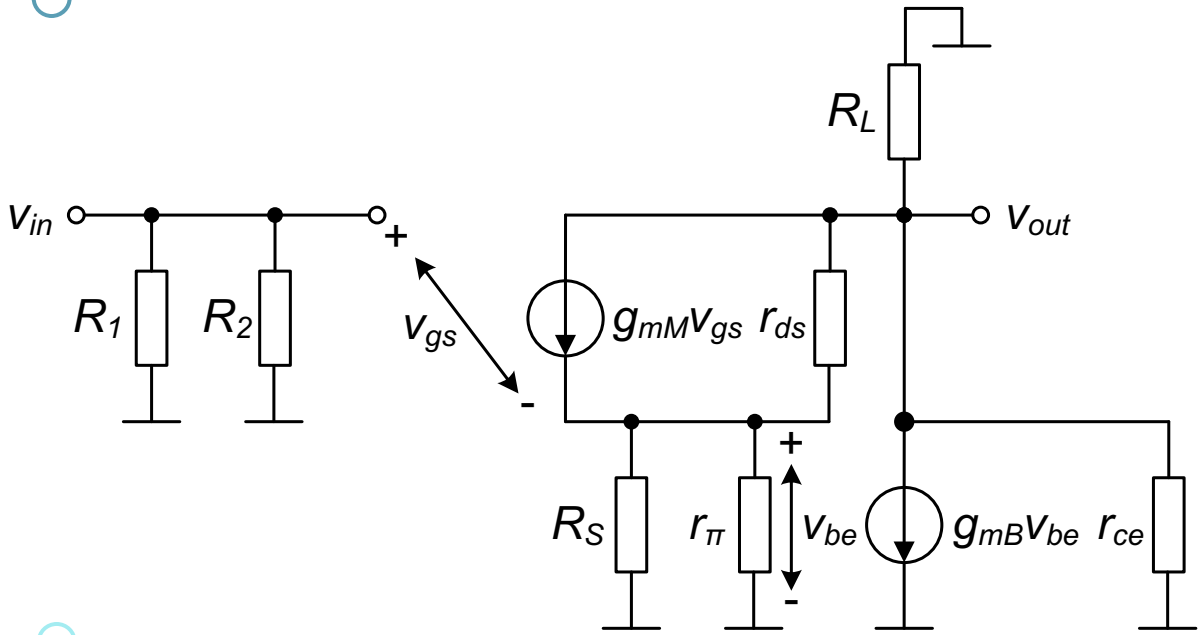
$$r_{ds} = \frac{1}{\lambda I_D} = 27.78\ \text{k}\Omega$$

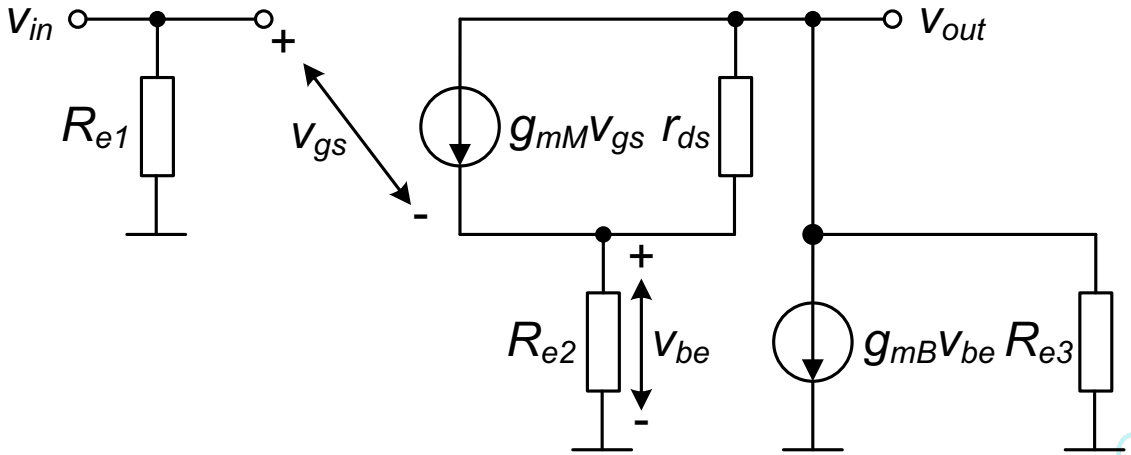
$$g_{mB} = \frac{I_C}{V_T} = 80\ \text{mS}$$

$$r_{ce} = \frac{V_A}{I_C} = 10\ \text{k}\Omega$$

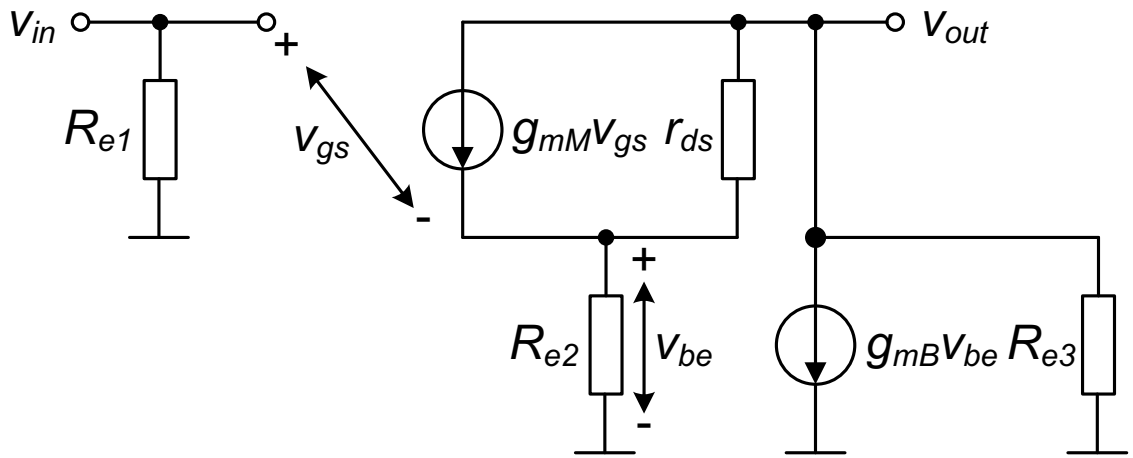
$$r_\pi = \frac{\beta_B}{g_{mB}} = 1.25\ \text{k}\Omega$$

ZADATAK 3 – ODREĐIVANJE NAPONSKOG POJAČANJA





ZADATAK 3

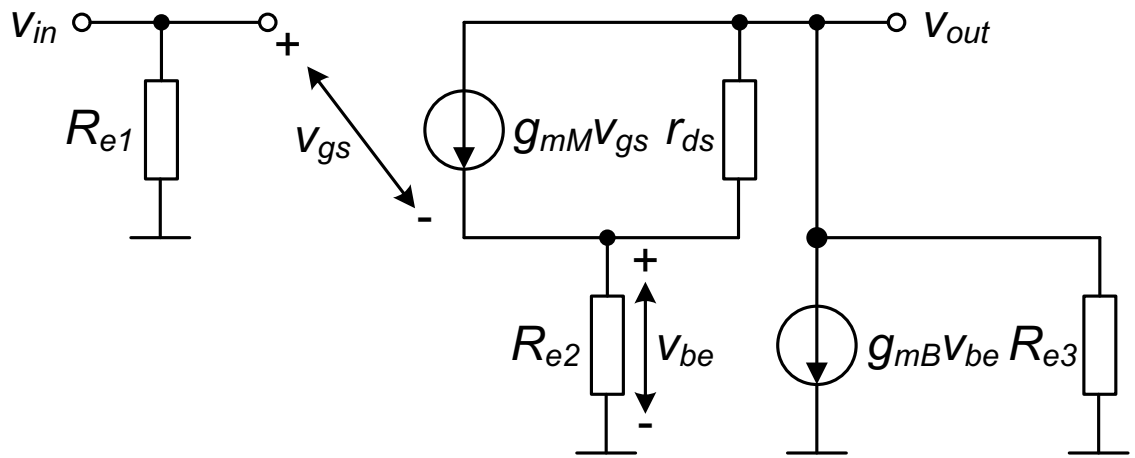


$$R_{e1} = \frac{R_1 R_2}{R_1 + R_2}$$

$$R_{e2} = \frac{R_S r_\pi}{R_S + r_\pi} = 0.55\ \text{k}\Omega$$

$$R_{e3} = \frac{R_L r_{ce}}{R_L + r_{ce}} = 0.91\ \text{k}\Omega$$

ZADATAK 3



$$g_{mM}v_{gs} + \frac{v_{out} - v_{be}}{r_{ds}} = \frac{v_{be}}{R_{e2}}$$

$$g_{mB}v_{be} + \frac{v_{out}}{R_{e3}} + \frac{v_{be}}{R_{e2}} = 0 \Longrightarrow v_{be} = -\frac{v_{out}}{\left(g_{mB} + \frac{1}{R_{e2}}\right)R_{e3}} = -\frac{R_{e2}v_{out}}{(g_{mB}R_{e2} + 1)R_{e3}}$$

$$g_{mM}(v_{in} - v_{be}) + \frac{v_{out} - v_{be}}{r_{ds}} = \frac{v_{be}}{R_{e2}}$$

ZADATAK 3

$$v_{be} = -\frac{R_{e2} v_{out}}{(g_{mB} R_{e2} + 1) R_{e3}}$$

$$g_{mM}(v_{in} - v_{be}) + \frac{v_{out} - v_{be}}{r_{ds}} = \frac{v_{be}}{R_{e2}}$$

$g_{mM} r_{ds} \gg 1$:

$$g_{mM} v_{in} + \frac{v_{out}}{r_{ds}} = v_{be}\left(g_{mM} + \frac{1}{r_{ds}} + \frac{1}{R_{e2}}\right) \approx v_{be}\left(g_{mM} + \frac{1}{R_{e2}}\right) = v_{be}\frac{g_{mM} R_{e2} + 1}{R_{e2}}$$

$$v_{in} = -\frac{1}{g_{mM}}\left(\frac{g_{mM} R_{e2} + 1}{(g_{mB} R_{e2} + 1) R_{e3}} + \frac{1}{r_{ds}}\right) v_{out}$$

$g_{mB} R_{e2} \gg 1$:

$$v_{in} = -\frac{1}{g_{mM}}\left(\frac{g_{mM} R_{e2} + 1}{g_{mB} R_{e2} R_{e3}} + \frac{1}{r_{ds}}\right) v_{out}$$

ZADATAK 3

$$v_{in} = -\frac{1}{g_{mM}}\left(\frac{g_{mM}R_{e2}+1}{g_{mB}R_{e2}R_{e3}}+\frac{1}{r_{ds}}\right)v_{out}$$

$$A_v = \frac{v_{out}}{v_{in}} = -\left[\left(\frac{1}{g_{mB}R_{e3}}+\frac{1}{g_{mM}g_{mB}R_{e2}R_{e3}}+\frac{1}{g_{mM}r_{ds}}\right)\right]^{-1} = -34.41$$