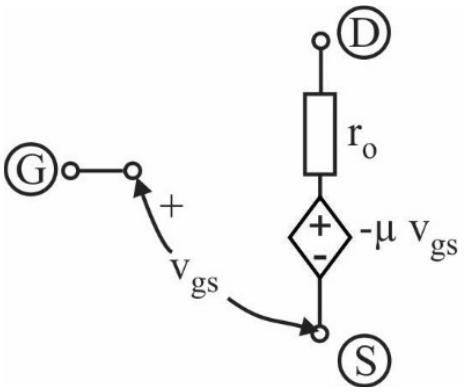
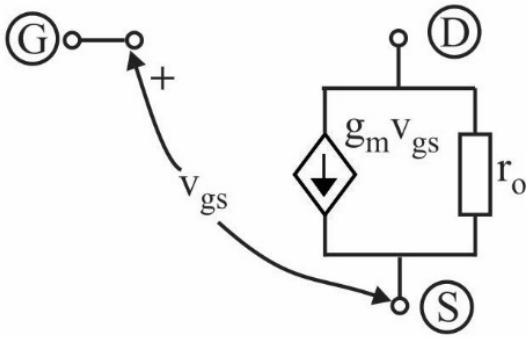
ANALIZA POJAČAVAČA SA MOSFET TRANZISTORIMA

$$g_m = 2\sqrt{A \cdot I_D} \qquad r_o = \frac{1}{\lambda \cdot I_D} = \frac{V_A}{I_D} \qquad \mu = g_m \cdot r_o$$



Naponski model



Strujni model

Model MOSFETa za naizmeničnu struju je isti i za n-kanalni i za p-kanalni MOSFET. Naizmenična struja drejna se uvek usmerava od drejna prema sorsu.

1. ZADATAK

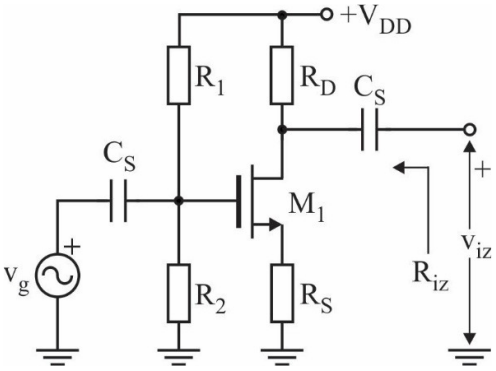
Za kolo pojačavača sa slike odrediti:

a) Dinamičke parametre tranzistora strminu g_m, izlaznu otpornost r_o i koeficijent naponskog pojačanja μ ako je $\lambda = 0{,}01\ V^{-1}$;

b) Naponsko pojačanje $A_n = v_{iz}/v_g$.

c) Izlaznu otpornost tranzistora R_{iz};

Poznato je $R_S = 1\ k\Omega$, $R_D = 6\ k\Omega$, $R_1 = 3\ M\Omega$, $R_2 = 1\ M\Omega$ i $V_{DD} = 12\ V$. C_S teži beskonačnosti. Parametri tranzistora su: $A = 1\ mA/V^2$ i $V_t = 1\ V$.



a)

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

$$V_S = R_S \cdot I_D$$

$$I_D = A \cdot (V_{GS} - V_t)^2$$

$$V_x = V_{GS} - V_t$$

$$V_{GS} = \frac{R_2}{R_1 + R_2} \cdot V_{DD} - R_S \cdot A \cdot (V_{GS} - V_t)^2$$

$$R_S \cdot A \cdot (V_{GS} - V_t)^2 + (V_{GS} - V_t) + V_t - \frac{R_2}{R_1 + R_2} \cdot V_{DD} = 0$$

$$R_S \cdot A \cdot V_x^2 + V_x + V_t - \frac{R_2}{R_1 + R_2} \cdot V_{DD} = 0$$

$$V_x^2 + V_x - 2 = 0$$

$$V_x = \frac{-1 \pm \sqrt{1+8}}{2}$$

$V_{x1} = 1\ V$

~~$V_{x1} = -2\ V$~~

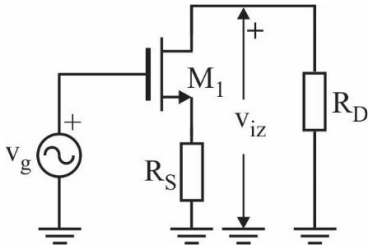
$I_D = A \cdot V_x^2 = 1\ mA$

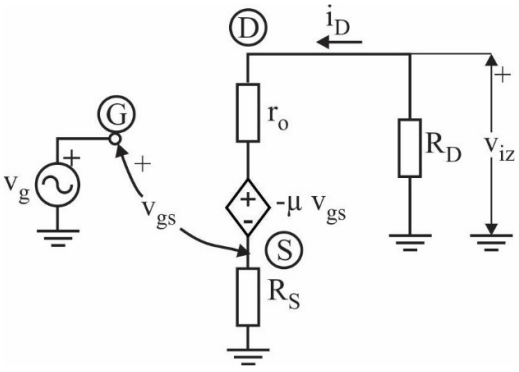
$g_m = 2 \cdot \sqrt{A \cdot I_D} = 2\ mS$

$r_o = \frac{1}{\lambda \cdot I_D} = 100\ k\Omega$

$\mu = g_m \cdot r_o = 200$

b) Otpornici R1 i R2 su izostavljeni iz šeme jer ne uticu na naponsko pojačanje. Ova dva otpornika imaju uticaj samo na ulaznu otoprnost.





$R_D \cdot i_d + r_o \cdot i_d - \mu \cdot v_{gs} + R_s \cdot i_d = 0$

$v_{gs} = v_g - i_d \cdot R_S$

$v_{iz} = -R_D \cdot i_d$

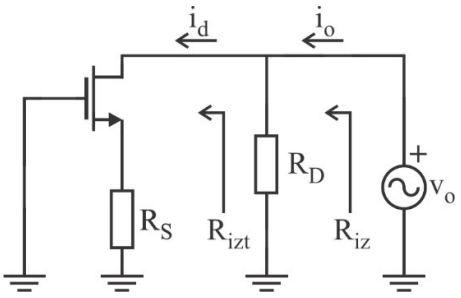
$R_D \cdot i_d + r_o \cdot i_d - \mu \cdot v_g + \mu \cdot i_d \cdot R_S + R_s \cdot i_d = 0$

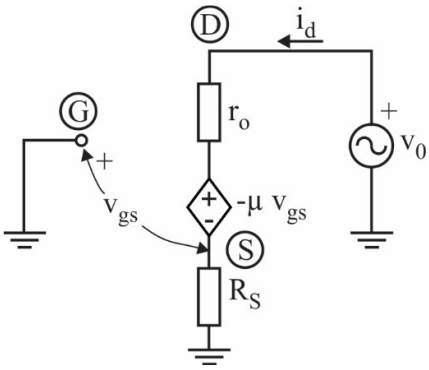
$i_d = \frac{\mu \cdot v_g}{R_D + r_o + (\mu + 1) \cdot R_s}$

$v_{iz} = \frac{-R_D \cdot \mu \cdot v_g}{R_D + r_o + (\mu + 1) \cdot R_s}$

$A_n = \frac{v_{iz}}{v_g} = \frac{-R_D \cdot \mu}{R_D + r_o + (\mu + 1) \cdot R_s} = -3{,}9$

C)





$$v_o = r_o \cdot i_d - \mu \cdot v_{gs} + R_s \cdot i_d$$

$$v_{gs} = -R_s \cdot i_d$$

$$v_o = r_o \cdot i_d + \mu \cdot R_s \cdot i_d + R_s \cdot i_d$$

$$R_{izt} = \frac{v_o}{i_d} = r_o + (\mu + 1) \cdot R_s = 301\ k\Omega$$

$$R_{iz} = R_{izt} \parallel R_D = 5{,}88\ k\Omega$$

$$R_{iz} \approx R_D$$

2. ZADATAK

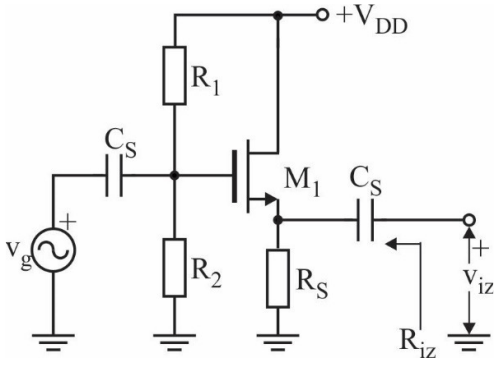
Za kolo pojačavača sa zajedničkim drejnom sa slike odrediti:

a) Dinamičke parametre tranzistora strminu g_m, izlaznu otpornost r_o i koeficijent naponskog pojačanja μ ako je $\lambda = 0{,}01\ V^{-1}$;

b) Naponsko pojačanje $A_n = v_{iz}/v_g$.

c) Izlaznu otpornost tranzistora R_{iz};

Poznato je $R_S = 6\ k\Omega$, $R_1 = 1\ M\Omega$, $R_2 = 2\ M\Omega$, $V_{DD} = 12\ V$. C_S teži beskonačnosti. Parametri tranzistora su: $A = 1\ mA/V^2$ i $V_t = 1\ V$.



a)

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

$$V_S = R_S \cdot I_D$$

$$I_D = A \cdot (V_{GS} - V_t)^2$$

$$V_x = V_{GS} - V_t$$

$$V_{GS} = \frac{R_2}{R_1 + R_2} \cdot V_{DD} - R_S \cdot A \cdot (V_{GS} - V_t)^2$$

$$R_S \cdot A \cdot (V_{GS} - V_t)^2 + (V_{GS} - V_t) + V_t - \frac{R_2}{R_1 + R_2} \cdot V_{DD} = 0$$

$$R_S \cdot A \cdot V_x^2 + V_x + V_t - \frac{R_2}{R_1 + R_2} \cdot V_{DD} = 0$$

$$V_x^2 + V_x - 2 = 0$$

$$V_x = \frac{-1 \pm \sqrt{1 + 8}}{2}$$

$V_{x1} = 1\ V$

~~$V_{x1} = -2\ V$~~

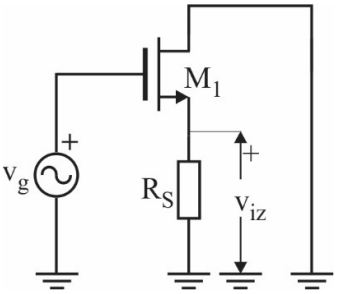
$I_D = A \cdot V_x^2 = 1\ mA$

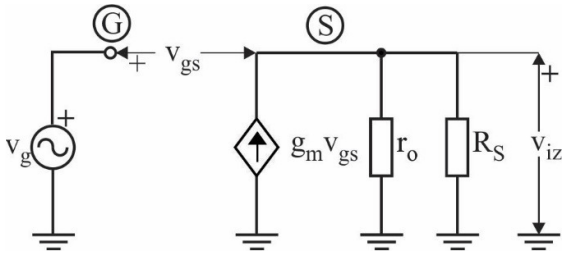
$g_m = 2 \cdot \sqrt{A \cdot I_D} = 2\ mS$

$r_o = \frac{1}{\lambda \cdot I_D} = 100\ k\Omega$

$\mu = g_m \cdot r_o = 200$

b)





$-g_m \cdot v_{gs} + \frac{v_s}{r_o} + \frac{v_s}{R_s} = 0$

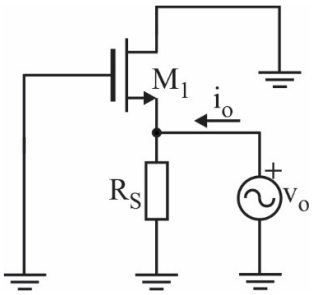
$v_{gs} = v_g - v_s$

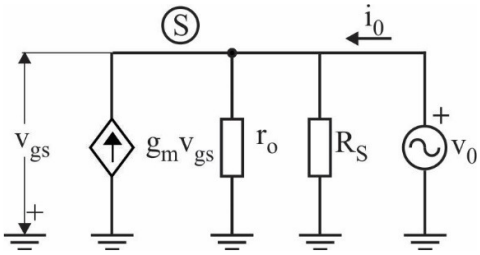
$-g_m \cdot v_g + g_m \cdot v_s + \frac{v_s}{r_o} + \frac{v_s}{R_s} = 0$

$v_{iz} = v_s = \frac{g_m \cdot v_g}{g_m + \frac{1}{r_o} + \frac{1}{R_s}}$

$A_n = \frac{v_{iz}}{v_g} = \frac{g_m}{g_m + \frac{1}{r_o} + \frac{1}{R_s}} = 0.92$

c)





$$i_o = \frac{v_o}{R_s} + \frac{v_o}{r_o} - g_m \cdot v_{gs}$$

$$v_{gs} = -v_s$$

$$R_{iz} = \frac{v_o}{i_o} = \frac{1}{\frac{1}{R_s} + \frac{1}{r_o} + g_m} = R_s \parallel r_o \parallel \left(\frac{1}{g_m}\right) = 497\ \Omega$$

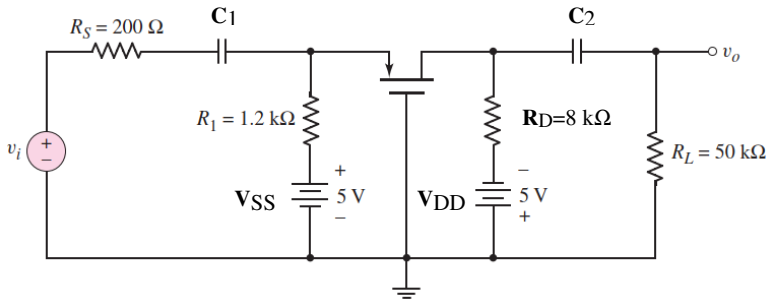
$$\left(\frac{1}{g_m}\right) \ll R_s, r_o$$

$$R_{iz} = R_s \parallel r_o \parallel \left(\frac{1}{g_m}\right) \approx \frac{1}{g_m}$$

3 ZADATAK

Parametri tranzistora u kolu sa slike su A = 0,5 mA/V^2 i V_t = -3,4 V, λ=0. Odrediti:

a) Radnu tačku tranzistora i dinamičke parametre tranzistora.
b) Naponsko pojačanje $A_n = v_{iz}/v_g$.
c) Ulaznu otpornost tranzistora R_{in}.



Rešenje:

$$-V_{SS} + R_1 \cdot I_D - V_{GS} = 0$$

$$-V_{SS} + R_1 \cdot A \cdot (V_{GS} - V_t)^2 - V_{GS} = 0$$

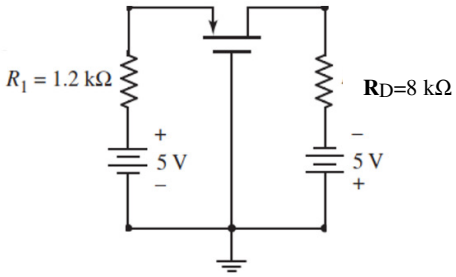
$$R_1 \cdot A \cdot V_X^2 - V_X - V_t - V_{SS} = 0$$

$$0{,}6 \cdot V_X^2 - V_X - 1{,}6 = 0$$

$$V_X = \frac{1 \pm \sqrt{1 + 4 \cdot 0{,}6 \cdot 1{,}6}}{1{,}2}$$

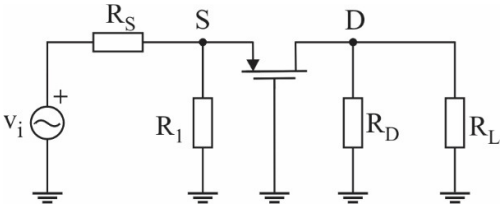
$$V_{x1} = -1\ V$$

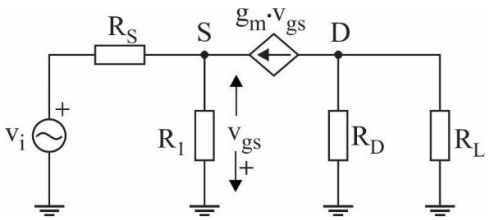
$$\cancel{V_{x2} = \frac{8}{3}\ V}$$



$$I_D = A \cdot V_x^2 = 0{,}5\ mA$$

$$g_m = 2 \cdot \sqrt{A \cdot I_D} = 1\ mS$$





$$\frac{v_s}{R_1} + \frac{v_s - v_i}{R_s} - g_m \cdot v_{gs} = 0$$

$$\frac{v_D}{R_D} + \frac{v_D}{R_L} + g_m \cdot v_{gs} = 0$$

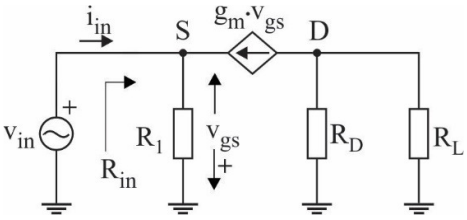
$$v_{gs} = -v_s$$

$$v_i = \left(1 + \frac{R_S}{R_1} + g_m \cdot R_S\right) \cdot v_s$$

$$v_d = -g_m \cdot v_{gs} \cdot R_d \parallel R_L$$

$$A_n = \frac{v_d}{v_i} = g_m \cdot R_d \parallel R_L \cdot \frac{R_1}{R_1 + R_s + g_m \cdot R_s \cdot R_1} = 5$$

b)



$$-i_{in} + \frac{v_{in}}{R_1} - g_m \cdot v_{gs} = 0$$

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

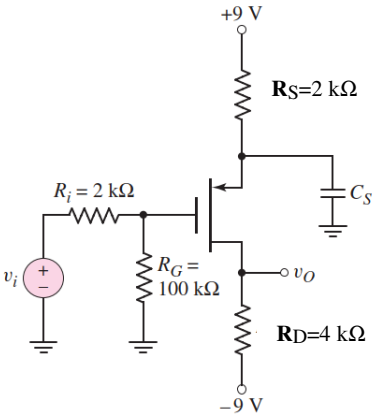
$$i_{in} = v_{in}\left(\frac{1}{R_1} + g_m\right)$$

$$R_{in} = \frac{R_1}{1 + g_m \cdot R_1} = 540\ \Omega$$

4 ZADATAK

Parametri tranzistora u kolu sa slike su A = 0,5 mA/V^2 i V_t = -3 V, λ=0,01 V^{-1}. Odrediti:

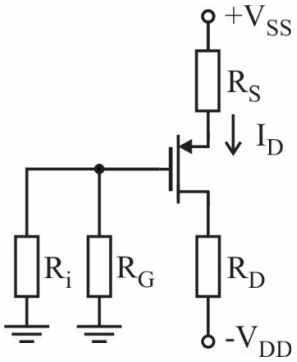
a) Radnu tačku tranzistora i dinamičke parametre tranzistora.
b) Naponsko pojačanje $A_n = v_{iz}/v_g$.
c) Izlaznu otpornost tranzistora R_{iz}.



Rešenje:

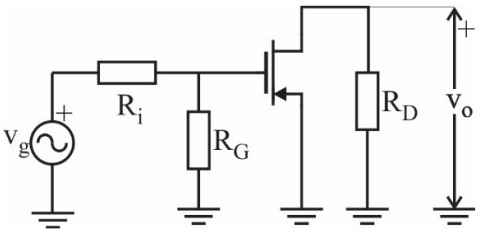
$$V_S = V_{DD} - R_S \cdot I_D$$
$$V_{GS} = -V_S = R_S \cdot I_D - V_{DD}$$
$$I_D = A \cdot (V_{GS} - V_t)^2$$

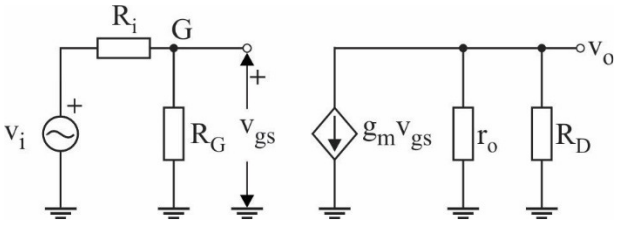
$$V_{GS} - V_t + V_t = R_S \cdot A \cdot (V_{GS} - V_t)^2 - V_{DD}$$
$$R_S \cdot A \cdot V_x^2 - V_x - V_{DD} - V_t = 0$$
$$V_X^2 - V_X - 6 = 0$$
$$V_X = \frac{1 \pm \sqrt{1 + 4 \cdot 6}}{2}$$
$$V_{x1} = 3\,V$$
$$V_{x2} = -2\,V$$



$$I_D = A \cdot V_x^2 = 2\,mA$$
$$g_m = 2 \cdot \sqrt{A \cdot I_D} = 2\,mS$$
$$r_o = \frac{1}{\lambda \cdot I_D} = 50\,k\Omega$$

b)





$$\frac{v_g}{R_G} + \frac{v_g - v_i}{R_i} = 0$$

$$g_m \cdot v_{gs} + \frac{v_o}{r_o} + \frac{v_o}{R_D} = 0$$

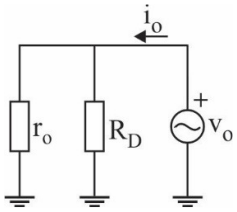
$$v_{gs} = v_g$$

$$v_{gs} = \frac{R_G}{R_G + R_i} \cdot v_i$$

$$v_o = -g_m \cdot v_{gs} \cdot \frac{1}{\frac{1}{r_o} + \frac{1}{R_D}} = -g_m \cdot v_{gs} \cdot r_o \parallel R_D$$

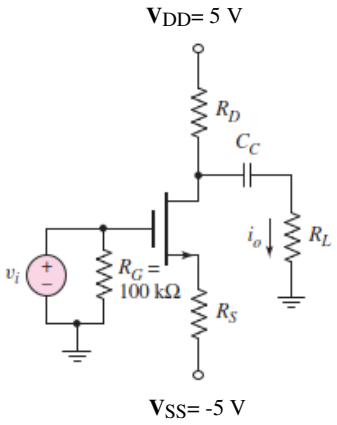
$$A_n = \frac{v_o}{v_i} = -g_m \cdot \frac{R_G}{R_G + R_i} \cdot r_o \parallel R_D = 7.25$$

c)



$$R_{iz} = r_o \parallel R_D = 3{,}7\ k\Omega$$

5 ZADATAK



Parametri tranzistora u kolu sa slike su A = 0,5 mA/V^2 i V_t = 2,5 V, λ=0,01 V^{-1}. Elementi kola su $R_S = 250\ \Omega$ $R_D = 2\ k\Omega$; $R_L = 2\ k\Omega$. Odrediti:

a) Radnu tačku tranzistora i dinamičke parametre tranzistora.

b) Naponsko pojačanje $A_n = v_{iz}/v_g$.

c) Izlaznu otpornost tranzistora R_{iz}.

Rešenje:

$$V_S = R_S \cdot I_D + V_{SS}$$

$$V_{GS} = -V_S = -V_{SS} - R_S \cdot I_D$$

$$I_D = A \cdot (V_{GS} - V_t)^2$$

$$V_{GS} - V_t + V_t = -R_S \cdot A \cdot (V_{GS} - V_t)^2 - V_{SS}$$

$$R_S \cdot A \cdot V_x^2 + V_x + V_{SS} + V_t = 0$$

$$0{,}125 \cdot V_X^2 + V_X - 2{,}5 = 0$$

$$V_X = \frac{-1 \pm \sqrt{1 + 4 \cdot 2{,}5 \cdot 0{,}125}}{0{,}25}$$

~~$V_{x1} = -10\ V$~~

$$V_{x2} = 2\ V$$

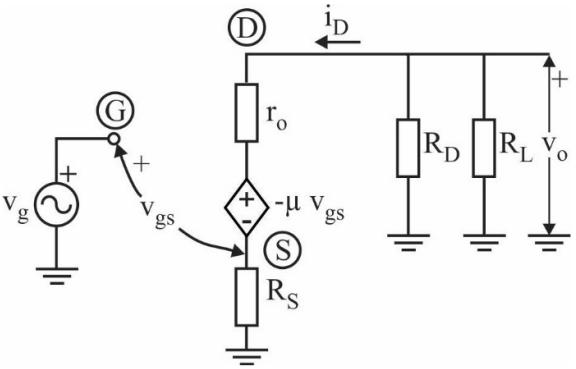
$$I_D = A \cdot V_x^2 = 2\ mA$$

$$g_m = 2 \cdot \sqrt{A \cdot I_D} = 2\ mS$$

$$r_o = \frac{1}{\lambda \cdot I_D} = 50\ k\Omega$$

$$\mu = r_o \cdot g_m = 100$$

b)



$$R_D \parallel R_L \cdot i_d + r_o \cdot i_d - \mu \cdot v_{gs} + R_s \cdot i_d = 0$$

$$v_{gs} = v_g - i_d \cdot R_S$$

$$v_{iz} = -R_D \parallel R_L \cdot i_d$$

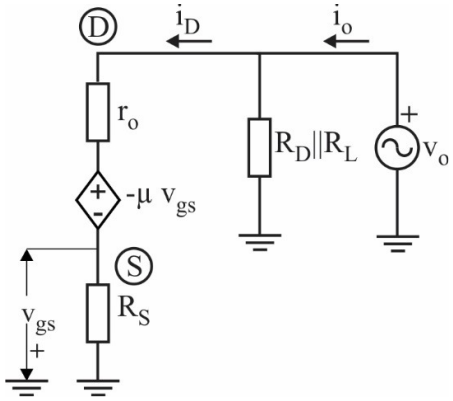
$$R_D \parallel R_L \cdot i_d + r_o \cdot i_d - \mu \cdot v_g + \mu \cdot i_d \cdot R_S + R_s \cdot i_d = 0$$

$$i_d = \frac{\mu \cdot v_g}{R_D \parallel R_L + r_o + (\mu + 1) \cdot R_s}$$

$$v_{iz} = \frac{-R_D \parallel R_L \cdot \mu \cdot v_g}{R_D \parallel R_L + r_o + (\mu + 1) \cdot R_s}$$

$$A_n = \frac{v_{iz}}{v_g} = -\frac{R_D \parallel R_L \cdot \mu}{R_D \parallel R_L + r_o + (\mu + 1) \cdot R_s} = -13{,}1$$

c)



$$r_o \cdot i_d - \mu \cdot v_{gs} + R_s \cdot i_d = v_o$$

$$v_{gs} = -i_d \cdot R_S$$

$$i_o = i_d + \frac{v_o}{R_D \parallel R_L}$$

$$i_d = \frac{v_o}{r_o + (\mu + 1) \cdot R_s}$$

$$R_{izt} = \frac{v_o}{i_d}$$

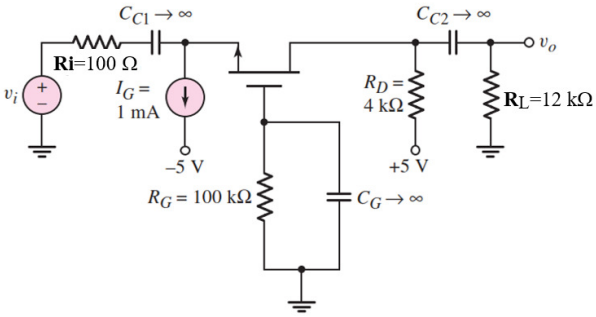
$$R_{izt} = r_o + (\mu + 1) \cdot R_S = 75\ k\Omega$$

$$i_o = \frac{v_o}{R_{izt}} + \frac{v_o}{R_D \parallel R_L}$$

$$R_{iz} = \frac{v_o}{i_o} = \frac{1}{\frac{1}{R_{izt}} + \frac{1}{R_D \parallel R_L}} = R_{izt} \parallel R_D \parallel R_L = 0{,}98\ k\Omega$$

6 ZADATAK

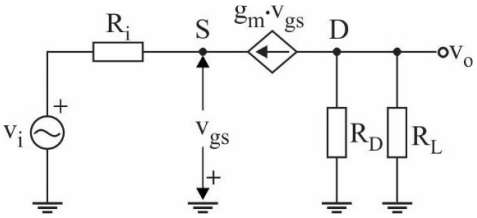
Parametri tranzistora u kolu sa slike su A = 1 mA/V^2 V_t = 1 V, λ=0 V^{-1}. Odrediti naponsko pojačanje $A_n = \frac{v_o}{v_i}$.



Rešenje:

$I_D = I_G = 1\ mA$

$g_m = 2\sqrt{A \cdot I_D}$=2 mS



$$\frac{v_s}{R_i} - \frac{v_g}{R_i} - g_m \cdot v_{gs} = 0$$

$$\frac{v_o}{R_D \parallel R_L} + g_m \cdot v_{gs} = 0$$

$$v_{gs} = -v_s$$

$$\frac{v_s}{R_i} + g_m \cdot v_s = \frac{v_g}{R_i}$$

$$v_s = \frac{v_g}{1 + g_m \cdot R_i}$$

$$v_o = \frac{g_m \cdot R_D \parallel R_L}{1 + g_m \cdot R_i} \cdot v_g$$

$$A_n = \frac{g_m \cdot R_D \parallel R_L}{1 + g_m \cdot R_i} = 5$$