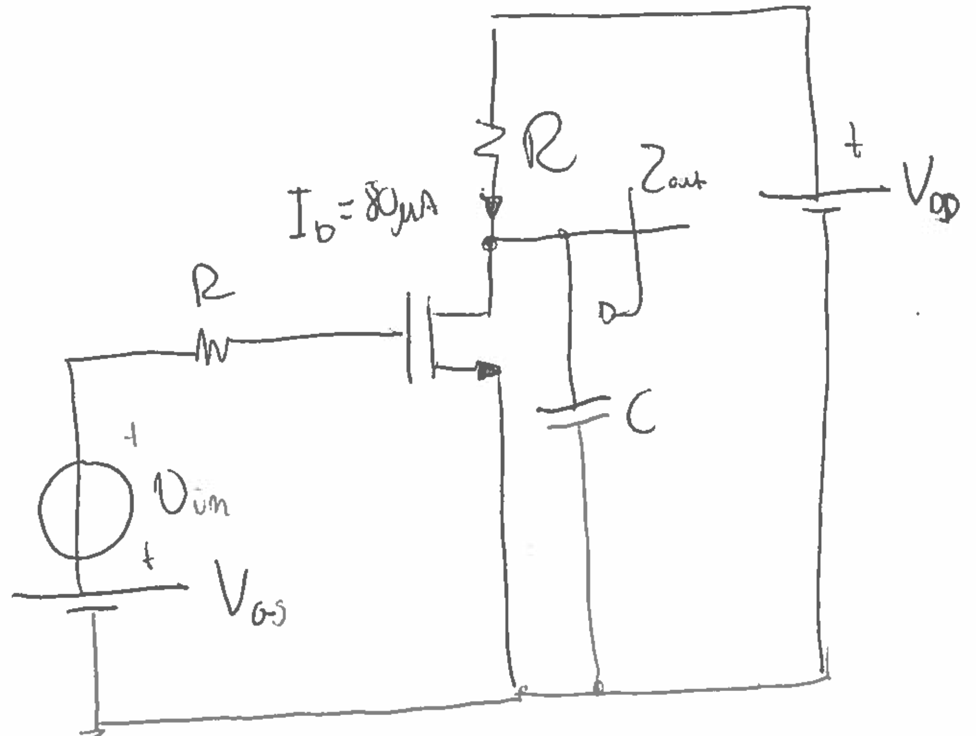
ES. 1

(1)



$C = 100pF$

$R = 25k\Omega$

$V_{TH} = 250mV$

$\beta = 16mA/V^2$

$\lambda = 0{,}01V^{-1}$

$V_{DD} = 5V$

- IPOTESI: SATURAZIONE

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

$$V_{DS} = V_{DD} - RI_D = 5V - 2V = 3V$$

$$V_{GS} = \sqrt{\frac{2 \cdot I_D}{\beta(1+\lambda V_{DS})}} + V_{TH} \cong \sqrt{\frac{2I_D}{\beta}} + V_{TH} = 350mV$$

- VERIFICA FUNZIONAMENTO IN SATURAZIONE

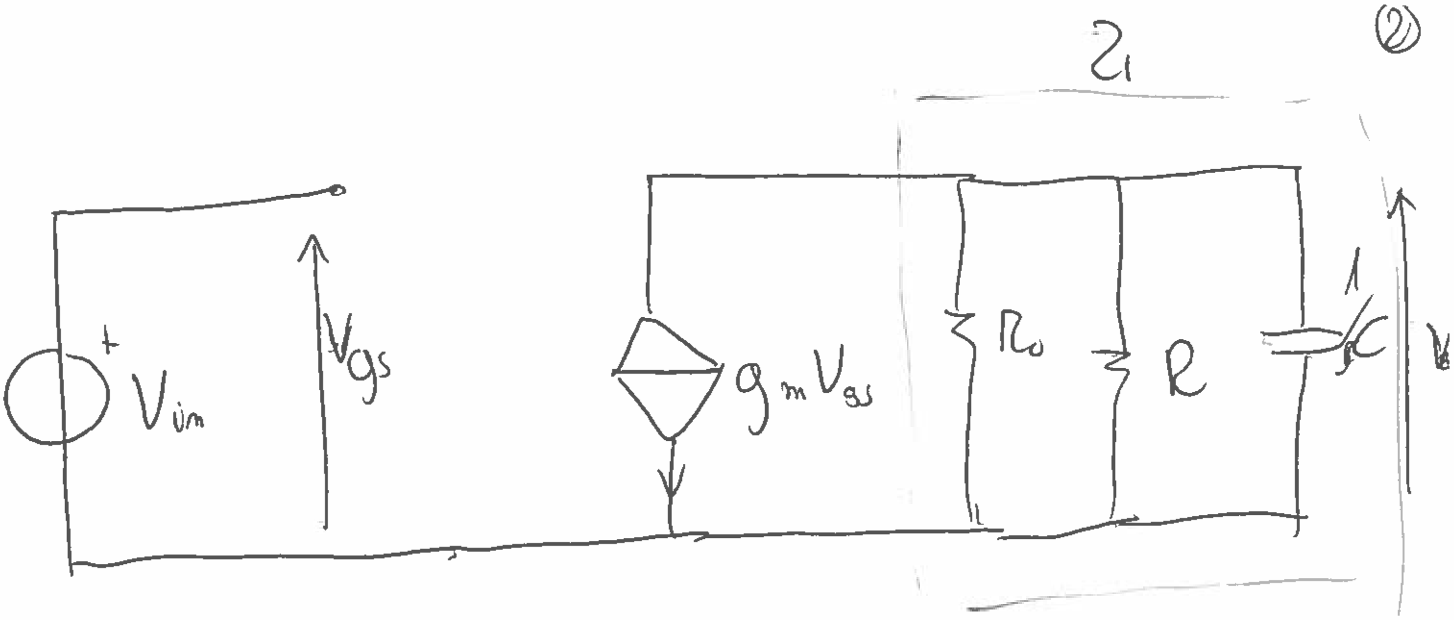
$V_{GS} = 350mV > V_T = 250mV$ ✓

$V_{DS} = 3V > V_{GS} - V_{TH} = 100mV$ ✓

2) $$g_m = \sqrt{2\beta I_D} = \sqrt{2 \cdot 16 \cdot 10^{-3} \cdot 80 \cdot 10^{-6}}\ S =$$

$$= 16 \cdot 10^{-4} S = 1{,}6\ mS$$

$$g_o = \lambda I_D = 0{,}01V^{-1} \cdot 80\mu A = 0{,}8\mu S = 1{,}25M\Omega$$



$$V_{out} = -g_m V_{gs} \underbrace{\left(r_o // R // \frac{1}{sC} \right)}_{Z_1} = V_{gs} \frac{-g_m (R // r_o)}{1 + s(R//r_o)C}$$

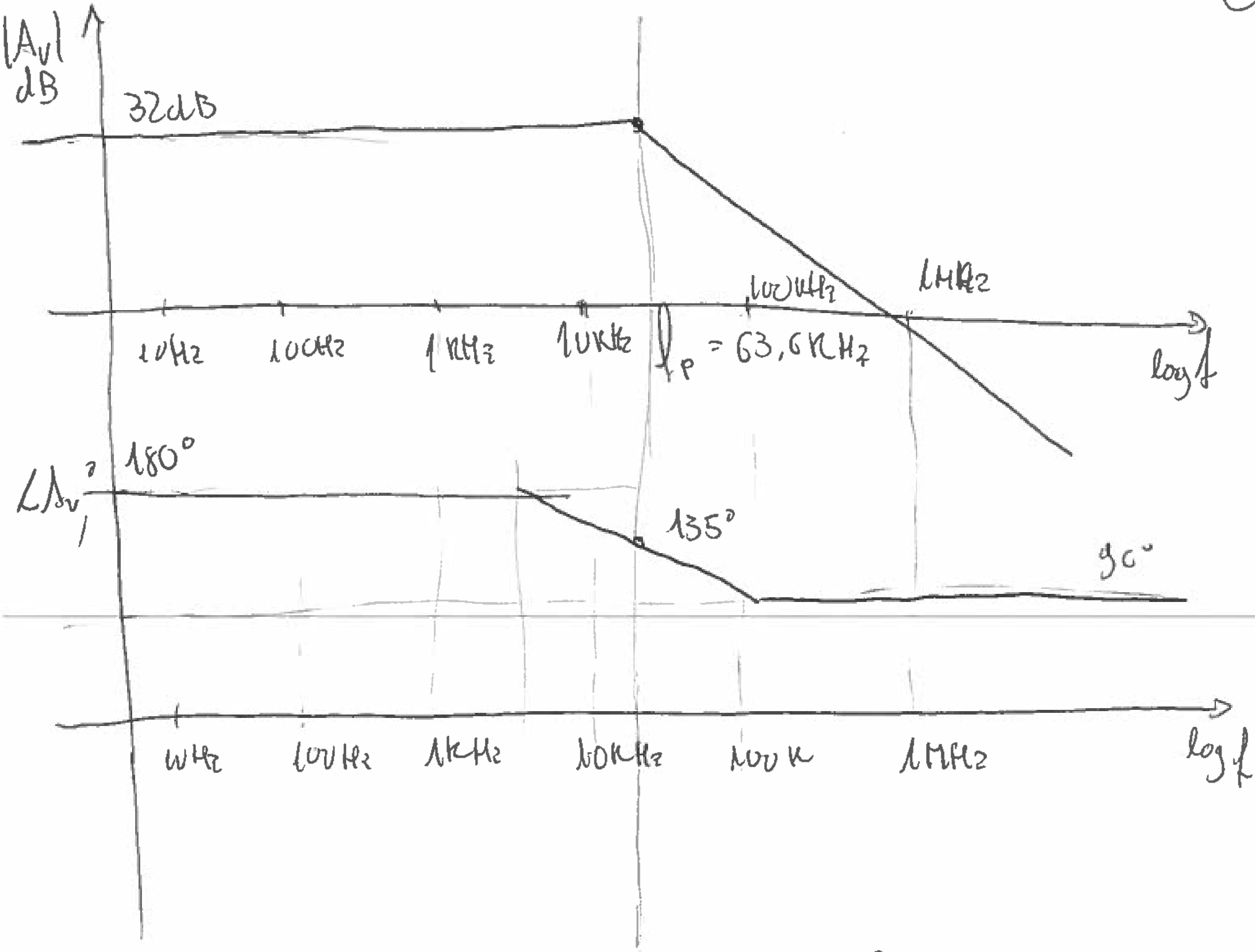
$$A_v(s) = \frac{V_{out}(s)}{V_{in}(s)} = \frac{-g_m (R//r_o)}{1 + s(R//r_o)C}$$

$$= \frac{A_0}{1 - s/s_p}$$

donc :

$$A_0 = -g_m (R // r_o) \simeq -39{,}2 \rightarrow |A_0| \Rightarrow 31{,}8\,dB$$

$$s_p = -\frac{1}{(R//r_o)C} = -392\ rad/ms \rightarrow f_p = \frac{1}{2\pi(R//r_o)C} = 62.3\,KHz$$

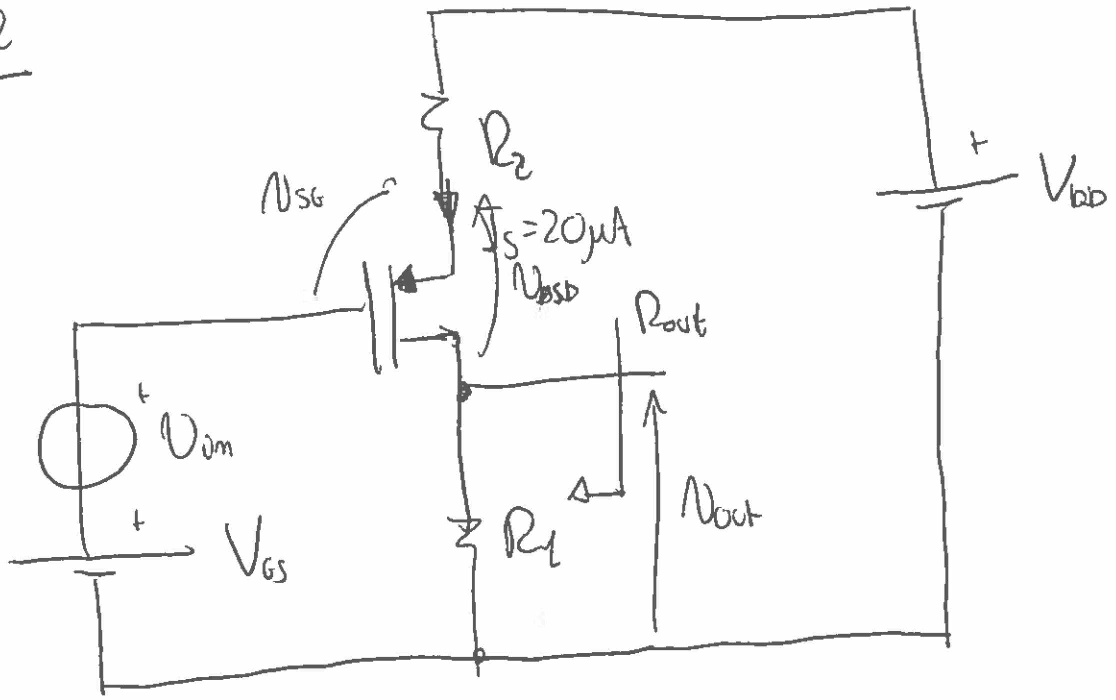


3) $Z_{out} = R_o \parallel R \parallel \frac{1}{sC} = \frac{R_o \parallel R}{1 + (R_o \parallel R)sC} = \frac{R_{out}}{1 + (R_o \parallel R)sC}$

$R_{out} = 24.5\,K\Omega$

(4)

ES. 2



$V_{DD} = 5V$
$R_1 = 100 k\Omega$
$R_2 = 10 k\Omega$
$V_{TH} = 300 mV$
$\beta = 4 mA/V^2$
$\lambda = 0$

1) VERIFICA FUNZIONAMENTO IN REGIONE DI SATURAZIONE

$$V_{SG} = \sqrt{\frac{2I_D}{\beta}} + V_{TH} = 100mV + 300mV = 400mV$$

$$V_{SD} = V_{DD} - R_2 I_S - R_1 I_D = V_{DD} - (R_1 + R_2) I_S = 5V - 2{,}2V = 2{,}8V$$

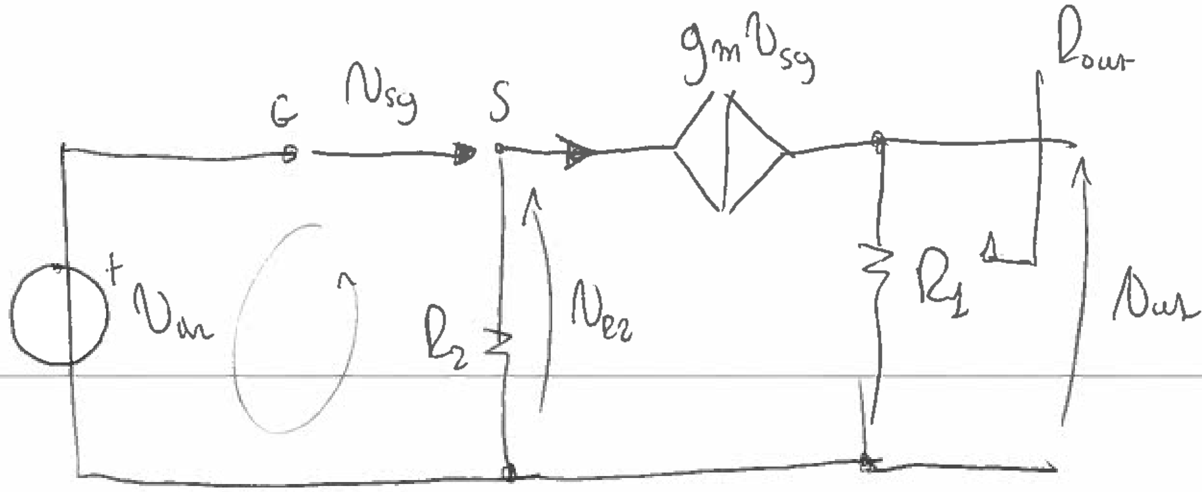
$(I_S = I_D)$

- $V_{SG} = 400mV > V_{TH} = 300mV$ ✓
- $V_{SD} = 2{,}8V > (V_{GS} - V_{TH}) = 100mV$ ✓

2) ANALISI DI PICCOLO SEGNALE

$$g_m = \sqrt{2\beta I_D} = 400\mu S$$

$$g_o = \lambda I_D \simeq 0$$



LKV alla maglia d'ingresso

$$v_{in} + v_{sg} = v_{R2}$$

essendo $i_{R2} = g_m v_{sg}$ (convenzioni di segno in figura)

$$v_{in} + v_{sg} = -g_m R_2 v_{sg} \rightarrow v_{sg} = \frac{-v_{in}}{1 + g_m R_2}$$

$$v_{out} = g_m v_{sg} \cdot R_1 = -\frac{g_m R_1}{1 + g_m R_2} v_{in}$$

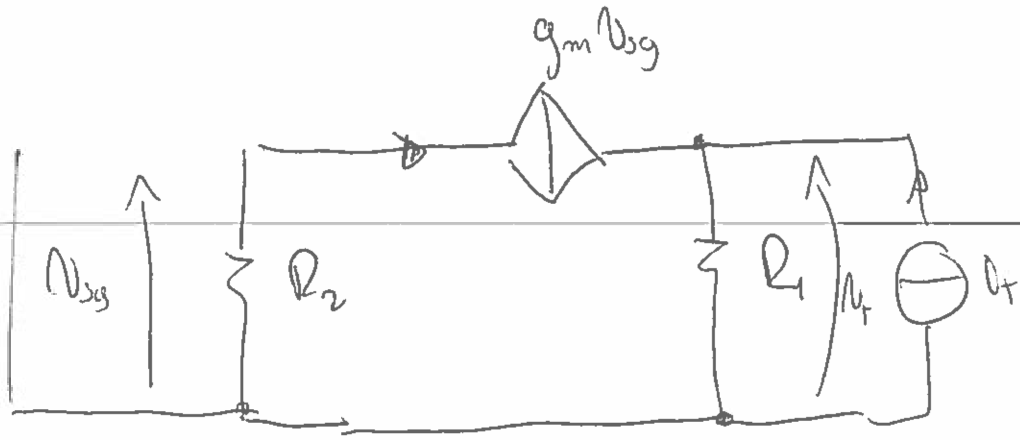
$$\boxed{A_v = \frac{v_{out}}{v_{in}} = -\frac{g_m R_1}{1 + g_m R_2} \simeq \frac{-40}{5} = -8}$$

(18dB)

3) Resistenze d'ingresso e d'uscita

$$R_{in} = \frac{v_{in}}{i_{in}}$$, essendo $i_{in} = 0$ sempre : $\boxed{R_{in} \to \infty}$

Resistenza di uscita



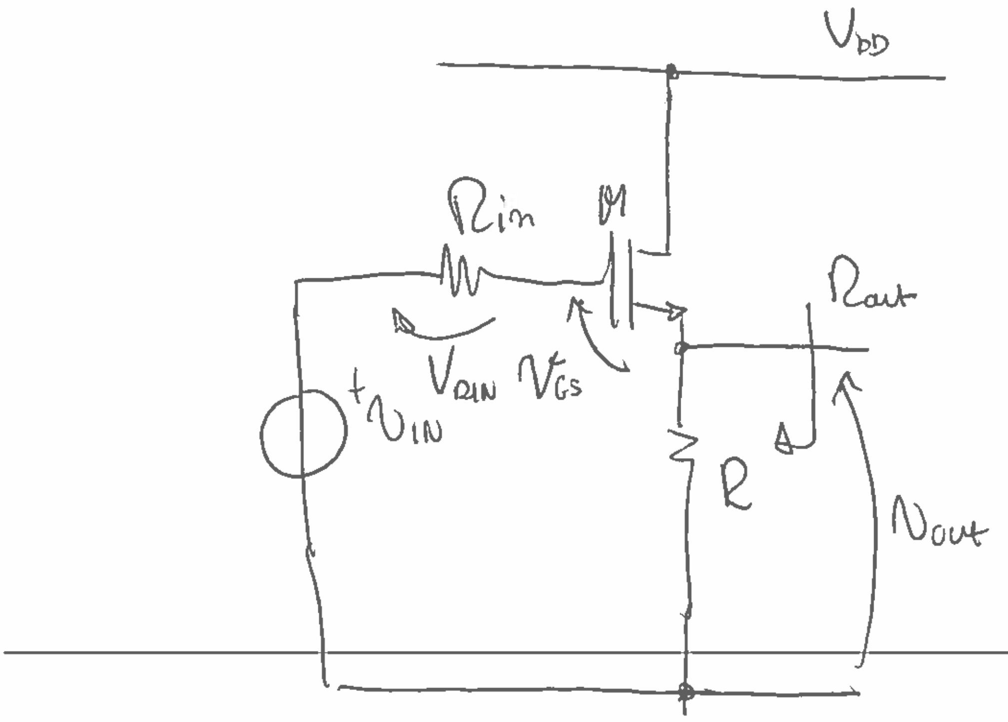
Spegnendo v_{in}, $\boxed{v_{sg} = 0}$ quindi $g_m v_{sg} = 0$

e $v_t = R_1 i_T$, quindi

$$\boxed{R_{out} = \frac{v_T}{i_T} = \frac{R_1 i_T}{i_T} = R_1 = 100\,k\Omega}$$

ES. 3

$$v_{IN} = V_{IN} + V_{in} \sin(2\pi f_0 t)$$



$V_{DD} = 5V$

$V_{IN} = 2.85V$

$V_{in} = 1V$

$f_0 = 10KHz$

$R = 25K\Omega$

$R_{in} = 600K\Omega$

$V_{TH} = 250mV$

$\beta = 20mA/V^2$

$\lambda \simeq 0$

1) PUNTO DI LAVORO

Il valore di I_D non era indicato. Lo si può ricavare dall'equazione della LKV alla maglia di ingresso:

$$V_{IN} = \underbrace{\cancel{V_{R_{in}}}}_{\to 0} + V_{GS} + I_D \cdot R$$

NELL'IPOTESI CHE M sia in saturazione:

$$V_{IN} = V_{GS} + R\,\frac{\beta}{2}\left(V_{GS} - V_{TH}\right)^2$$

sviluppando:

$$\frac{\beta R}{2} V_{GS}^2 + \left(1 - \beta R V_{TH}\right) V_{GS} + \frac{\beta R}{2} V_{TH}^2 - V_{IN} = 0$$

equazione di II grado in V_{GS} (tutto il resto è noto)

Con soluzioni

$$V_{GS} = \begin{cases} 0{,}146\,V & < V_{TH} \\ 0{,}350\,V & > V_{TH} \end{cases}$$

Consideriamo la seconda soluzione $\boxed{V_{GS} = 350\,mV}$

Si ricava:

$$I_D = \frac{\beta}{2}\left(V_{GS} - V_{TH}\right)^2 = 10\,mA/V^2\,(100\,mV)^2 = 100\,\mu A$$

e poi

$$V_{DS} = V_{DD} - R I_D = 5V - 2{,}5V = 2{,}5V$$

in conclusione:

$$V_{GS} = 350\,mV > V_{TH} = 250\,mV \quad \checkmark$$

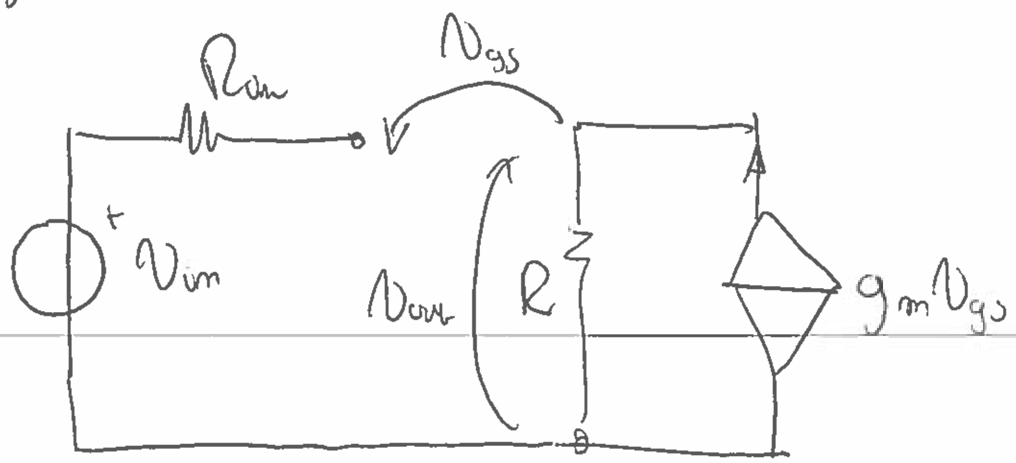
$$V_{DS} = 2{,}5V > V_{GS} - V_{TH} = 100\,mV \quad \checkmark$$

il transistore MOS è polarizzato in SATURAZIONE

2) ANALISI DI PICCOLO SEGNALE

$$g_m = \frac{2I_D}{V_{GS} - V_{TH}} = \frac{200\mu A}{0,1V} = 2mS$$

$$g_0 = \lambda I_D \simeq 0$$



LKV)

$$v_{in} = v_{gs} + g_m v_{gs} R$$

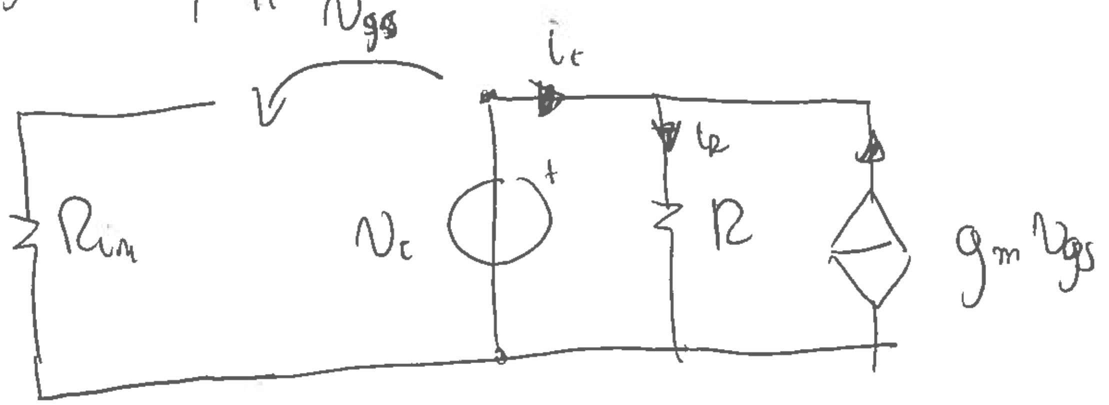
$$v_{gs} = \frac{v_{in}}{1 + g_m R}$$

$$v_{out} = g_m v_{gs} \cdot R = \frac{g_m R}{1 + g_m R} v_{in}$$

$$A_V = \frac{v_{out}}{v_{in}} = \frac{g_m R}{1 + g_m R} = \frac{50}{51} = 0,98 \quad (-0,17dB)$$

3) RESISTENZA D'USCITA

Spengo v_{in}, applico generatore di test v_T, $R_{out} = \frac{v_t}{i_t}$



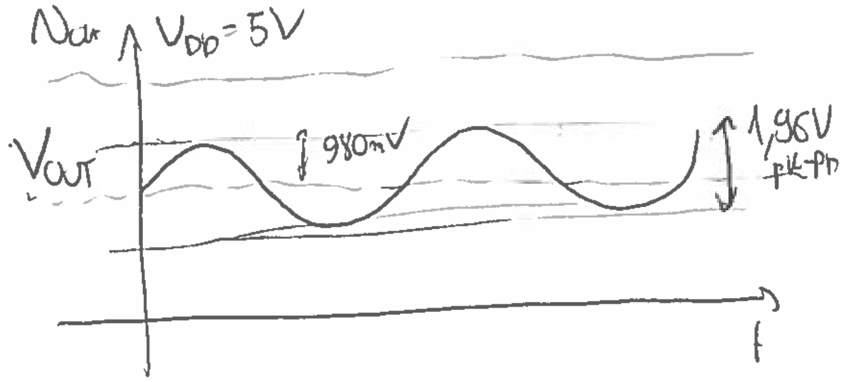
$v_{gs} = -v_t$

$i_t = i_R - g_m v_{gs} = \frac{v_T}{R} + g_m v_T$

$$\boxed{R_{out} = \frac{v_t}{i_T} = \frac{\cancel{v_t}\ 1}{\frac{\cancel{v_T}}{R} + g_m \cancel{v_T}} = \frac{R}{1 + g_m R} = 490\Omega}$$

4)

$v_{OUT} = V_{OUT} + v_{out}$

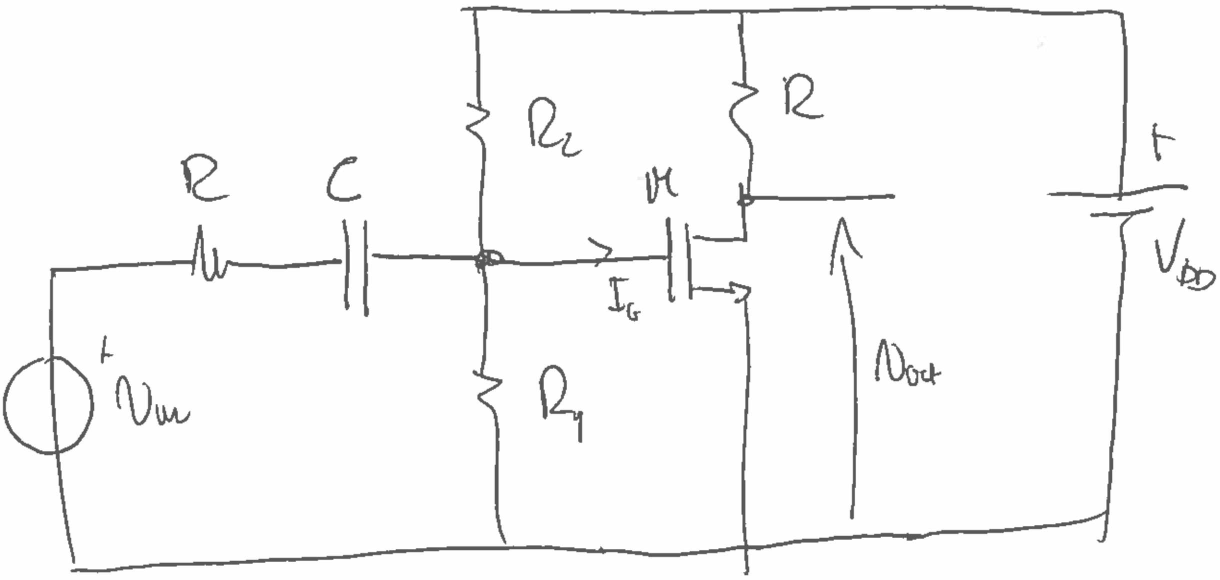


$V_{OUT} = R J_D = 2,5V$

$v_{out} = A_v \cdot v_{in} = A_v \cdot V_{in} \cdot \sin(2\pi f_0 t)$

$= 980mV \cdot \sin(2\pi \cdot (1KHz) \cdot t)$

Es 4)



$$M \begin{cases} V_{TH} = 400mV \\ \beta = 2mA/V^2 \\ \lambda = 0 \end{cases}$$

$V_{DD} = 5V$
$R_1 = 25K\Omega$
$R_2 = 225K\Omega$
$R = 250K\Omega$
$C = 10\mu F$

1) $I_D = \beta/2 \left(V_{GS} - V_{TH}\right)^2 = 10\mu A$

$$V_{GS} = V_{DD} \frac{R_1}{R_1 + R_2} = 5V \cdot \frac{25K\Omega}{250K\Omega} = 0,5V$$

(Essendo $I_G = 0$, R_1 e R_2 sono in serie)

$V_{DS} = V_{DD} - RI_D = 5V - 2,5V = 2,5V$

VERIFICA FUNZIONAMENTO IN SATURAZIONE

$V_{GS} = 0,5V > V_{TH} = 0,4V$ ✓

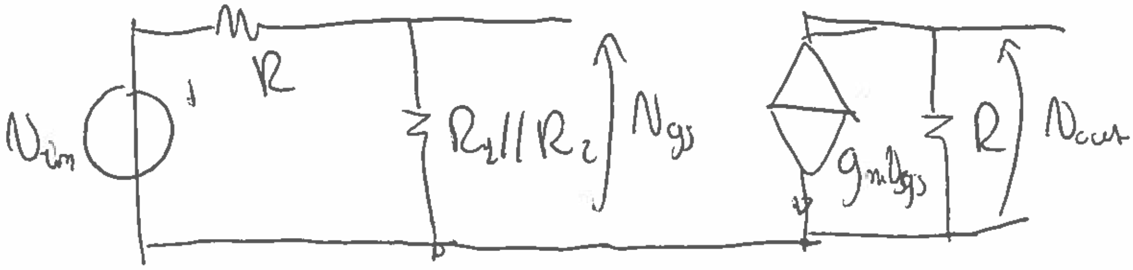
$V_{DS} = 2,5V > V_{GS} - V_{TH} = 100mV$ ✓

2) PICCOLO SEGNALE

$$g_m = \sqrt{2\beta I_D} = 200\mu S$$

$$g_0 = \lambda I_D \simeq 0$$

con $C \to \infty$

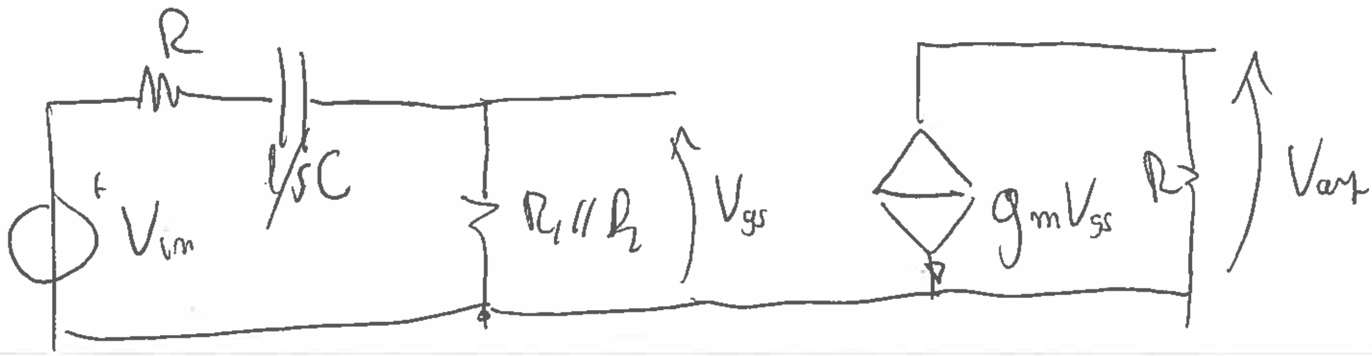


$$v_{gs} = \frac{R_1 // R_2}{R + R_1 // R_2} v_{in}$$

$$v_{out} = -g_m R \, v_{gs} = \frac{-g_m R \cdot R_1 // R_2}{R + R_1 // R_2} v_{in}$$

$$\boxed{A_{v0} = \frac{v_{out}}{v_{in}} = -\frac{g_m R \cdot R_1 // R_2}{R + R_1 // R_2} = -4{,}128 \; (12{,}3\,dB)}$$

Considerando C



$$V_{gs} = \frac{R_1 \parallel R_2}{R + \frac{1}{sC} + R_1 \parallel R_2} V_{in} = \frac{sC\,(R_1 \parallel R_2)}{1 + (R_0 + R_1 \parallel R_2)\,sC} V_{in}$$

$$A_V(s) = \frac{V_{out}}{V_{in}} = \frac{-g_m R\,(R_1 \parallel R_2)\,sC}{1 + (R + R_1 \parallel R_2)\,sC} =$$

$$= - \frac{s/s_0}{1 - s/s_p}$$

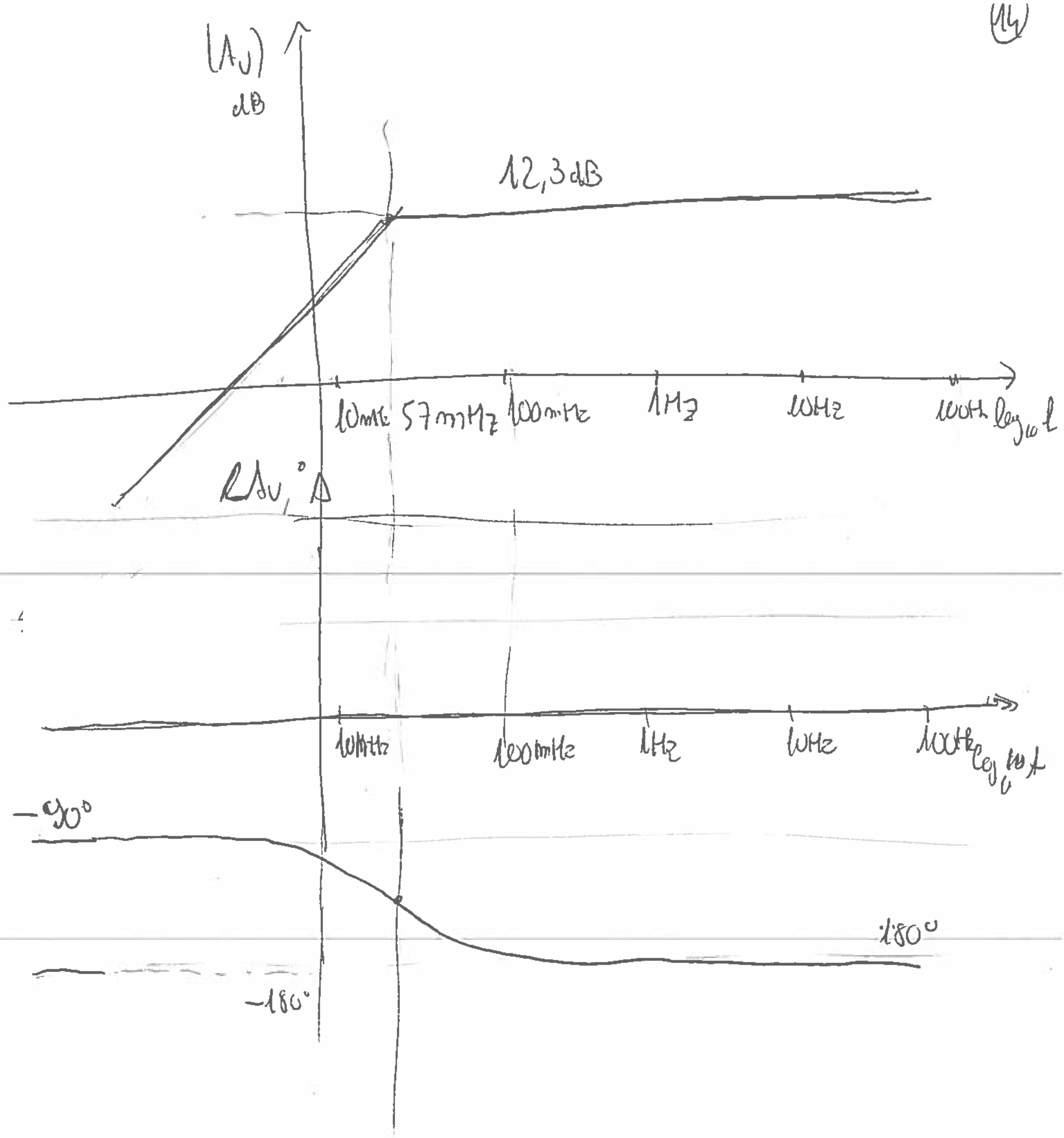
$$s_0 = \frac{1}{g_m R\,(R_1 \parallel R_2)\,C} = 0{,}087 \text{ rad/s}$$

per $|s| \to \infty$ $A_V(s) \to \frac{s_p}{s_0} = A_{V0}$

ma questo è il valore A_{V0} considerato prima, per $C \to \infty$

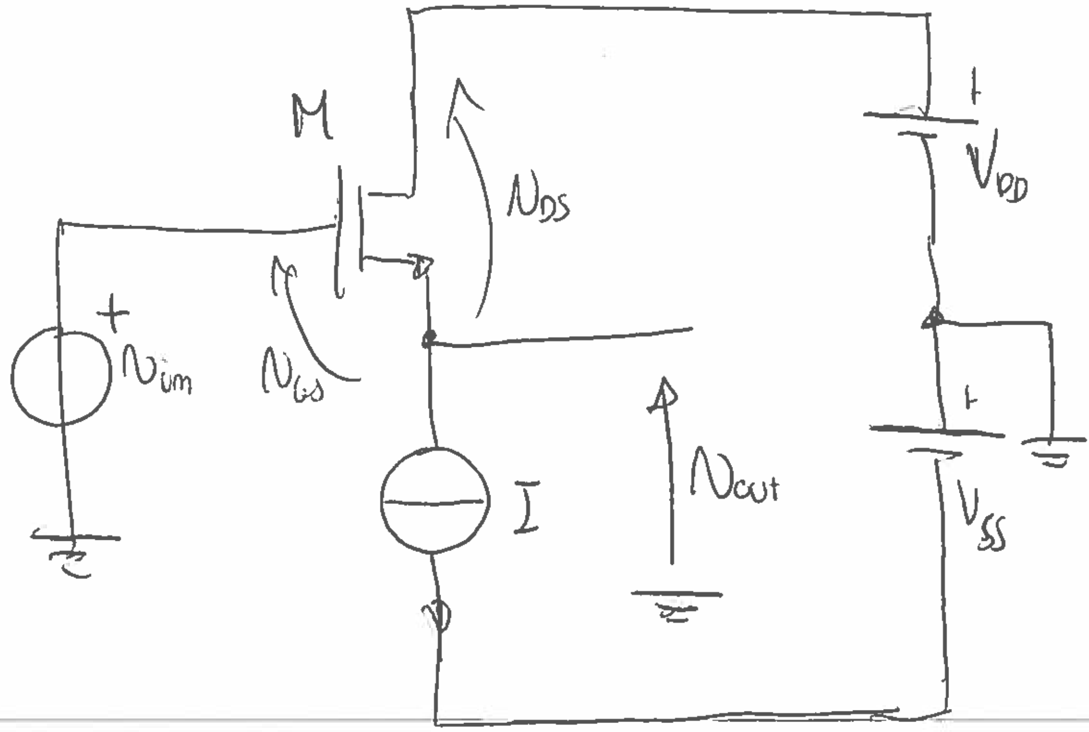
quindi $s_p = A_{V_0} \cdot s_0 = -0{,}359$ rad/s $\to$

$$f_p = \frac{|s_p|}{2\pi} = 57 \text{ mHz}$$



- L'ASSUNZIONE $C \to \infty$ è valida oltre la frequenza del primo polo, cioè per $\boxed{f > f_{P1} = 57\,mHz}$

ES 5:



$V_{DD} = V_{SS} = 5V$
$J = 1mA$
$V_{TH} = 400mV$
$\beta = 2mA/V^2$
$\lambda \simeq 0$

1) $$V_{GS} = \sqrt{\frac{2J_D}{\beta}} + V_{TH} = 1{,}4V$$

$$V_{DS} = V_{DD} - V_S = 5V - (-1{,}4V) = 6{,}4V$$

($V_G = 0V$ per la polarizzazione, quindi

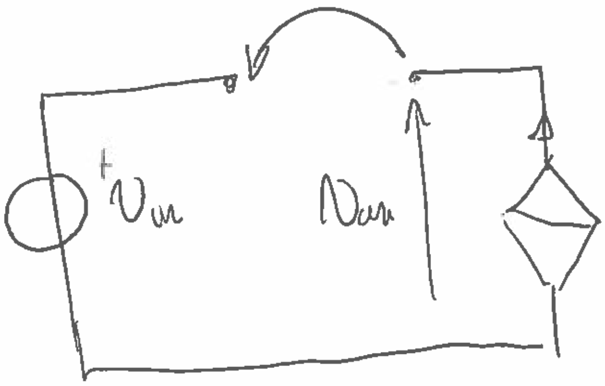
$$V_S = -V_{GS} = -1{,}4V$$

VERIFICA FUNZIONAMENTO in SATURAZIONE

$$V_{GS} = 1.4V > V_{TH} = 400mV \quad \checkmark$$

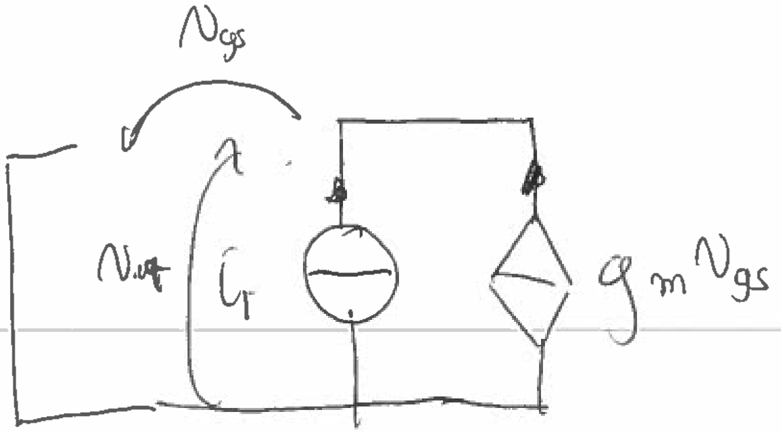
$$V_{DS} = 6{,}4V > V_{GS} - V_{TH} = 1V \quad \checkmark$$

2) $g_m = \sqrt{2\beta I_D} = 2\,mS$, $g_o = \lambda I_D = 0$



essendo $i_S = 0$, $g_m v_{gs} = 0 \rightarrow v_{gs} = 0$, quindi

$v_{out} = v_{in} \rightarrow \boxed{A_v = 1}$



$R_{out} = \dfrac{v_T}{i_T}$

- spengo v_{in}
- applico generatore di test i_T , $R_{out} = \dfrac{v_T}{i_T}$

. essendo $g_m v_{gs} + i_T = 0 \rightarrow v_{gs} = -\dfrac{i_t}{g_m} = -v_{out}$

. quindi $\boxed{R_{out} = \dfrac{v_T}{v_T} = \dfrac{i_t}{g_m} \cdot \dfrac{1}{i_T} = \dfrac{1}{g_m} = 500\Omega}$