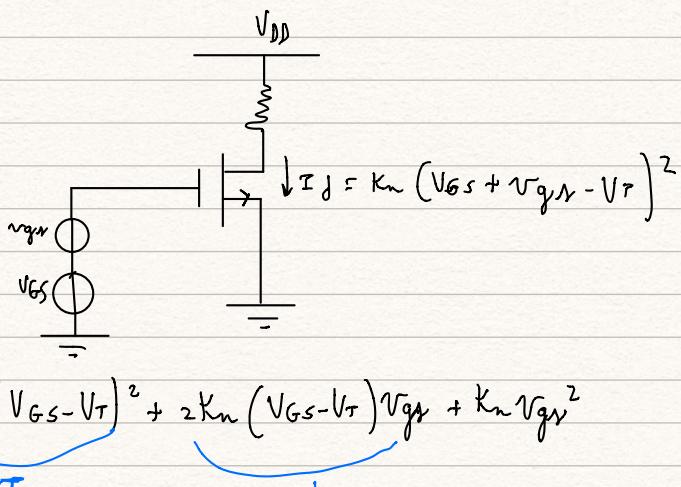


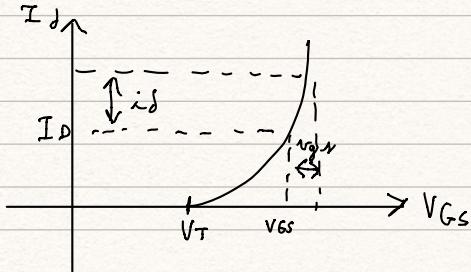
MOS COME AMPLIFICATORE:



$$I_d \approx I_D + i_d$$

$$i_d = g_m v_{GR}$$

$$g_m = 2kn (V_{GS} - V_T) \approx \frac{2 I_D}{V_{GS} - V_T}$$

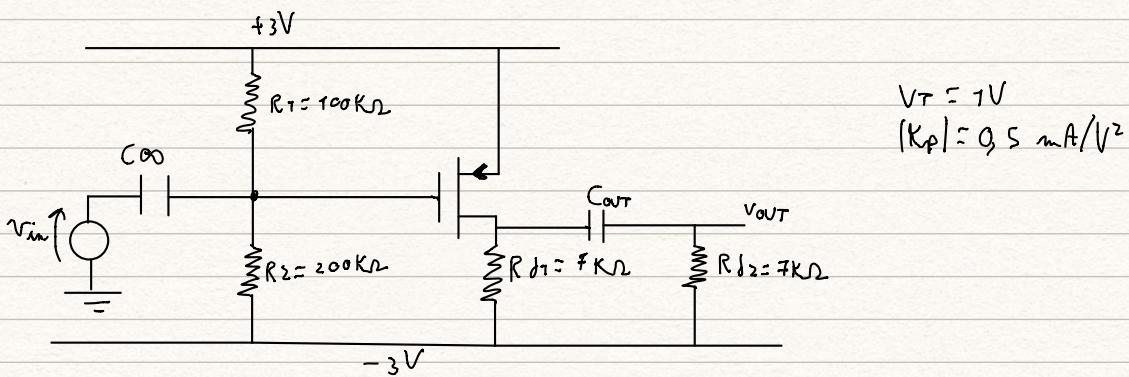


BUONA APPROSSIMAZIONE SE:

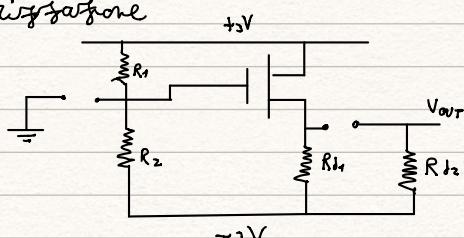
$$kn v_{GR}^2 \ll 2kn (V_{GS} - V_T) v_{GR}$$

$$v_{GR} \ll 2(V_{GS} - V_T)$$

esercizio 1: (con un pmos)



1) Polarizzazione



$$V_{R2} = 5V \cdot \frac{R_2}{R_1 + R_2} \approx 5V \cdot \frac{200k\Omega}{300k\Omega} = +4V$$

$$V_G = -3V + 4V = 1V$$

$$V_{GS} = -1V - 3V = -2V < V_T \text{ mas è ACCESO}$$

HP: mos in saturazione

$$|I_D| = |K_P| (V_{GS} - V_T)^2 = 0,5 \text{ mA/V}^2 (-2V - (-1V))^2 = 0,5 \text{ mA}$$

$$V_{RD1} = |I_D| \cdot R_{D1} = 0,5 \text{ V}$$

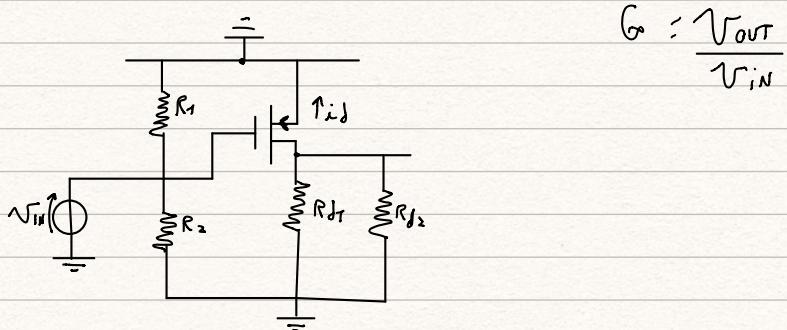
$$V_D = -3V + 0,5V = -2,5V$$

VERIFICA DI SATURAZIONE:

$$V_{GD} = +1 - 0,5V = 0,5V > V_T$$

$$g_m = \frac{2|I_D|}{V_{ov}} = \frac{2 \cdot 0,5 \text{ mA}}{|-2V + 1V|} = 1 \text{ mA/V}$$

2) Guadagno a media frequenza (Corti circuiti)



$$V_{gs} = V_{in}$$

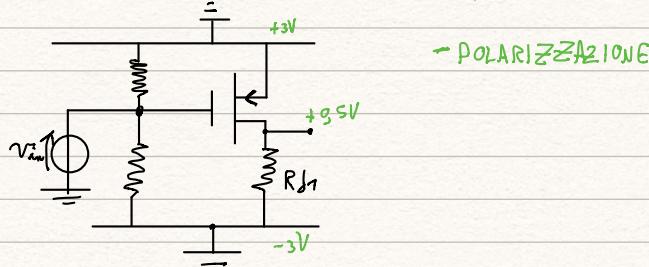
$$\frac{V_{out}}{V_{in}} = -g_m (R_{d1}/(R_{d1} + R_{d2})) = -3,5$$

$$V_{gs} = V_{in}$$

$$i_d = g_m V_{gs} = g_m V_{in}$$

$$V_{ovr} = -i_d \cdot (R_{d1}/(R_{d1} + R_{d2})) = -g_m V_{in} (R_{d1}/(R_{d1} + R_{d2}))$$

3) Dinamica del modo di drain a bassaf (Corti circuiti aperto)



• Dinamica negativa di V_f

$$V_f = V_{in} (-g_m R_{d1})$$

$$V_{f\min} = -3V$$

$$\Delta V_f^- = -3,5V$$

$$V_g = V_{in} \frac{V_d}{-g_m R_{d1}} = \frac{V_d}{-7}$$

• Dinamica positiva di V_f

Problema: garantire che il pmos rimanga in SATURAZIONE

$$V_{GD} + V_{gd} > V_T$$

$$V_{GD} + \frac{V_f}{-7} - V_d > V_T$$

$$0,5V - (-1V) > V_d \left(1 + \frac{1}{7}\right)$$

$$V_f < 1,5V \cdot \frac{7}{8} = 1,31V$$

$$\Delta V_f^+ = 1,31V$$

4) Dimensionare C_{out} per amplificare segnali nella banda $[100Hz, 100kHz]$

$$G|_{LF} = \emptyset$$

$$f_p \ll f_{mix}$$

$$Z \approx C_{out} \cdot (R_{d2} + R_{d1})$$

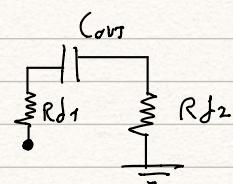
$$G|_{HF} = -3,5$$

$$f_p = \frac{f_{mix}}{10}$$

$$\frac{1}{2\pi C_{out}(R_{d2} + R_{d1})} = \frac{100Hz}{10}$$

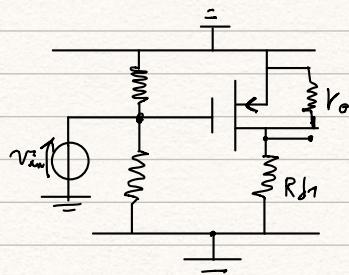
$$\downarrow C_{out} = 1,14 \mu F$$

per calcolare Z



5) Come cambia il guadagno (and alta f) se $V_A = 100V$

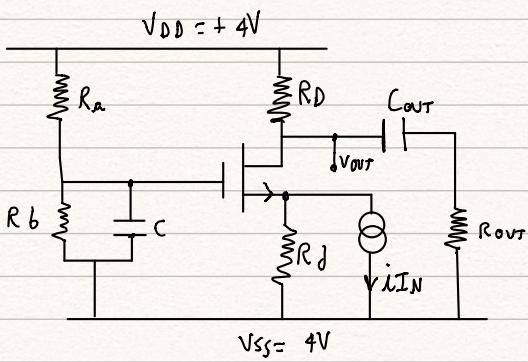
$$r_o = \frac{|V_A|}{|I_D|} = \frac{100V}{0,5mA} = 200k\Omega$$



$$\begin{aligned} V_{gr} &= V_{in} \\ i_D &= g_m V_{in} \\ V_{out} &= -i_D \cdot (R_{d1} / R_{d2} / R_o) \end{aligned}$$

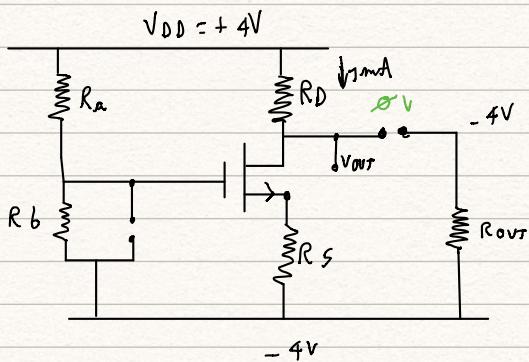
$$\frac{V_{out}}{V_{in}} \Big|_{HF} \approx -3,44$$

esercizio 2:



$$\begin{aligned}
 RA &= Rb = 500 \text{ k}\Omega \\
 V_{Tm} &\approx 1 \text{ V} \\
 \frac{1}{2} \mu_n C_{ox} &= 100 \mu\text{A}/\text{V}^2 \\
 R_0 &= 4 \text{ k}\Omega \\
 R_S &= 2 \text{ k}\Omega \\
 R_{OUT} &= 2 \text{ k}\Omega \\
 C &= 1 \text{ nF} \\
 C_{OUT} &= 100 \text{ pF} \\
 r_o &= \infty
 \end{aligned}$$

1) Polarizzazione, determinando $\frac{W}{L}$ per avere $V_{OUT} = 0 \text{ V}$



$$V_{RD} = +4 \text{ V} \rightarrow I_{RD} = \frac{4 \text{ V}}{4 \text{ k}\Omega} = 1 \text{ mA}$$

$$V_S = -4 \text{ V} + V_{RS} = -4 \text{ V} + 1 \text{ mA} \cdot 2 \text{ k}\Omega = -2 \text{ V}$$

$$V_G = -4 \text{ V} + V_{RB} = -4 \text{ V} + 8 \text{ V} \frac{R_b}{R_b + R_A} = -4 \text{ V} + 4 \text{ V} = 0 \text{ V}$$

$$V_{GS} = 0 \text{ V} - (-2 \text{ V}) = +2 \text{ V} > V_T \quad \text{mos è ACCESO}$$

$$V_{GD} = 0 \text{ V} < V_T \quad \text{IL mos È IN SATURAZIONE}$$

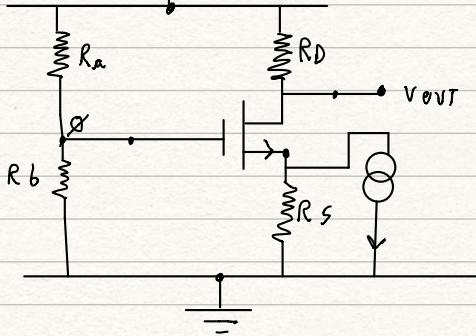
$$I_D = K_N (V_{GS} - V_T)^2 = \frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L} \right)_n (V_{GS} - V_T)^2$$

$$\frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L} \right)_n (V_{GS} - V_T)^2 = 1 \text{ mA}$$

$$\left(\frac{W}{L} \right)_n = 10$$

$$g_m = \frac{2 I_D}{V_{DS}} = \frac{2 \cdot 1 \text{ mA}}{2 \text{ V} - 1 \text{ V}} = 2 \text{ mA/V}$$

2) trasferimento $\frac{V_{OUT}}{I_{in}}$ $\xrightarrow{\text{a bassa f}}$ $\xrightarrow{\text{ad alta f}}$



$$\begin{cases} I_{in} = I_d - I_s = g_m V_{GS} - I_s \\ V_S = i_s R_s \end{cases}$$

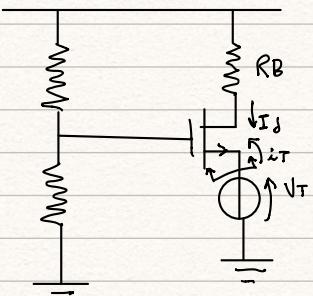
$$i_{IN} = -g_m V_S - \frac{V_S}{R_s}$$

$$V_S = -\frac{I_{in}}{g_m + \frac{1}{R_s}}$$

$$I_d = -g_m V_S = -g_m \left(-\frac{I_{in}}{g_m + \frac{1}{R_s}} \right) = I_{in} \frac{g_m}{g_m + \frac{1}{R_s}} =$$

$$= i_{IN} \cdot \frac{R_s}{R_s + 1/g_m}$$

Calcolo impedenza di uscita di source



$$Z_S = \frac{V_T}{I_T}$$

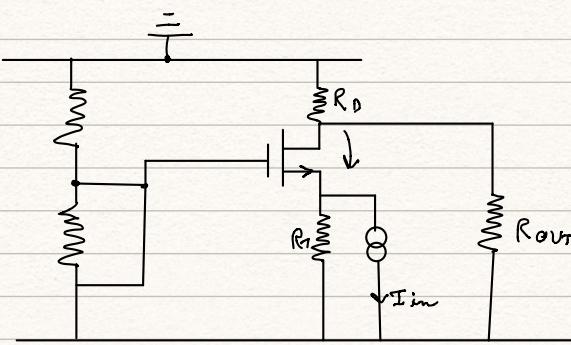
$$V_{GS} = -V_T$$

$$Z_S = \frac{V_S}{i_T} = \frac{V_T}{g_m V_T} = \frac{1}{g_m}$$

$$V_{out} = -I_d R_D = -\left(i_{IN} \frac{R_s}{R_s + 1/g_m}\right) R_s = \frac{-g_m R_s}{1 + g_m R_s} R_D i_{IN}$$

$$\left| \frac{V_{out}}{I_{in}} \right|_{BF} = \frac{-g_m R_s}{1 + g_m R_s} \cdot R_D = 3,2 \text{ k}\Omega$$

ad alta f

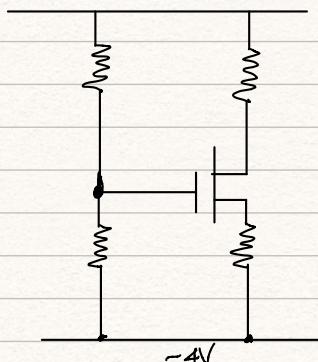


$$I_d = I_{in} \frac{R_s}{R_s + 1/g_m}$$

$$V_{out} = -i_{IN} \frac{R_s}{R_s + 1/g_m} (R_D // R_{out})$$

$$\left| \frac{V_{out}}{I_{in}} \right|_{AF} = \frac{-g_m R_s}{1 + g_m R_s} (R_D // R_{out}) = -1,1 \text{ k}\Omega$$

3) Varioce R_D per massimizzare il trasferimento $\frac{V_{out}}{V_{in}}$ a bassa tensione di polarizzazione



V_D min per garantire saturazione è

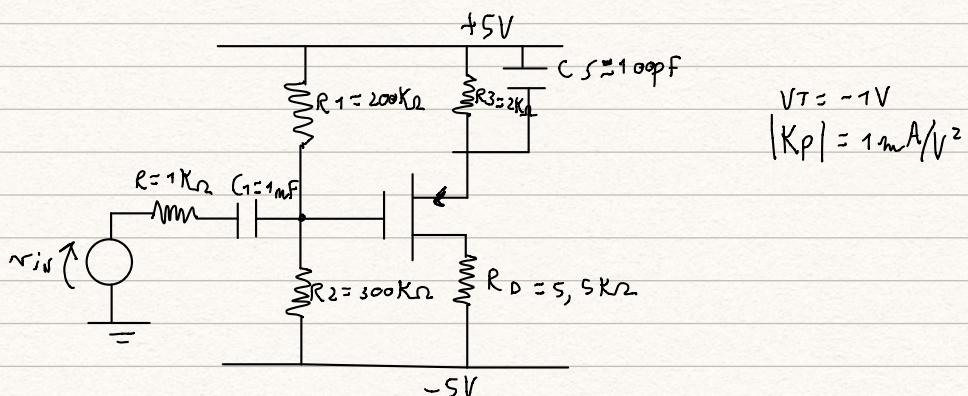
$$V_{Dn,sat} = -1V$$

(in queste condizioni $V_{GD} = +1V = V_T$)

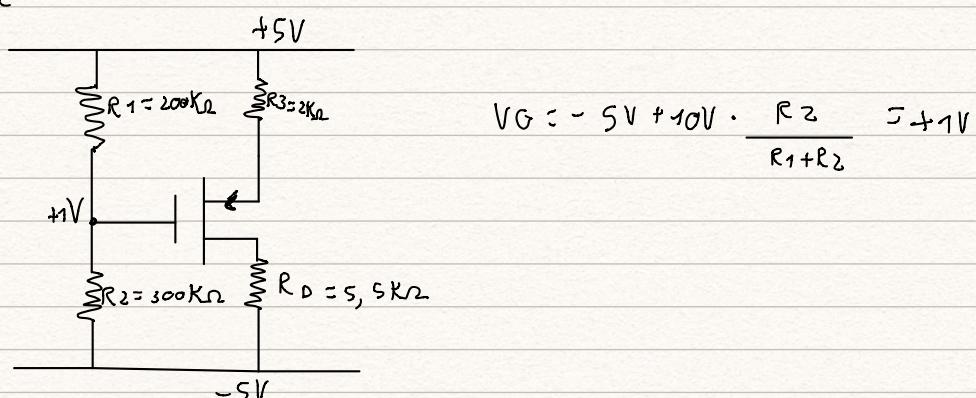
$$V_{RD\max} = +5V \text{ con } I_D = 1mA$$

$$R_{D\max} = \frac{5V}{1mA} = 5k\Omega$$

Esercizio 3: (Poco con degenerazione al source)



1) Polarizzazione



HP: MOS IN SATURAZIONE

$$\begin{cases} I = |K_p| (V_{GS} - V_T)^2 \\ I = \frac{5V - V_S}{R_S} \end{cases}$$

$$2V_S^2 - 7VS + 3V = 0 \rightarrow V_S = 0,5V \text{ (NON ACCETTABILE MOS SPENTO)} \quad V_S = 3V$$

$V_{GS} = 1V - 3V = -2V < V_T$ mos è ACCESO

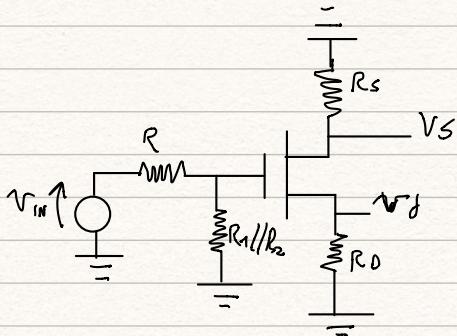
$$I = |K_p| (V_{GS} - V_T)^2 = 1mA/V^2 (-2V + 1V)^2 = 1mA$$

$$V_D = -5V + I \cdot R_D = -5V + 1mA \cdot 5\Omega = 0V$$

Verified MP: $V_{GD} = +1V > 0V$, $5V > V_T$ ✓

B) Calcolare $\frac{V_f}{V_{IN}}$ e $\frac{V_s}{V_{IN}}$

Considerando C un certo circuito e Cs un circuito aperto



$$V_g = V_{IN} \cdot \frac{R_1 // R_2}{R_1 // R_2 + r_e} = 0,99 V_{IN}$$

$$\begin{cases} i_d = g_m V_{GS} = g_m (V_g - V_S) \\ V_S = i_d \cdot R_S \end{cases}$$

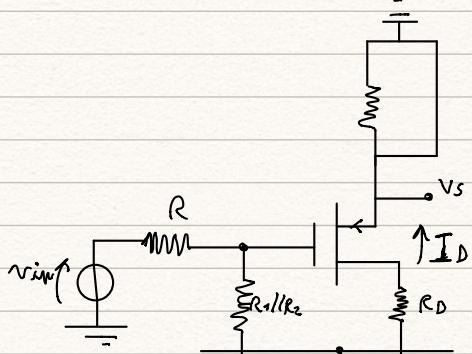
$$V_S = V_g \cdot \frac{R_S}{R_S + 1/g_m} = V_g \cdot \frac{g_m R_S}{1 + g_m R_S} = 0,99 V_{IN} \cdot \frac{g_m R_S}{1 + g_m R_S}$$

$$\frac{V_S}{V_{IN}} = 0,99$$

$$V_S = 0,99 V_{IN} \cdot \frac{R_S}{R_S + 1/g_m} \quad I_D = \frac{V_S}{R_S} = 0,99 V_{IN} \cdot \frac{1}{R_S + 1/g_m} = 0,99 V_{IN} \cdot \frac{g_m R_S}{1 + g_m R_S}$$

$$\frac{V_f}{V_{IN}} = -2,18$$

C) Calcolare $\frac{V_s}{V_{IN}}$ e $\frac{V_f}{V_{IN}}$ con Cs e C entrambi certi circuiti



$$V_g = 0,99 V_{IN}$$

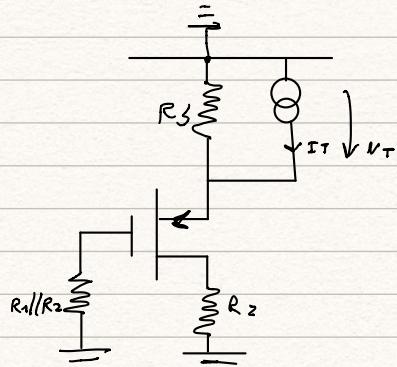
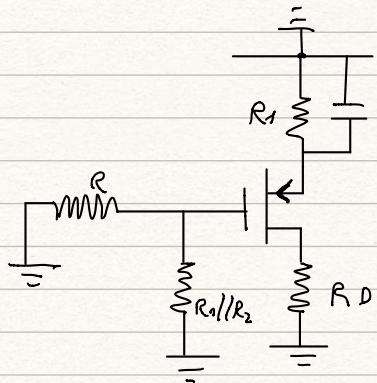
$$\frac{V_s}{V_{IN}} = 0 \quad V_f = -i_d R_D$$

$$i_d = g_m V_{GS} = g_m (0,99 V_{IN} - 0) = 0,99 V_{IN} \cdot g_m$$

$$V_f = -0,99 V_{IN} \cdot \text{gm } R_D$$

$$\frac{V_f}{V_{IN}} = -10,9$$

d) Indicare le costanti di tempo associate a C_s



$$i_d = \text{gm} (V_D - V_T)$$

$$i_T = \frac{V_T}{R_S} + \text{gm} V_T$$

$$R_{eq} = \frac{1}{R_S} + \text{gm} = R_S \parallel \frac{1}{\text{gm}}$$

$$\tau_{CS} = C_S \cdot \left(R_S \parallel \frac{1}{\text{gm}} \right) \approx 40 \text{ ms}$$