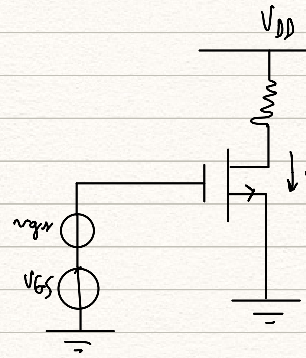
MOS COME AMPLIFICATORE:

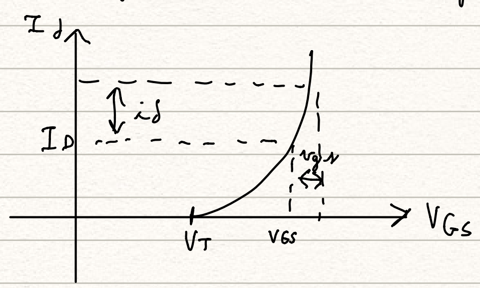


$$I_d = K_n \left(V_{GS} + v_{gs} - V_T\right)^2$$

$$I_d = \underbrace{K_n\left(V_{GS}-V_T\right)^2}_{I_D} + \underbrace{2K_n\left(V_{GS}-V_T\right)v_{gs}}_{i_d} + K_n v_{gs}^2$$

$$I_d \simeq I_D + i_d$$

$$i_d = g_m v_{gs} \qquad g_m = 2K_n\left(V_{GS}-V_T\right) \simeq \frac{2 I_D}{V_{GS}-V_T}$$



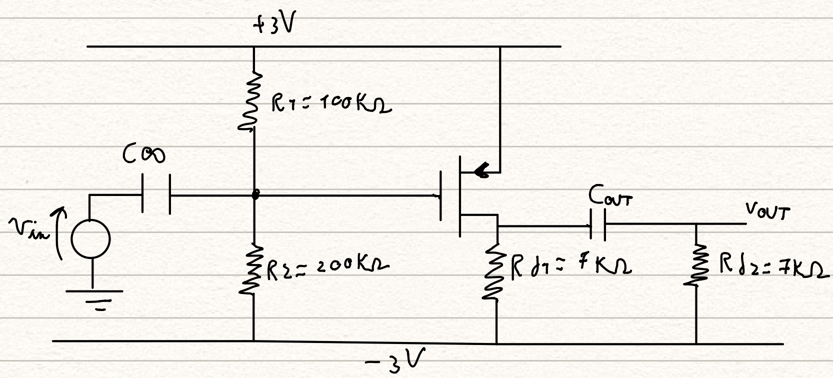
BUONA APPROSSIMAZIONE SE:

$$\cancel{K_n} v_{gs}^{\cancel{2}} \ll 2\cancel{K_n}\left(V_{GS}-V_T\right)\cancel{v_{gs}}$$

$$\downarrow$$

$$v_{gs} \ll 2\left(V_{GS}-V_T\right)$$

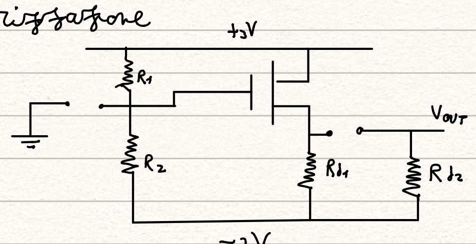
esercizio 1: (con un PMOS)



$V_T = 1V$

$|K_p| = 0{,}5 \ mA/V^2$

1) Polarizzazione



$$V_{R_2} = 6V \cdot \frac{R_2}{R_1+R_2} = 6V \cdot \frac{200 K\Omega}{300 K\Omega} = +4V$$

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

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

HP: MOS in saturazione

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

$V_{RD_1} = |I_D| \cdot R_{D1} = +3,5V$

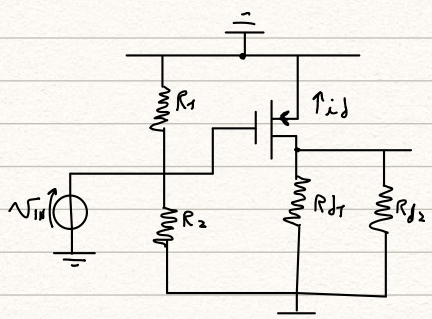
$V_D = -3V + 3,5V = +0,5V$

VERIFICA DI SATURAZIONE:

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

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

2) Guadagno a media frequenza (Cout in corto circuito)



$G = \frac{V_{OUT}}{V_{IN}}$

$V_g = V_{IN}$

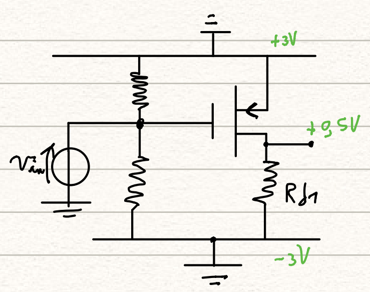
$\frac{V_{OUT}}{V_{in}} = -g_m (R_{d1} // R_{d2}) = -3,5$

$V_{gs} = V_{in}$

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

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

3) Dinamica del nodo di drain a bassa f (Cout circuito aperto)



- POLARIZZAZIONE

• Dinamica negativa di V_d

$$V_{d\,min} = -3V$$
$$\Delta V_d^- = -3{,}5V$$

$$v_d = v_{in}(-g_m R_{d1})$$
$$v_g = v_{in} = \frac{v_d}{-g_m R_{d1}} = \frac{v_d}{-7}$$

• Dinamica positiva di v_d

Problema: garantire che il PMOS rimanga in SATURAZIONE

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

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

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

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

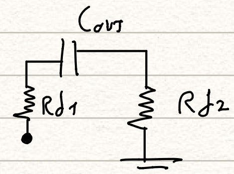
$$\Delta v_d^+ = 1{,}31V$$

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

$$G\Big|_{LF} = \varnothing \qquad f_P \ll f_{MINS} \qquad \tau = C_{OUT} \cdot (R_{d2} + R_{d1})$$
$$G\Big|_{HF} = -3{,}5 \qquad f_P = \frac{f_{MINS}}{10}$$

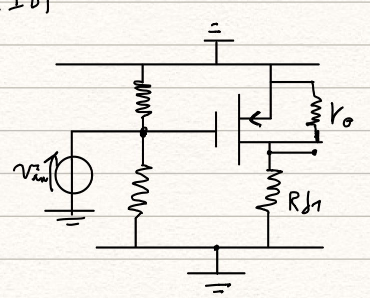
$$\frac{1}{2\pi C_{OUT}(R_{d2} + R_{d1})} = \frac{100\,Hz}{10}$$
$$\downarrow$$
$$C_{OUT} = 1{,}14\,\mu F$$

per calcolare τ



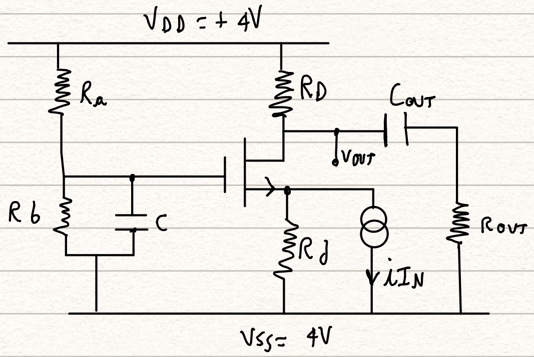
5) Come cambia il guadagno (ad alta f) se $V_A = 100V$

$$r_0 = \frac{|V_A|}{|I_D|} = \frac{100V}{0{,}5mA} = 200\,k\Omega$$



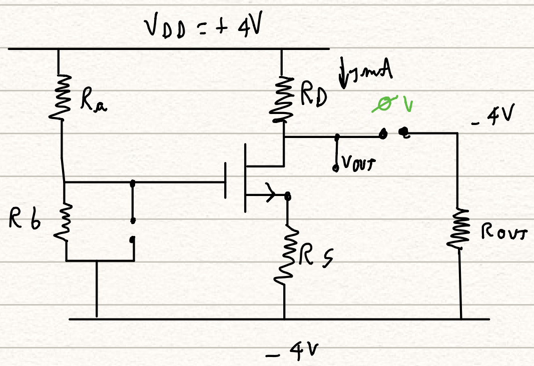
$$v_{gs} = v_{IN}$$
$$i_d = g_m v_{in}$$
$$v_{OUT} = -i_d \cdot (R_{d1} // R_{d2} // r_0)$$
$$\frac{v_{OUT}}{v_{IN}}\Big|_{HF} = -3{,}44$$

Esercizio 2:



$R_A = R_b = 500 k\Omega$
$V_{Tn} = 1 V$
$\frac{1}{2} \mu_n C_{ox} = 100 \mu A / V^2$
$R_D = 4 k\Omega$
$R_S = 2 k\Omega$
$R_{OUT} = 2 k\Omega$
$C = 1 mF$
$C_{OUT} = 100 pF$
$r_0 = \infty$

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



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

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

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

$V_{GS} = 0V - (-2V) = +2V > V_T$ MOS è ACCESO

$V_{GD} = 0V < V_T$ IL MOS È IN SATURAZIONE

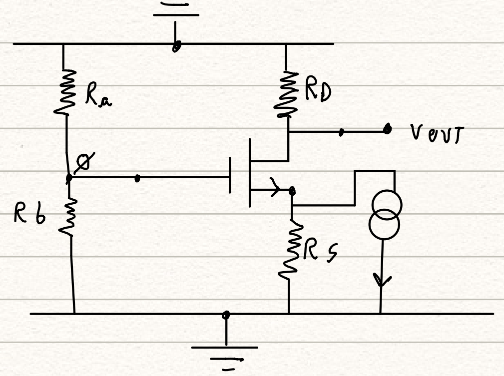
$$I_D = K_N (V_{GS} - V_T)^2 = \frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L}\right)_n (V_{GS} - V_T)^2$$

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

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

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

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



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

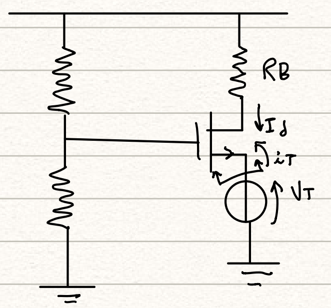
$$i_{IN} = -g_m V_S - \frac{V_S}{R_S}$$

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

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

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

Calcolo impedenza al nodo di source



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

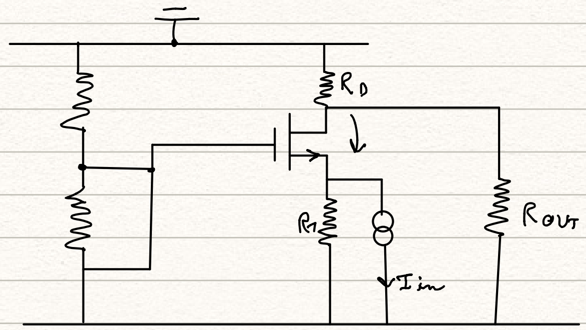
$$V_{gs} = -V_T$$

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

$$V_{OUT} = -I_d R_d = -\left(i_{IN}\frac{R_S}{R_S + 1/g_m}\right) R_S = \frac{-g_m R_S}{1 + g_m R_S} R_D\, i_{IN}$$

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

ad alta f

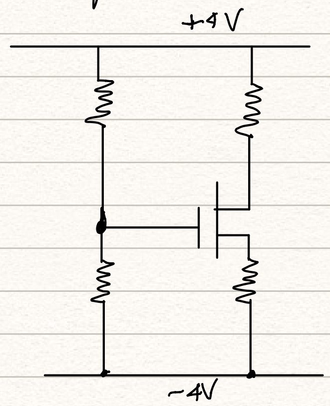


$$I_d = I_{in}\frac{R_S}{R_S + 1/g_m}$$

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

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

3) Variare R_D per massimizzare il trasferimento $\frac{V_{OUT}}{v_{IN}}$ a bassa f in polarizzazione

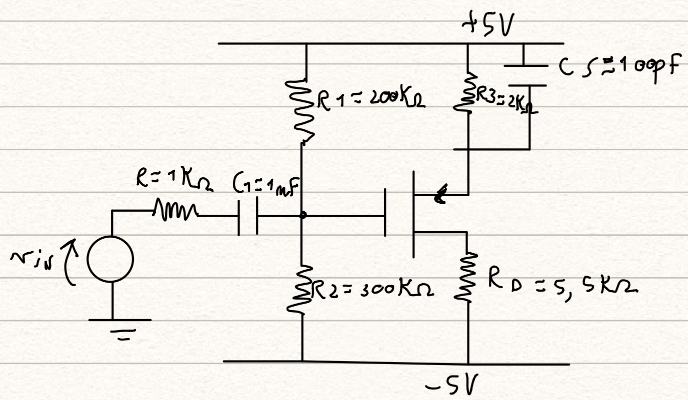


VD min per garantire saturazione è

$V_{D\,MIN} = -1V$ (in queste condizioni $V_{GD} = +1V = V_T$)

$V_{RD\,MAX} = +5V$ con $I_D = 1mA$ $\quad R_{D\,MAX} = \frac{5V}{1mA} = 5k\Omega$

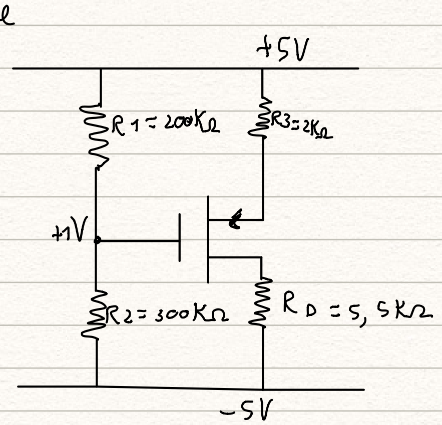
esercizio 3: (PMOS con degenerazione al source)



$V_T = -1V$

$|K_P| = 1mA/V^2$

1) Polarizzazione



$$V_G = -5V + 10V \cdot \frac{R_2}{R_1+R_2} = +1V$$

HP: MOS IN SATURAZIONE

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

$2V_S^2 - 7V_S + 3V = 0 \longrightarrow V_S \to 0,5V$ NON ACCETTABILE (MOS SPENTO)

$\qquad\qquad\qquad\qquad\quad\; V_S \to 3V$

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

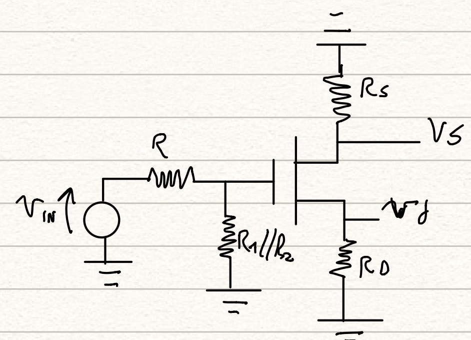
$$I = |K_P|\,(V_{GS}-V_T)^2 = 1mA/V^2\,(-2V+1V)^2 = 1mA$$

$V_D = -5V + I \cdot R_D = -5V + 1mA \cdot 5{,}5k\Omega = +0{,}5V$

Verifico HP: $V_{GD} = +1V - 0{,}5V = +0{,}5V > V_T$ ✓

B) Calcolare $\frac{v_d}{v_{IN}}$ e $\frac{v_s}{v_{IN}}$

Considerando C un corto circuito e Cs un circuito aperto



$$v_g = v_{IN} \cdot \frac{R_1//R_2}{R_1//R_2 + R} = 0{,}99\, v_{IN}$$

$$\begin{cases} i_d = g_m v_{gs} = g_m (v_g - v_s) \\ v_s = i_d \cdot R_s \end{cases}$$

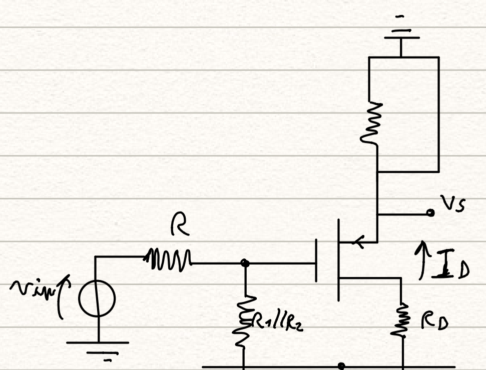
$$v_s = v_g \cdot \frac{R_s}{R_s + 1/g_m} = v_g \cdot \frac{g_m R_s}{1 + g_m R_s} = 0{,}99\, v_{IN} \cdot \frac{g_m R_s}{1 + g_m R_s}$$

$$\frac{v_s}{v_{IN}} = 0{,}8$$

$$v_s = 0{,}99\, v_{IN} \cdot \frac{R_s}{R_s + 1/g_m} \qquad I_d = \frac{v_s}{R_s} = 0{,}99\, v_{IN} \frac{1}{R_s + 1/g_m} = -0{,}99\, v_{IN} \cdot \frac{g_m R_D}{1 + g_m R_s}$$

$$\frac{v_d}{v_{IN}} = -2{,}18$$

C) Calcolare $\frac{v_s}{v_{IN}}$ e $\frac{v_d}{v_{IN}}$ con Cs e C entrambe corto circuito



$$v_g = 0{,}99\, v_{IN}$$

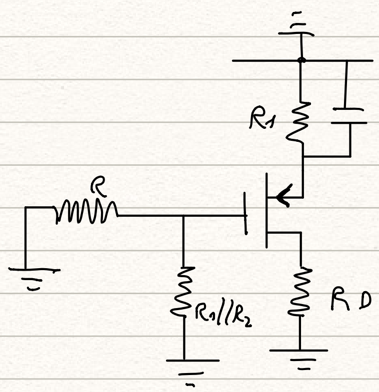
$$\frac{v_s}{v_{IN}} = 0 \qquad v_d = -i_d R_d$$

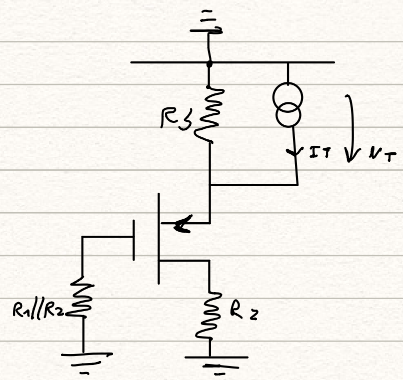
$$i_d = g_m v_{gs} = g_m (0{,}99 v_{IN} - 0) = 0{,}99 v_{IN} \cdot g_m$$

$v_d = -0{,}99\, v_{IN} \cdot g_m R_D$

$\frac{v_d}{v_{IN}} = -19{,}9$

d) Calcolare la costante di tempo associata a C_S





$i_d = g_m (v_D - v_T)$

$i_T = \frac{v_T}{R_S} + g_m v_T$

$R_{eq} = \frac{1}{R_S} + g_m = R_S // \frac{1}{g_m}$

$\tau_{CS} = C_S \cdot \left(R_S // \frac{1}{g_m} \right) = 40\, ms$