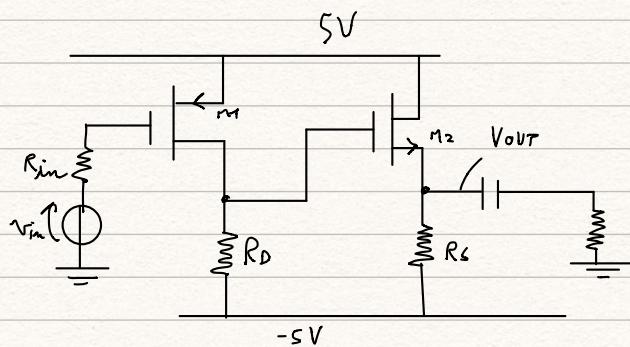


ESERCITAZIONE SUGLI AMPLIFICATORI A TRANSISTOR

Esercizio 1: TFE 70 Maggio 2013



Dati:

$$\frac{1}{2} \mu n C_{ox} = 100 \mu A/V^2$$

$$|K_p| = 100 \mu A/V^2$$

$$R_L = 10 k\Omega$$

$$C = 47 nF$$

$$r_d = \infty$$

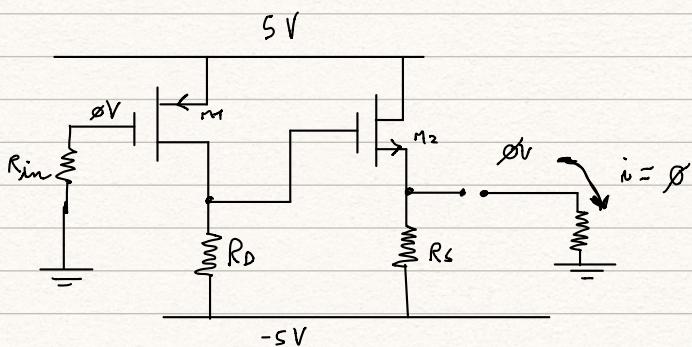
$$V_{TP} = |V_{TP}| = 1 V$$

$$R_{in} = 50 \Omega$$

$$R_D = 3 k\Omega$$

$$R_S = 900 \Omega$$

A) Calcolare la polarizzazione del circuito e dimensionare $(\frac{W}{L})_2$ per avere $I_{Dn_2} = 2 mA$



$$V_{GSn_1} = -5V < V_{TP} \quad PMOS \text{ ACCESO}$$

MP. PMOS IN SATURAZIONE

$$I_D = K_p (V_{GS} - V_T)^2 = 100 \mu A/V^2 (-5V + 1V)^2 = -1,6 mA$$

$$V_{RD} = I_D \cdot R_D = -1,6 mA \cdot 3 k\Omega = -4,8 V$$

$$V_{GM2} = -5V - (-4,8V) = -0,2 V$$

$$V_{SSn_2} = -5V + I_{Dn_2} \cdot R_S = -5 + 2 mA \cdot 900 \Omega = -5V + 1,8V = -3,2 V$$

M₂ È IN SATURAZIONE (non ho neanche bisogno di ipotesi)

$$I_{Dn_2} = K_n \left(V_{GS} - V_T \right)^2 = \frac{1}{2} \mu n C_{ox} \left(\frac{W}{L} \right)_{n_2} \left(V_{GS} - V_T \right)^2$$

$$I_{Dn_2} = 2 mA$$

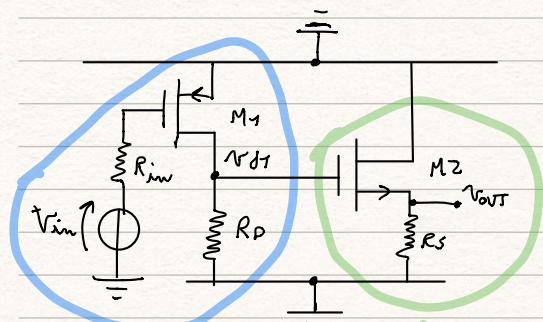
$$\left(\frac{W}{L} \right)_N = 5$$

$$g_{m1} = \frac{2 I_D}{V_{GS} - V_T} = \frac{2 (-1,6 mA)}{-5 V + 1 V} = -0,8 mA/V$$

$$g_{m2} = 2 I_D = 2 \cdot 2 mA = 2 mA/V$$

$$V_{GS} - V_T \quad +3V - 1V$$

b) $\frac{V_{OUT}}{V_{IN}}$ a bassa frequenza (c circuito aperto)



configurazione
fonte a molla

configurazione
a fonte degenerata

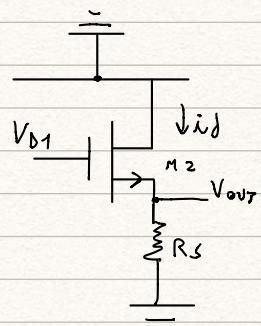
$$\frac{V_{OUT}}{V_{IN}} = \frac{V_{D1}}{V_{IN}} = \frac{V_{out}}{V_{D1}}$$

$$V_{g_{m1}} = V_{IN} \rightarrow V_{g_{m1}} = V_{IN}$$

$$i_D = g_{m1} V_{gs} \rightarrow i_{D1} = g_{m1} V_{IN}$$

$$V_{D1} = -i_{D1} R_D = -g_{m1} R_D V_{IN}$$

$$\frac{V_{D1}}{V_{IN}} = -g_{m1} R_D$$



$$\begin{cases} i_D = g_{m1} V_{gs} \\ V_S = i_D R_S \end{cases}$$

$$V_S = V_G \cdot \frac{R_S}{R_S + 1/g_{m1}} = V_g \frac{g_{m1} R_S}{1 + g_{m1} R_S}$$

$$\frac{V_{out}}{V_{D1}} = \frac{g_{m1} R_S}{1 + g_{m1} R_S}$$

c) Determinare le singolarità introdotte da C in $\frac{V_{OUT}}{V_{IN}}$

$$\left. \frac{V_{OUT}}{V_{IN}} \right|_{BF} = \sim 1,54$$

$$\left. \frac{V_{OUT}}{V_{IN}} \right|_{AF} = -g_{m1} R_D \cdot \left(\frac{g_{m2} = R_S / R_L}{1 + g_{m2} = R_S / R_L} \right) = -1,49$$

(c corti circuiti)

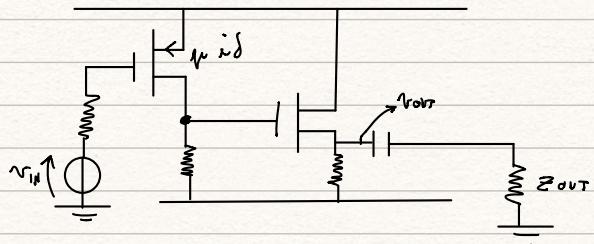
$$POLO: Y_p = C \cdot R_{eq}$$

$$R_{eq} = R_L + (R_S // 1/g_{m2})$$

$$\gamma_p = 485 \text{ ps}$$

$$f_p = \frac{1}{2\pi\gamma_p} = 328 \text{ Hz}$$

ZERO:

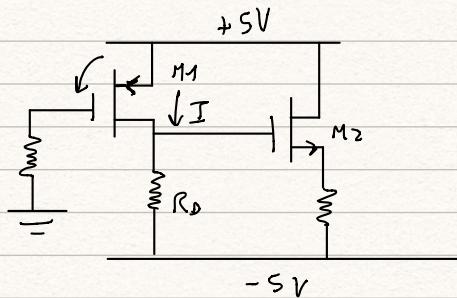


$$\begin{aligned} V_{IN} &\neq 0 \rightarrow V_{G_M2} \neq 0 \\ V_{OUT} &= i_d \cdot Z_{out} \\ V_{OUT} &= 0 \rightarrow Z_{out} = 0 \\ Z_{out} &= R_s / \left(\frac{1}{sC} + R_L \right) \end{aligned}$$

$$\frac{1}{sC} + R_L = 0 \quad s = -\frac{1}{R_L \cdot C}$$

$$\gamma_z = C \cdot R_L = 470 \mu\text{s} \quad f_z = 339 \text{ Hz}$$

D) Determinare $R_D \text{ MAX}$ per garantire M_1, M_2 in saturazione in polarizzazione



M_2 è SEMPRE IN SATURAZIONE

$$V_{GS} = -5 \text{ V}$$

$$V_D = -5 \text{ V} + IR_D$$

I_{D1} , con M_1 in SAT

$$-5 \text{ V} + IR_D < 1 \text{ V}$$

$$I_{D1} = K_p (V_{GS} - V_T)^2 \approx -1,6 \text{ mA}$$

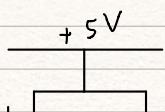
$$R_D < 3,75 \text{ k}\Omega$$

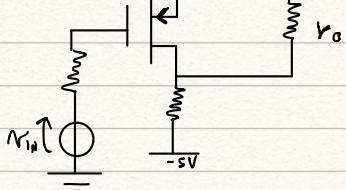
$$I = -I_{D1} = +1,6 \text{ mA}$$

$$R_{D \text{ MAX}} = 3,75 \text{ k}\Omega$$

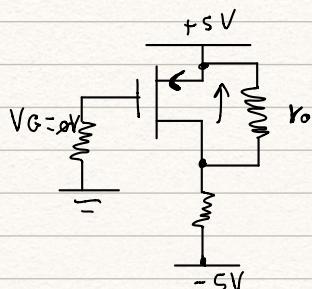
$$V_D < 1 \text{ V}$$

E) Indicare polarizzazione e $\frac{V_{D1}}{V_{IN}}$ considerando solo il I stadio e r_o di M_1 pari a $30 \text{ k}\Omega$





① POLARIZZAZIONE



$$V_{GS} = -5V$$

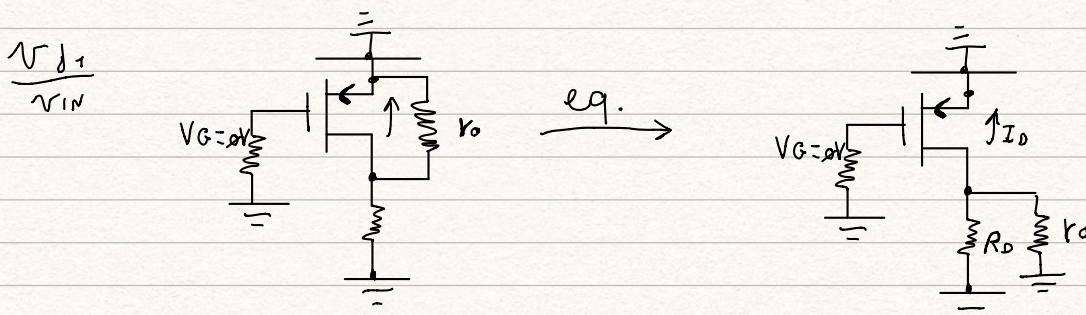
hyp. M_1 in SAT.

$$I_D = K_p (V_{GS} - V_T)^2 = -1,6 \text{ mA}$$

$$-I_D + \frac{5V - V_D}{R_o} = \frac{V_D + 5V}{R_o} \rightarrow V_D = 0,273V$$

$$I_{R_o} = \frac{5V - 0,273V}{R_o} = 0,157 \text{ mA}$$

$$g_m = \frac{2 I_D}{V_{DS}} = +0,8 \text{ mA/V}$$

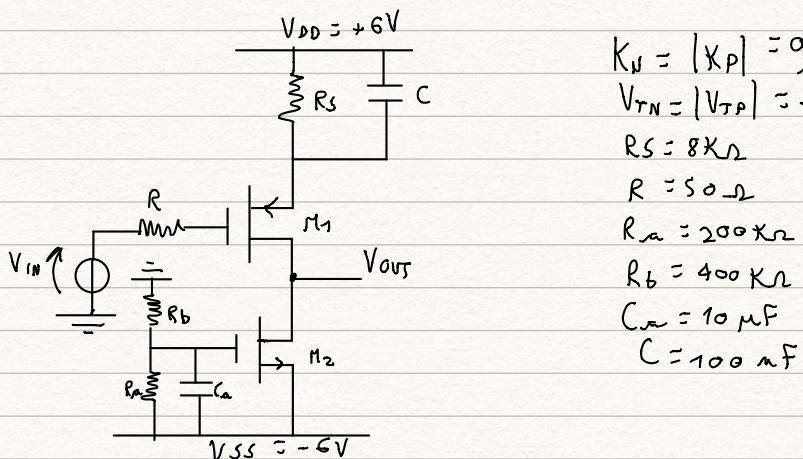


$$i_D = V_{GS} \cdot g_m = g_m V_{IN}$$

$$V_{D1} = -i_D (R_D || R_o)$$

$$\frac{V_D}{V_{IN}} = -g_m (R_D || R_o) = -2,18$$

esercizio 2: TDE 9 LUGLIO 2018



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

$$V_{T_P} = |V_{T_P}| = 1V$$

$$R_S = 8k\Omega$$

$$R = 50\Omega$$

$$R_a = 200k\Omega$$

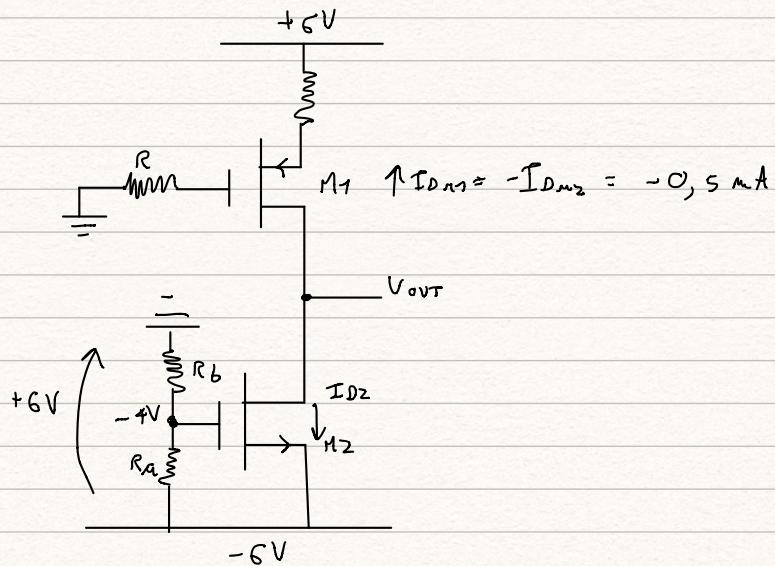
$$R_b = 400k\Omega$$

$$C_{in} = 10 \mu F$$

$$C = 100 nF$$

A) Polarizzazione

Rango di tensioni V_{OUT} per il corretto funzionamento del circuito



$$\sqrt{R_A} = \frac{+6V}{\frac{R_A}{R_A + R_b}} = +2V = V_{GS12}$$

HP: n2 in SFT

$$I_{D2} = K_p (V_{GS2} - V_{T2})^2 = 0.5 \text{ mA}$$

$$V_S = +6V + I_{Dn1} \cdot R_S = 6V - 0.5 \text{ mA} \cdot 8k\Omega = +2V$$

$$I_{Dn1} = -0.5 \text{ mA}$$

HP: n1 sia in saturazione

$$V_{GS1} = -1V - 1V = -2V$$

$$I_{Dn1} = K_p (V_{GS1} - V_{T1})^2$$

$$V_{GS1} = \sqrt{\frac{I_{Dn1}}{K_p}} + V_{T1}$$

M2 è in saturazione

$$V_{OUT} > V_{GS2} - V_{T2} = -4V - 1V = -5V$$

(Con $V_{OUT} = -5V$
 $V_{GDS2} = -4V - (-5V) = +1V = V_T$ pinch off)

M1 in saturazione se

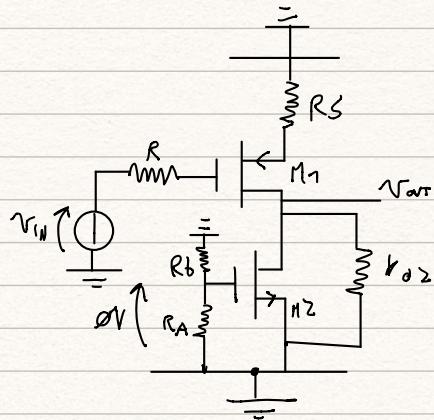
$$V_{OUT} < V_{GM1} - V_{Tp} = 0V - (-1V) = +1V$$

$$(con) V_{out} = 1V \quad V_{GDM1} = \phi V - 1V = -1V \quad (\text{pinch off})$$

$$V_{out} \in [-5V; +1V]$$

b) $\left| \frac{V_{out}}{V_{in}} \right|_{AF}$

$$\begin{aligned} & con \quad r_{on2} = 65k\Omega \\ & (r_{on1} \approx \infty) \end{aligned}$$



$$V_{GS, n2} = 0 \rightarrow i_{ds, n2} = 0$$

$$V_{g_{M1}} = V_{in} \rightarrow V_{gs, n1} = V_g \cdot \frac{1/g_{m1}}{1/g_{m1} + R_S}$$

$$i_{ds, n1} = g_{m1} V_{gs, n1}$$

$$i_{ds, n1} = V_g \cdot \frac{g_{m1}}{1 + g_{m1} R_S} = V_{in} \cdot \frac{g_{m1}}{1 + g_{m1} R_S}$$

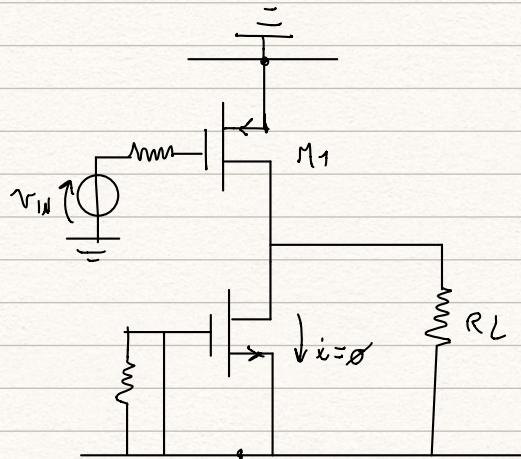
$$g_m = \frac{2I_D}{V_{GS} - V_T} = \frac{-1mA}{-1V} = +1mA/V$$

$$V_{out} = -i_{ds, n1} R_{o2}$$

$$V_{out} = -V_{in} \cdot \frac{g_{m1} \cdot R_{o2}}{1 + g_{m1} R_S}$$

$$\frac{V_{out}}{V_{in}} = -\frac{g_{m1} R_{o2}}{1 + g_{m1} R_S} = -\frac{1mA/V \cdot 65k\Omega}{1 + 1mA/V \cdot 8k\Omega} = -7,22$$

c) $\left| \frac{V_{out}}{V_{in}} \right|_{AF}$



$$V_{GS, n1} = V_{in}$$

$$i_d = g_{m1} V_{in}$$

$$V_{out} = -g_{m1} R_L V_{in}$$

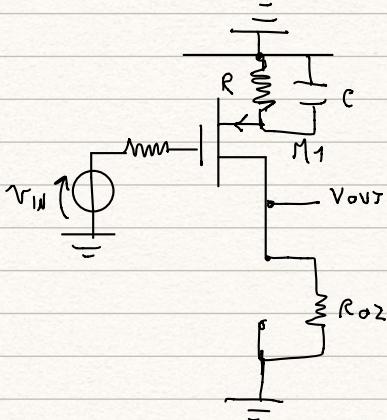
$$\left| \frac{V_{out}}{V_{in}} \right|_{AF} = -g_{m1} R_L = -65$$

d) Singolarità nel trasferimento $\frac{V_{OUT}}{V_{IN}}$

C non introduce alcuna singolarità

C introduce via un polo che inserisce

Z_{RB}



$$V_{OUT} = -i_d \cdot R_o2$$

$$V_{OUT} = 0 \text{ e } i_d = 0$$

$$i_d = 0 \text{ e } V_{GS} = 0 \text{ e } i_d = g_m V_{GS}$$

$$V_{GS} = V_{IN} \cdot \frac{1/g_m}{1/g_m + Z_s}$$

$$\text{dove } Z_s = \frac{1}{SC} R_s$$

$$V_{GS} \rightarrow 0 \text{ e } Z_s \rightarrow \infty$$

$$Z_s = \frac{R_s}{1 + SC R_s} \rightarrow \infty$$

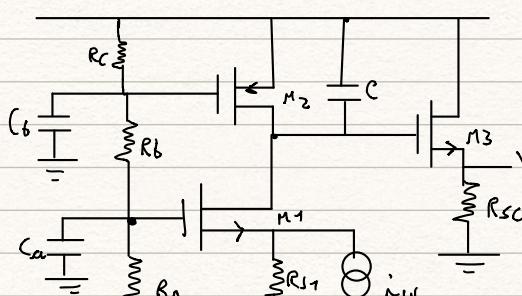
$$S = \frac{1}{CR_s}$$

$$Z_s = C \cdot R_s = ?$$

?

$$\tau_p : 88,9 \mu s \rightarrow f_p = 1,11 \text{ kHz}$$

esercizio 3: TIE 11 settembre 2018



$$|K_P| = 1 \text{ mA/V}^2$$

$$|V_T| = 1 \text{ V}$$

$$\frac{1}{2} \mu_n C_{ox} = 100 \mu\text{A/V}^2$$

$$\left(\frac{W}{L}\right)_3 = 10$$

$$R_A = 25 \text{ k}\Omega$$

$$R_B = 15 \text{ k}\Omega$$

$$\begin{aligned}
 R_C &= 20 \Omega \\
 C_a &= C_b = 470 \text{nF} \\
 R_{S1} &= 0,5 \text{k}\Omega \\
 R_{S2} &= 2 \text{k}\Omega \\
 C &= 2 \text{pF}
 \end{aligned}$$

1) Polarizzazione

$$\text{Determinare } \left(\frac{V}{I}\right)_{M1}$$

affinché $|I_D|$ sia tutto in nos sia tatt in polarizzazione

$$V_{S+I_1} = 1 \text{mA} \cdot R_{S1} = +0,5 \text{V}$$

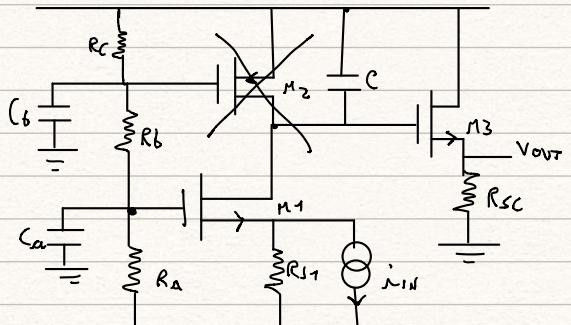
$$V_{\text{OUT}} = 1 \text{mA} \cdot R_{S2} = +2 \text{V}$$

$$V_{G M3} = \sqrt{\frac{|I_D|}{K_3}} + V_S + V_T = 4 \text{V}$$

$$\left(\frac{V}{I}\right)_{M1} = 10$$

b) $\frac{V_{\text{OUT}}}{V_{IN}}$ è media di $(C_a, C_b \text{ elettronico})$
 (circ. operativo)

considerando $r_{o2} = 100 \text{k}\Omega$



$$V_{d2} = -i_{d2} \cdot r_{o2}$$

$$i_{d1} = -i_{in} \cdot \frac{R_{S1}}{R_{S2} + 1/g_m} \cdot r_{o2}$$

$$\frac{V_{d1}}{i_{in}} = -g_m R_{S1} \cdot r_{o2} = -40 \text{k}\Omega$$

$$V_{GS, M2} = 0 \rightarrow i_{d2} = 0$$

$$\frac{V_{\text{OUT}}}{V_{d1}} = \frac{R_{S2}}{R_{S2} + 1/g_m} = +g_m^3 R_{S2}$$

$$i_{d1} = i_{in} \cdot \frac{R_{S1}}{R_{S1} + 1/g_m}$$

$$\frac{V_{\text{OUT}}}{i_{in}} = -\frac{g_m R_{S1}}{1 + g_m R_{S1}} \cdot \frac{g_m^3 R_{S2}}{1 + g_m^3 R_{S2}}$$