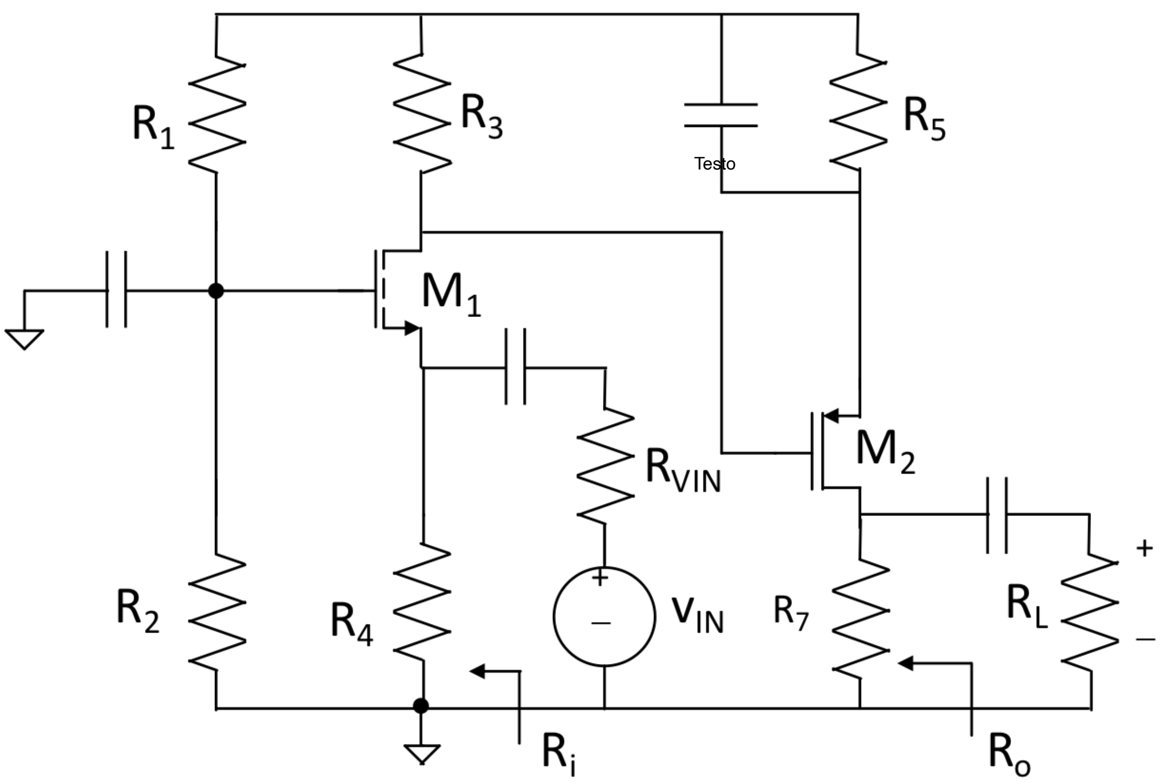
TEMA PROPOSTO 5 – SOLUZIONE

PROBLEMA P1

Dato il circuito riportato nella figura sottostante, supponendo che funzioni a T=300K, determinare:

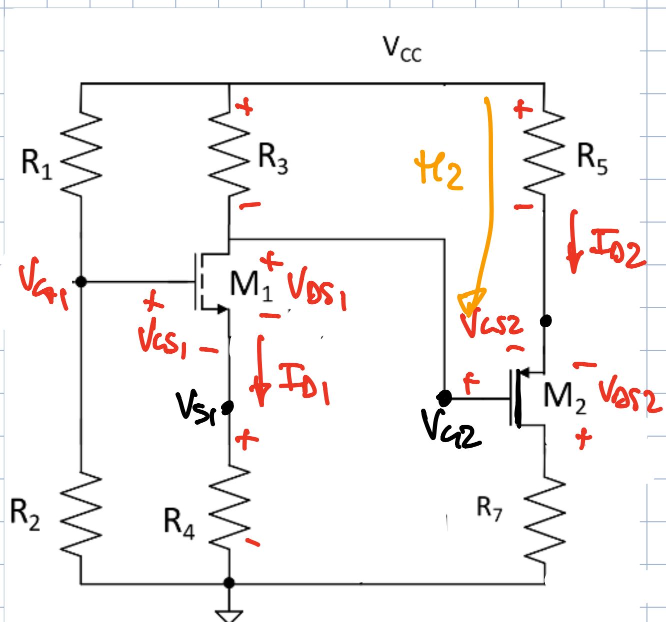
1) il valore della resistenza R_4 in modo che la corrente di drain del transistor M_1 sia $I_{D1} = 2.0$ mA;
2) il punto di lavoro dei transistor M_1 e M_2;
3) la resistenza di ingresso ai piccoli segnali ac R_i;
4) la resistenza di uscita ai piccoli segnali ac R_o;
5) il guadagno di tensione ai piccoli segnali ac $A_v=v_{out}/v_{in}$;



DATI:

V_{CC}=12V,
R_1=250 kΩ,
R_2=350 kΩ,
R_3= 2.2 kΩ,
R_5= 1.0 kΩ,
R_6=50 Ω,
R_7=1 kΩ,
R_{VIN}=500 Ω,
R_L=1 kΩ,
M_1:
K_n=4mA/V^2,
V_{TN}=2V,
λ_n=0 V^{-1}
M_2:
K_p=4mA/V^2,
V_{TP}=2V,
λ_n=0 V^{-1}

POLARIZZAZIONE



$$V_{G_1} = V_{CC}\cdot\frac{R_2}{R_1+R_2} = 7V$$

$$V_{GS1} = V_{TN} + \sqrt{\frac{2I_D}{K_n}} = 2V + 1V = 3V$$

$$V_{S1} = V_{G1} - V_{GS1} = 4V$$

$$\Rightarrow R_4 = \frac{V_{S1}}{I_{D1}} = \frac{4V}{2mA} = \underline{2k\Omega}$$

$$V_{G2} = V_{D1} = V_{CC} - R_3 I_{D1} = 7{,}6V$$

$$V_{DS1} = 7{,}6V - 4V = 3{,}6V > V_{GS} - V_{TN} = 1V$$

OK M_1 SATUR.

$V_{CC} = R_5 I_{D2} - V_{GS2} + V_{G2}$

$$\begin{cases} I_{D2} = \dfrac{V_{CC}-V_{G2}+V_{GS2}}{R_5} \\ I_{D2} = \dfrac{K_P}{2}\left(V_{GS_2}-V_{TP}\right)^2 \end{cases} \Rightarrow \frac{2(V_{CC}-V_{G2})}{R_5 K_P} + \frac{2V_{GS2}}{R_5 K_P} = V_{GS_2}^2 + V_{TP}^2 - 2V_{GS_2}V_{TP}$$

$$\Rightarrow V_{GS2}^2 + V_{GS_2}\left(-2V_{TP} - \frac{2}{R_5 K_P}\right) + V_{TP}^2 - \frac{2(V_{CC}-V_{G2})}{R_5 K_P} = 0$$

$a=1 \qquad b = -4 - \frac{1}{2} = -4{,}5 \qquad 4 - 2{,}2 = 1{,}8$

$V_{GS_2} \to 4{,}056\,V$ no $> V_{TP}$

$V_{GS_2} \to 0{,}444$ OK $< V_{TP}$

$I_{D2} = 4{,}844\,mA \qquad V_{S_2} = V_{G2} - V_{GS_2} = 7.156$

$V_{D2} = R_6 I_{D2} = 1K\Omega \cdot 4{,}844\,mA = 4{,}844\,V$

$\Rightarrow V_{DS_2} = V_{D2} - V_{S2} = 4{,}844 - 7{,}156 = -2{,}312 < V_{GS_2} V_{TN} = -1{,}556$

OK M_2 SATUR.

$\Rightarrow M_1\ (I_{D_1} = 2\,mA,\ V_{DS} = 3{,}6\,V)$

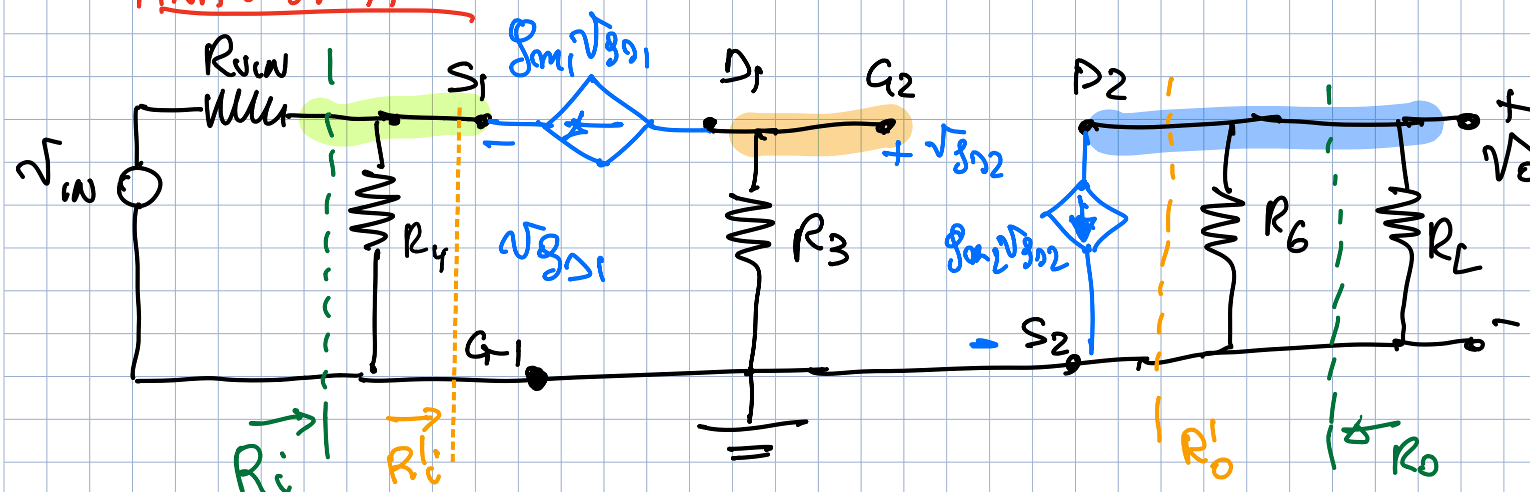
$M_2\ (I_{D2} = 4{,}844\,mA,\ V_{DS} = -2{,}312\,V)$

PARAMETRI AC PICCOLO SEGNALE

$$g_{m_1} = \frac{2I_{D_1}}{V_{GS} - V_{TN}} = \frac{4\,mA}{1\,V} = 4\,mS$$

$$g_{m_2} = \frac{2I_{D2}}{|V_{GS} - V_{TP}|} = \frac{9{,}688\,mA}{1{,}556\,V} = 6{,}225\,mS$$

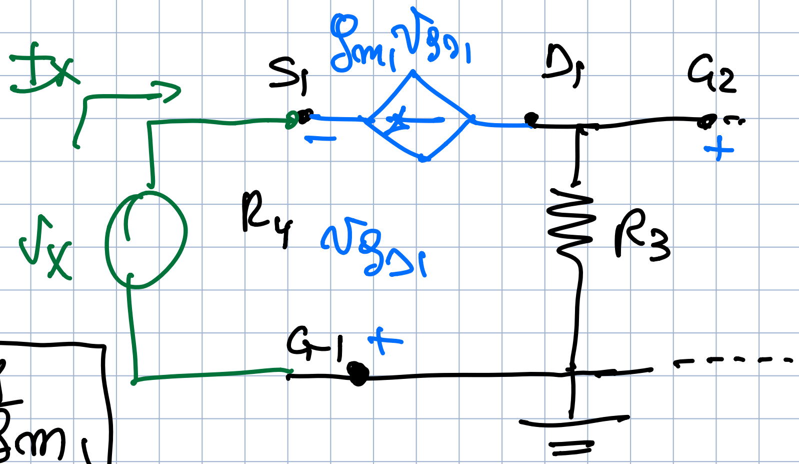
ANALISI AC



CALCOLO DI Ri e Ro

$R_i = R_4 // R_i'$

$R_i' = ?$



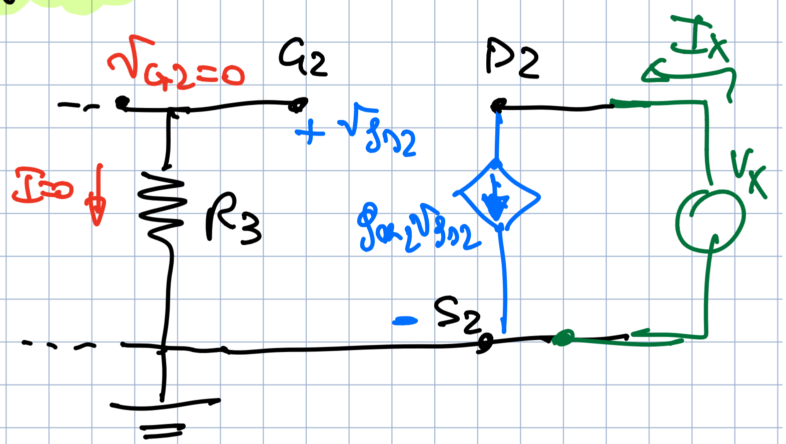
$I_x = -g_{m1} v_{gs1}$

$V_x = -v_{gs1}$

$$\Rightarrow \boxed{\frac{V_x}{I_x} = \frac{1}{g_{m1}}}$$

$$\Rightarrow R_i = R_4 // \frac{1}{g_{m1}} = \frac{R_4}{1+g_{m1}R_4} = 222,22\,\Omega$$

$R_o = R_6 // R_o'$ $\quad R_o' = ?$



CON $V_{IN} = 0 \Rightarrow$

$v_{G2} = 0 = v_{gs2} = 0$

$\Rightarrow g_{m2} v_{gs2} = 0$

$\Rightarrow I_x = 0$

$$\Rightarrow R_o' = \infty \Rightarrow R_o = R_6 = 1\,k\Omega$$

CALCOLO DEL GUADAGNO DI TENSIONE

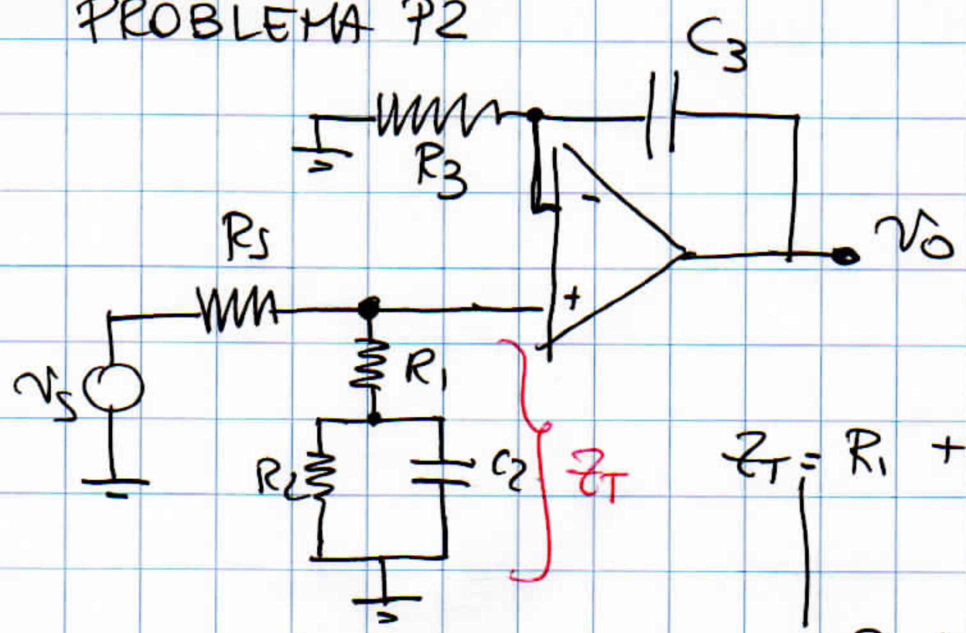
$$A_v = \frac{v_o}{v_i} = \frac{v_o}{v_{G2}} \cdot \frac{v_{G2}}{v_{S1}} \cdot \frac{v_{S1}}{v_i} = \frac{v_{D2}}{v_{G2}} \cdot \frac{v_{D1}}{v_{S1}} \cdot \frac{v_{S1}}{v_i}$$

$$\frac{v_{D1}}{v_{S1}} = A_{vt1}^{CG} = \frac{-g_{m1} v_{gs1} R_3}{-v_{gs1}} = g_{m1} R_3 = 4\,mS \cdot 2{,}2\,k\Omega \doteq 8.8$$

$$\frac{v_{D2}}{v_{G2}} = A_{vt2}^{CS} = \frac{-g_{m2} v_{gs2}\, R_6 // R_L}{v_{gs2}} = -g_{m2}\, R_6 // R_L = -3{,}112$$

$$\frac{v_{S1}}{v_i} = \frac{R_i}{R_i + R_{VIN}} = 0{,}308 \quad \Rightarrow A_v = -8.428$$

PROBLEMA P2



$R_1 = 100\,\Omega$

$R_2 = 1\,K\Omega$

$R_3 = 1\,K\Omega$

$R_S = 2{,}4\,K\Omega$

$C_2 = 10\,nF$

$C_3 = 10\,\mu F$

$$Z_T = R_1 + \frac{R_2 \cdot \frac{1}{sC_2}}{R_2 + \frac{1}{sC_2}} = R_1 + \frac{R_2}{1 + sC_2R_2} = \frac{R_1 + R_2 + sC_2R_1R_2}{1 + sC_2R_2}$$

$$\frac{v_+}{v_S} = \frac{Z_T}{R_S + Z_T} = \frac{\frac{R_1 + R_2 + sC_2R_1R_2}{1 + sC_2R_2}}{R_S + \frac{R_1 + R_2 + sC_2R_1R_2}{1 + sC_2R_2}} = \frac{\frac{R_1 + R_2 + sC_2R_1R_2}{\cancel{1 + sC_2R_2}}}{\frac{R_S + sC_2R_2R_S + R_1 + R_2 + sC_2R_1R_2}{\cancel{1 + sC_2R_2}}} = \frac{(R_1 + R_2)(1 + sC_2\,R_1/\!/R_2)}{(R_1 + R_2 + R_S)(1 + sC_2R_{EQ})}$$

$$R_{EQ} = \frac{R_1R_2 + R_2R_S}{R_1 + R_2 + R_S} = 714{,}3\,\Omega$$

$$R_1/\!/R_2 = 90{,}1\,\Omega$$

$$\frac{v_O}{v_+} = \left(1 + \frac{\frac{1}{sC_3}}{R_3}\right) = 1 + \frac{1}{sC_3R_3} = \frac{1 + sC_3R_3}{sC_3R_3}$$

$$= W(s) = \frac{v_O}{v_S} = \frac{v_O}{v_+} \cdot \frac{v_+}{v_S}$$

$$\boxed{= \frac{R_1+R_2}{R_1+R_2+R_S} \cdot \frac{1+sC_2 R_1//R_2}{1+sC_2 R_{EQ}} \cdot \frac{1+sC_3R_3}{sC_3R_3}}$$

$$G_{BIN} = \frac{R_1+R_2}{R_1+R_2+R_S} = 0{,}314 \qquad = \underline{-10\,dB}$$

$$\omega_{z_2} = \frac{1}{C_2 R_1//R_2} = 1.1 \cdot 10^6 \text{ rad/sec}$$

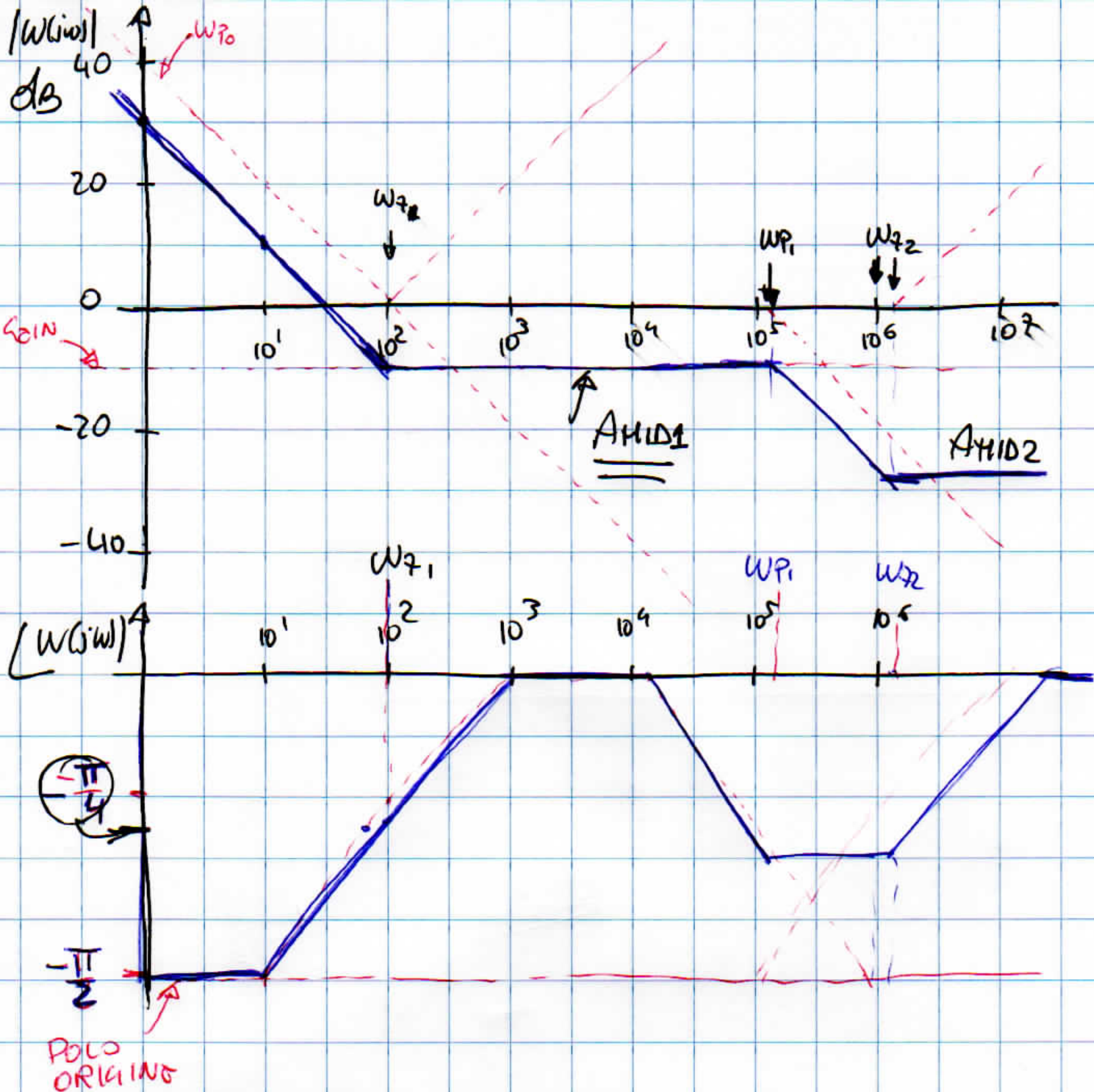
$$\omega_{z_1} = \frac{1}{C_3R_3} = 100$$

$$\omega_{P_1} = \frac{1}{C_2R_{EQ}} = 1{,}4 \cdot 10^5 \text{ rad/sec}$$

$$\omega_{P_0} = \frac{1}{R_3C_3} = 100 \Rightarrow \left|\frac{1}{j\omega C_3R_3}\right|_{\omega=1} = 100 = \underline{\underline{40\,dB}}$$

$$A_{MID_1} = \frac{R_1+R_2}{R_1+R_2+R_3} \cdot \frac{C_3R_3}{C_3R_3} = 0{,}314 = \underline{\underline{-10\,dB}}$$

$$A_{MID_2} = A_{MID_1} \cdot \frac{R_1//R_2}{R_{EQ}} = 3.96 \cdot 10^{-2} = \underline{\underline{-28\,dB}}$$



3) <u>PER $\omega_1 = 100$</u> : $|W(j\omega_1)| = A_{MID1} \times \sqrt{2} = 0{,}444$

$$\angle W(j\omega_1) = -\frac{\pi}{4}$$

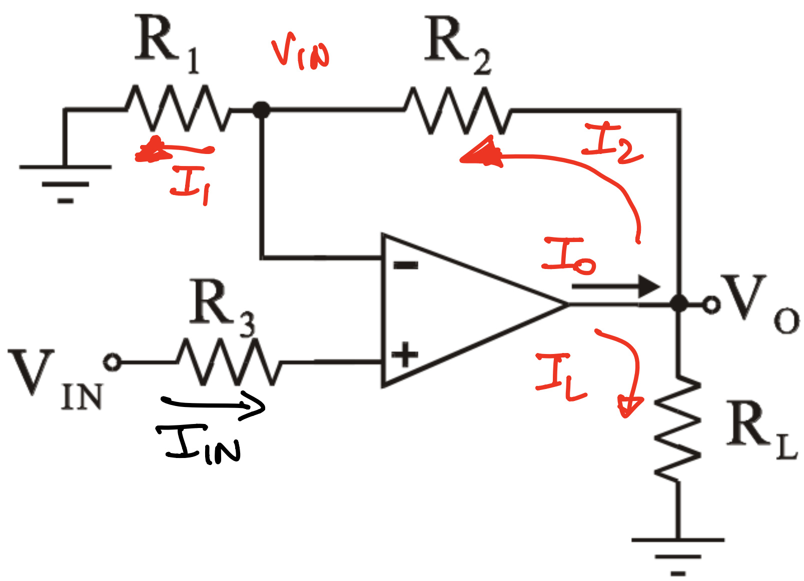
<u>PER $\omega_2 = 10^8$</u> $|W(j\omega_2)| = A_{MID2} = 0{,}0396 = -28\,dB$

$$\angle W(j\omega_2) = 0$$

ESERCIZIO Q1

Il circuito di figura impiega un amplificatore operazionale ideale. Determinare la corrente erogata dal generatore di tensione V_{IN} e la corrente erogata dall'amplificatore operazionale. Calcolare l'effetto delle correnti di polarizzazione: I_{B1}=95uA, I_{B2}=105uA. Trovare il valore di R_3 che annulla l'effetto delle correnti di BIAS.

Dati: R_1 = 1 kΩ, R_2 = 4 kΩ, R_3 = 3 kΩ, R_L = 10 kΩ, V_{IN} = -5 V,



1) $I_{IN} = 0 \quad (I_+ = 0)$

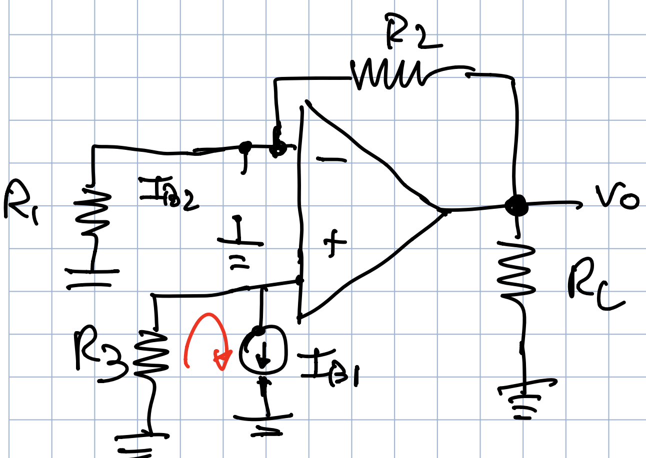
2) $I_2 = I_1 = \dfrac{V_{IN}}{R_1} = -\dfrac{5V}{1k\Omega} = -5\,mA$

$V_o = V_{IN}\left(1+\dfrac{R_2}{R_1}\right) = 5V_{IN} = -25V$

$\Rightarrow I_L = \dfrac{V_o}{R_L} = \dfrac{-25V}{10k\Omega} = -2{,}5\,mA$

$I_o = I_2 + I_L = -7{,}5\,mA$ (CORRENTE ASSORBITA

EFFETTO I_{BIAS}



SOVRAPP. EFFETTI'

I_{B1} $(I_{B2}=0)$ $\quad v_+ = -R_3 I_{B1}$

$\Rightarrow v_o' = v_+\left(1+\dfrac{R_2}{R_1}\right)$

$v_o' = -R_3 I_{B1}\left(1+\dfrac{R_2}{R_1}\right)$

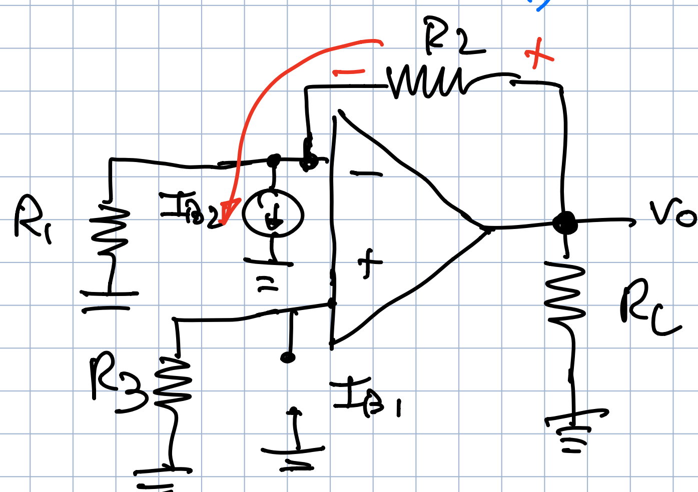
SOVRAPP. EFFETTI'

I_{B2} $(I_{B1}=0)$

$v_+ = 0 = v_-$

$I_{R_1} = 0$

$V_o'' = I_{B2} \cdot R_2$



$\Rightarrow V_{OBIAS} = I_{B2} R_2 - I_{B1} R_3 \left(1 + \frac{R_2}{R_1}\right)$

PER ANNULLARLO:

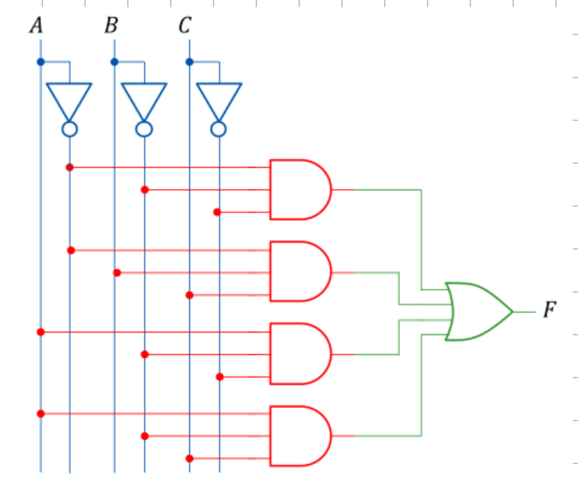
$$I_{B2} R_2 = I_{B1} R_3 \left(\frac{R_1 + R_2}{R_1}\right)$$

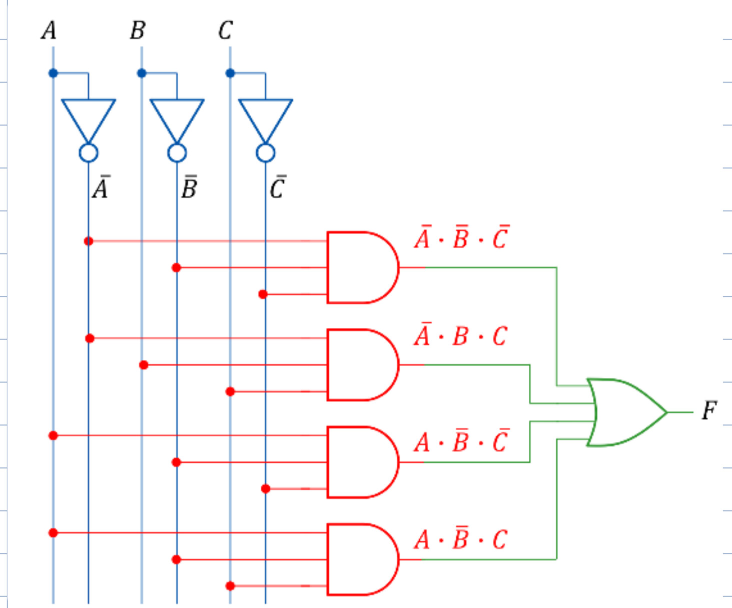
$$\Rightarrow R_3 = \frac{I_{B2}}{I_{B1}} \cdot \frac{R_1 R_2}{R_1 + R_2} = \frac{105}{95} \cdot \frac{4}{5}\, k\Omega = \underline{\underline{884\,\Omega}}$$

PROBLEMA Q2

Dato il circuito digitale di figura:

1) Determinare l'espressione Booleana dell'uscita F;
2) Ricavare la mappa di Karnaugh corrispondente;
3) Trovare una F minimizzata (utilizzando algebra booleana o la Mappa di Karnaugh);
4) Disegnare il circuito digitale minimizzato;





AB \ C	0	1
00	1	
01		1
11		
10	1	1

Forma ridotta

$\bar{B} \cdot \bar{C} + \bar{A} \cdot B \cdot C + A \cdot \bar{B}$

$= \overline{B + C} + \bar{A} \cdot B \cdot C + A \cdot \bar{B}$

Forma non ridotta

$F = \bar{A} \cdot \bar{B} \cdot \bar{C} + \bar{A} \cdot B \cdot C + A \cdot \bar{B} \cdot \bar{C} + A \cdot \bar{B} \cdot C$