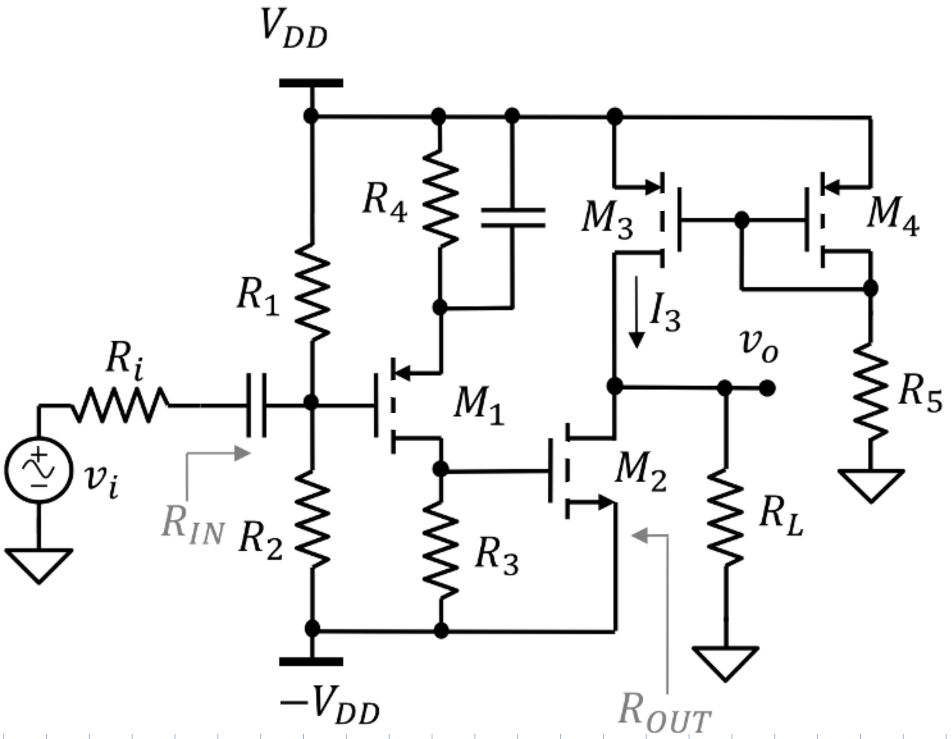
PROBLEMA P1

Dato il circuito riportato nella figura sottostante, determinare:

1) il valore della resistenza R_5 in modo che la corrente $I_3 = 70$ mA;
2) il punto di lavoro dei transistor M_1, M_2, M_3, M_4
3) il guadagno di tensione ai piccoli segnali ac $A_v = v_{out}/v_{sig}$ (**considerare $\lambda_{p3} = 0.01$ V^{-1}**);
4) la potenza totale dissipata dal circuito;
5) le resistenze di ingresso e uscita ai piccoli segnali ac R_{in} e R_{out}.



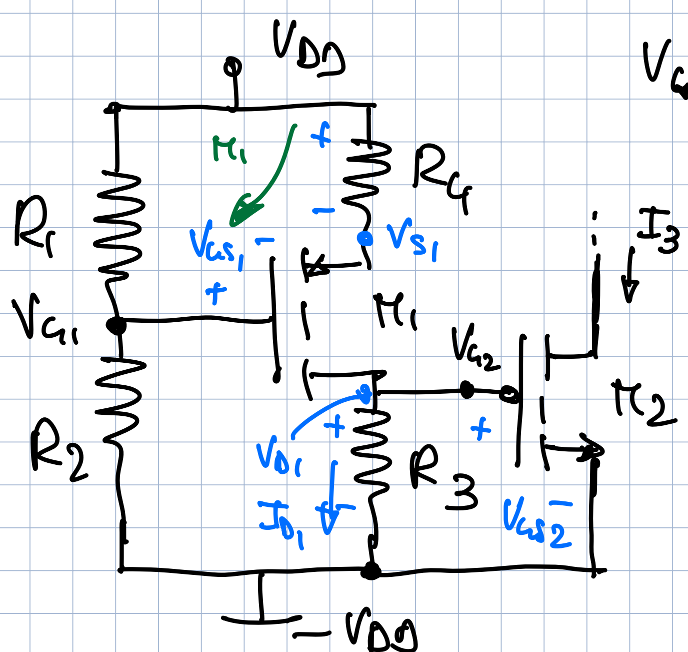
Dati:

V_{DD}=12 V
R_1=120 kΩ,
R_2=180 kΩ,
R_3=0.5 kΩ,
R_4=0.5 kΩ,
R_L=1.0 kΩ,
R_i= 1.0 kΩ,

M_1: k_{p1}=5 mA/V^2, V_{TP1} = -1 V
M_2: k_{n2}=5 mA/V^2, V_{TN2} = 1 V
M_3: k_{p1}=40 mA/V^2, V_{TP3} = -1 V
M_4: k_{p4}=10 mA/V^2, V_{TP4} = -1 V

Per analisi DC: $\lambda_p = \lambda_n$=0 V^{-1};

POLARIZZAZIONE



$$V_{G_1} = V_{DD} \cdot \frac{R_2}{R_1+R_2} - V_{DD}\frac{R_1}{R_1+R_2} = 2,4\text{ V}$$

$$M_1: \begin{cases} V_{DD} = R_4 I_{D_1} - V_{GS_1} + V_{G_1} \\ I_{D_1} = \frac{K_{P_1}}{2}\left(V_{GS_1} - V_{TP_1}\right)^2 \end{cases}$$

$$I_{D_1} = \frac{V_{DD} - V_{G_1}}{R_4} + \frac{V_{GS_1}}{R_4}$$

$$\frac{2(V_{DD} - V_{G_1})}{R_4 K_{P_1}} + \frac{2V_{GS_1}}{R_4 K_{P_1}} = V_{GS_1}^2 + V_{TP_1}^2 - 2V_{GS_1}V_{TP_1}$$

$$V_{GS_1}^2 + V_{GS_1}\left(-\frac{2}{R_G K_{P_1}} - 2V_{TP_1}\right) + V_{TP_1}^2 - \frac{2(V_{DD} - V_{G_1})}{R_G K_{P_1}} = 0$$

$a = 1$ $\quad b = 1{,}2\ [V]$ $\quad c = -6{,}68\ [V^2]$

$\Delta = b^2 - 4ac = 28{,}16\ V^2 \qquad \sqrt{\Delta} = 5{,}31\ V$

$$V_{GS1} = \frac{-b \overset{(*)}{-} \sqrt{\Delta}}{2a} = -3{,}25\ V$$

(*) USO IL "−" DOVENDO ESSERE $V_{GS_1} < V_{TP_1}$

$$I_{D_1} = \frac{K_{P_1}}{2}\left(V_{GS_1} - V_{TP_1}\right)^2 = 12{,}7\ mA$$

$V_{S_1} = V_{DD} - R_G I_{D_1} = 5{,}65\ mA$

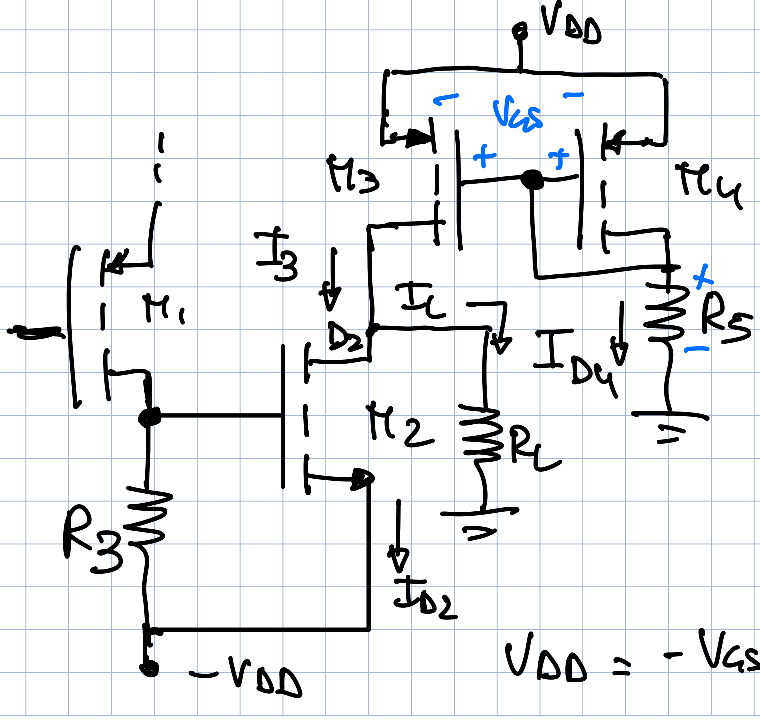
$V_{D_1} = -V_{DD} + R_3 I_{D_1} = -5{,}65\ mA$

$V_{DS_1} = V_{D_1} - V_{S_1} = -11{,}3\ V < V_{GS_1} - V_{TP_1} = -2{,}25\ V$

OK M_1 SATURAZIONE

$V_{GS_2} = R_3 I_{D_1} = 6{,}35\ V$

$$I_{D2} = \frac{K_{n2}}{2}\left(V_{GS_2} - V_{tn_2}\right)^2 = 71{,}5\ mA$$



$$I_o = I_{REF} \cdot \frac{K_{P3}}{K_{P4}} \frac{\cancel{(1 + \lambda V_{DS3})}}{\cancel{(1 + \lambda V_{DS4})}}$$

$$I_{D4} = I_3 \frac{K_{P4}}{K_{P3}} = \frac{I_3}{4} = 17{,}5\ mA$$

$$I_{D4} = \frac{K_{P4}}{2}\left(V_{GS4} - V_{TP4}\right)^2$$

$$\Rightarrow V_{GS4} = V_{TP4} - \sqrt{\frac{2 I_{D4}}{K_{P4}}} = -2{,}87\ V$$

$V_{DD} = -V_{GS4} + R_S I_{REF}$

$$\Rightarrow R_S = \frac{V_{DD} + V_{GS4}}{I_{D4}} = 521{,}7\ \Omega$$

$$I_L = I_3 - I_{D2} = -1{,}5\ mA$$

$$V_{D2} = R_L I_L = -1{,}5\ V$$

$$V_{DS2} = -1{,}5V - (-V_{DD}) = 10{,}5V > V_{GS2} - V_{TN2} = 5{,}35V$$

OK M_2 SATURAZIONE

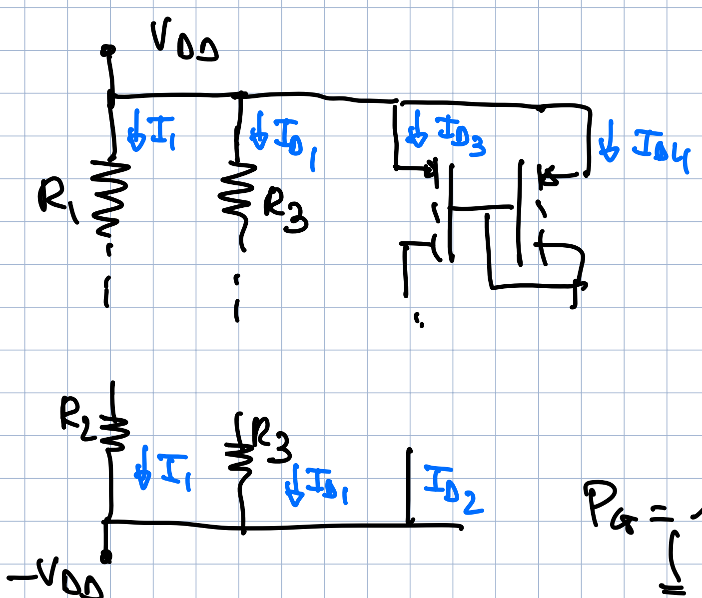
$$V_{DS3} = V_{D2} - V_{DD} = -13{,}5\ V < V_{GS3} - V_{TP3} = -1{,}87V$$

$$V_{DS4} = V_{GS4} = -2{,}87V < V_{GS4} - V_{TP4} = -1{,}87V$$

OK M_3 e M_4 SATURAZ.

$$\begin{bmatrix} I_{D1} = 12{,}7\ mA, & V_{DS1} = -11{,}3V \\ I_{D2} = 71{,}5\ mA & V_{DS2} = 10{,}5V \\ I_{D3} = 70\ mA & V_{DS3} = -13{,}5V \\ I_{D4} = 17{,}5\ mA & V_{DS4} = -2{,}87V \end{bmatrix}$$

3) POTENZA DISSIPATA



$$P_{DISSIPATA} = P_{GENERATA}$$

$$P_G = V_{DD}(I_1 + I_{D1} + I_{D3} + I_{D4}) +$$

$$+ (-V_{DD})(-I_1 - I_{D1} - I_{D2})$$

$$P_G = 12V \cdot (100{,}27\ mA) + 12V(84{,}24\ mA)$$

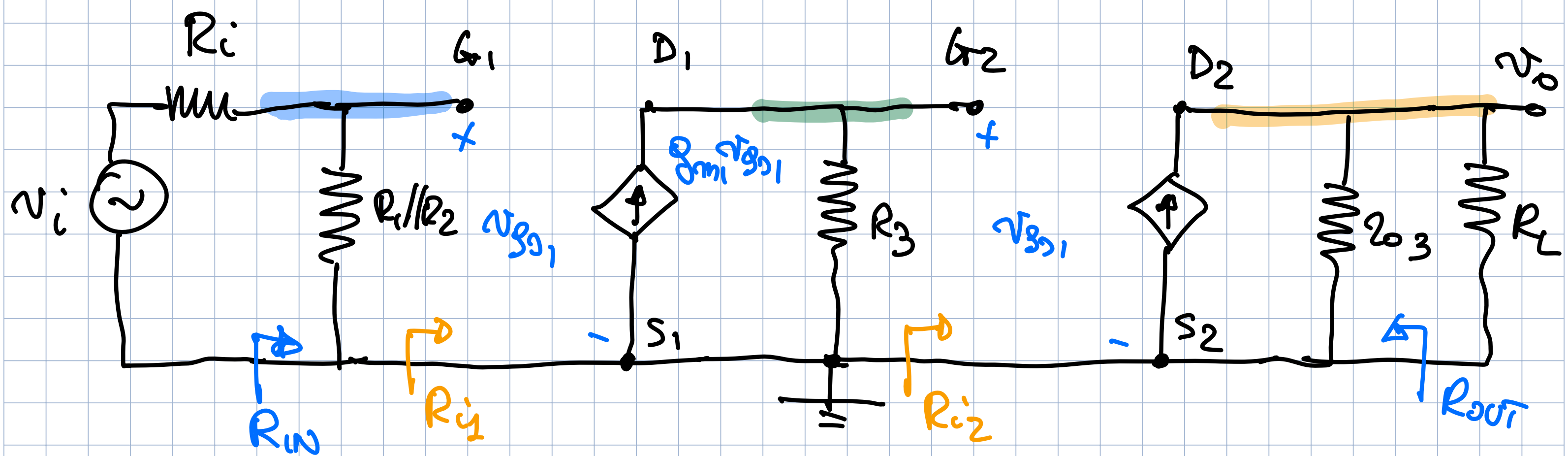
$$= 2{,}214\ W$$

4) ANALISI AL PICCOLO SEGNALE

$$g_{m1} = \sqrt{2 I_{D1} K_{P1}} = 11{,}27 \text{ mS}$$

$$g_{m2} = \sqrt{2 I_{D2} K_{n2}} = 26{,}73 \text{ mS}$$

$$r_{o3} = \frac{\frac{1}{\lambda_3} + |V_{DS3}|}{I_{D3}} = 1{,}62 \text{ k}\Omega$$



$$A_v = \frac{v_o}{v_i} = \frac{v_o}{v_{G2}} \cdot \frac{v_{G2}}{v_{G1}} \cdot \frac{v_{G1}}{v_i}$$

Poi considerato che

$$v_o = v_{D2}$$
$$v_{G2} = v_{D1}$$

$$= \frac{v_{D2}}{v_{G2}} \cdot \frac{v_{D1}}{v_{G1}} \cdot \frac{v_{G1}}{v_i} = A_{vt}^{CS2} \cdot A_{vt}^{CS1} \cdot \alpha$$

$$\alpha = \frac{R_1 \| R_2}{R_i + R_1 \| R_2} = 0{,}986$$

$\boxed{\text{N.B. } R_{i1} = \infty}$

$\boxed{\text{N.B. } R_{i2} = \infty}$

$$A_{vt}^{CS1} = -g_{m1} R_3 = -5{,}63 \text{ V}$$

$$A_{vt}^{CS2} = -g_{m2}\, r_{o3} // R_L = -16{,}53$$

$$A_v = \frac{v_o}{v_s} = 91{,}86$$

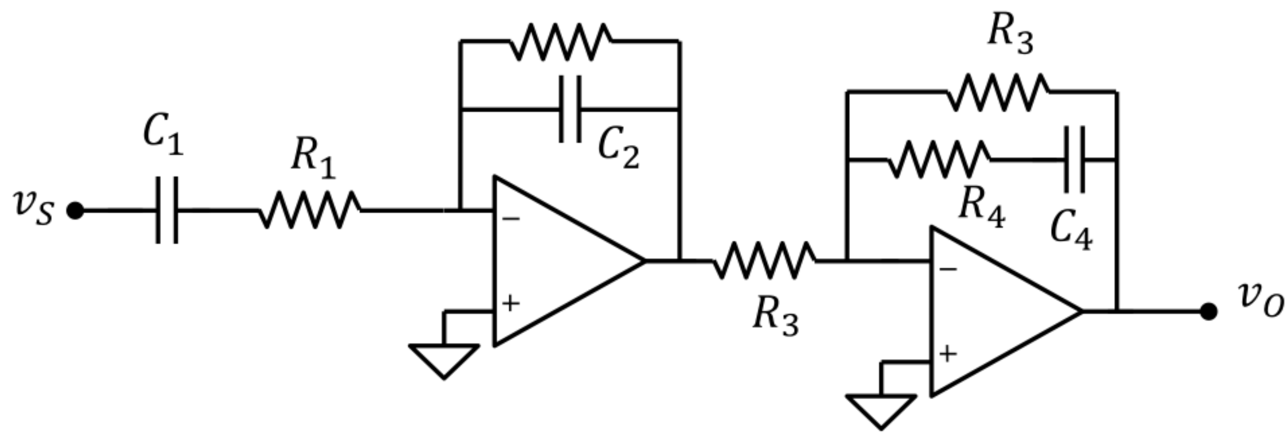
$$A_i = \frac{i_L}{i_i} = \frac{v_o}{v_i} \cdot \frac{R_i + R_1 \| R_2}{R_L} = 670{,}6$$

$$R_{IN} = R_1 \| R_2 = 72 \text{ k}\Omega$$

$$R_{OUT} = r_{o3} = 16{,}2 \text{ k}\Omega$$

PROBLEMA P2

Sia dato il circuito in figura che usa un amplificatore operazionale ideale. **Dati:** $R_1 = 2\ k\Omega$, $R_2 = 200\ k\Omega$, $R_3 = 180\ k\Omega$, $R_4 = 20\ k\Omega$. Le capacità valgono: $C_1 = 5\mu F$, $C_2 = 0.5pF$, $C_4 = 0.5nF$.



1) ricavare l'espressione della funzione di trasferimento $W(s)=v_o(s)/v_{in}(s)$;
2) tracciare il diagramma di Bode asintotico dell'ampiezza e della fase di $W(s)$, (per la fase non usare l'approssimazione a gradino).
3) Calcolare $v_o(t)$ sapendo che $v_s = 2V + 1V{*}\sin(\omega_o t)$ con $\omega_o = 100$ rad/s.
4) Determinare il nuovo valore di C_2 che permetta di eliminare dalla $W(s)$ un polo e uno zero.

$$Z_1 = R_1 + \frac{1}{sC_1} = \frac{1 + sR_1C_1}{sC_1}$$

$$Z_2 = R_2 \,//\, \frac{1}{sC_2} = \frac{R_2 \cdot \frac{1}{sC_2}}{R_2 + \frac{1}{sC_2}} = \frac{R_2}{1 + sC_2R_2}$$

$$Z_{34} = R_3 \,//\, \frac{1 + sC_4R_4}{sC_4} = \frac{R_3 \cdot \frac{(1 + sC_4R_4)}{sC_4}}{R_3 + \frac{1 + sC_4R_4}{sC_4}} =$$

$$= \frac{R_3(1 + sC_4R_4)}{sC_4R_3 + 1 + sC_4R_4} = \frac{R_3(1 + sC_4R_4)}{1 + sC_4(R_3 + R_4)}$$

$$v_{o1} = v_s\left(-\frac{Z_2}{Z_1}\right) = v_s \cdot -\frac{sC_1R_2}{(1 + sC_1R_1)(1 + sC_2R_2)}\Bigg]$$

$$v_{o2} = v_{o1} \cdot \left(- \frac{Z_{34}}{R_3} \right) = v_{o1} \cdot \left[- \frac{1 + sC_4R_4}{1 + sC_4(R_3+R_4)} \right]$$

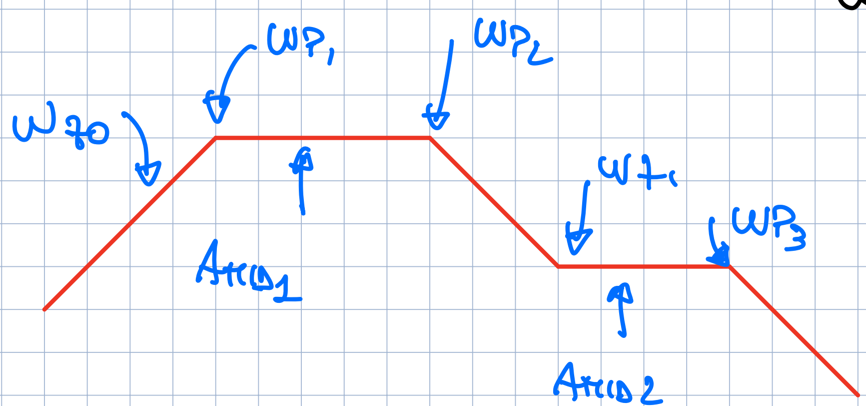
$$W(s) = \frac{V_o}{V_s} = \frac{sC_1R_2 \cdot (1+sC_4R_4)}{(1+sC_1R_1)(1+sC_2R_2)[1+sC_4(R_3+R_4)]}$$

$$\omega_{z0} = \frac{1}{C_1R_2} = 1 \text{ rad/sec} \qquad \omega_{P1} = \frac{1}{C R_1} = 10^2 \text{ rad/sec}$$

$$\omega_{P2} = \frac{1}{C_4(R_3+R_4)} = 10^4 \text{ rad/sec}$$

$$\omega_{z1} = \frac{1}{C_4R_4} = 10^5 \text{ rad/sec}$$

$$\omega_{P3} = \frac{1}{C_2R_2} = 10^7 \text{ rad/sec}$$

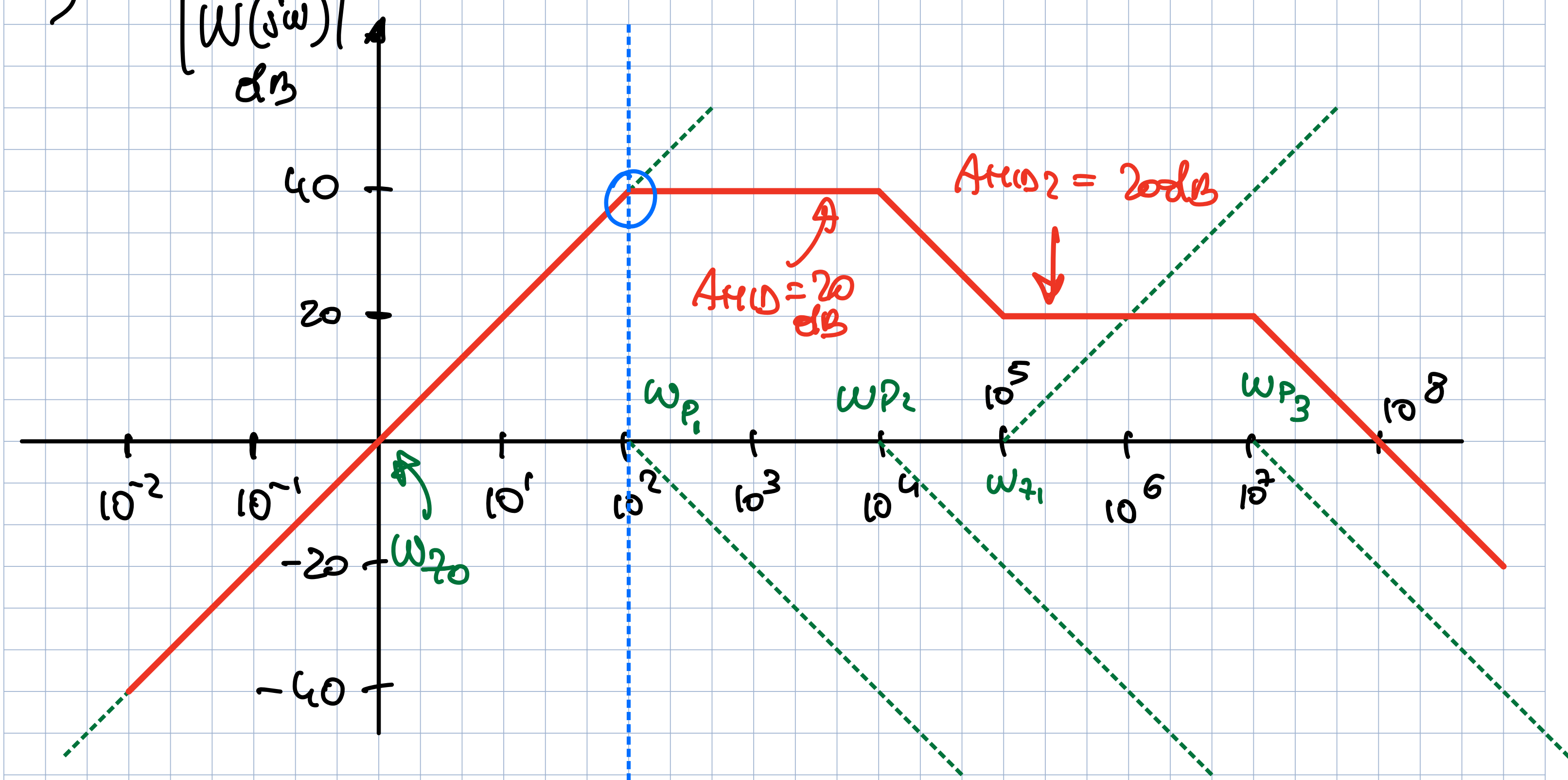


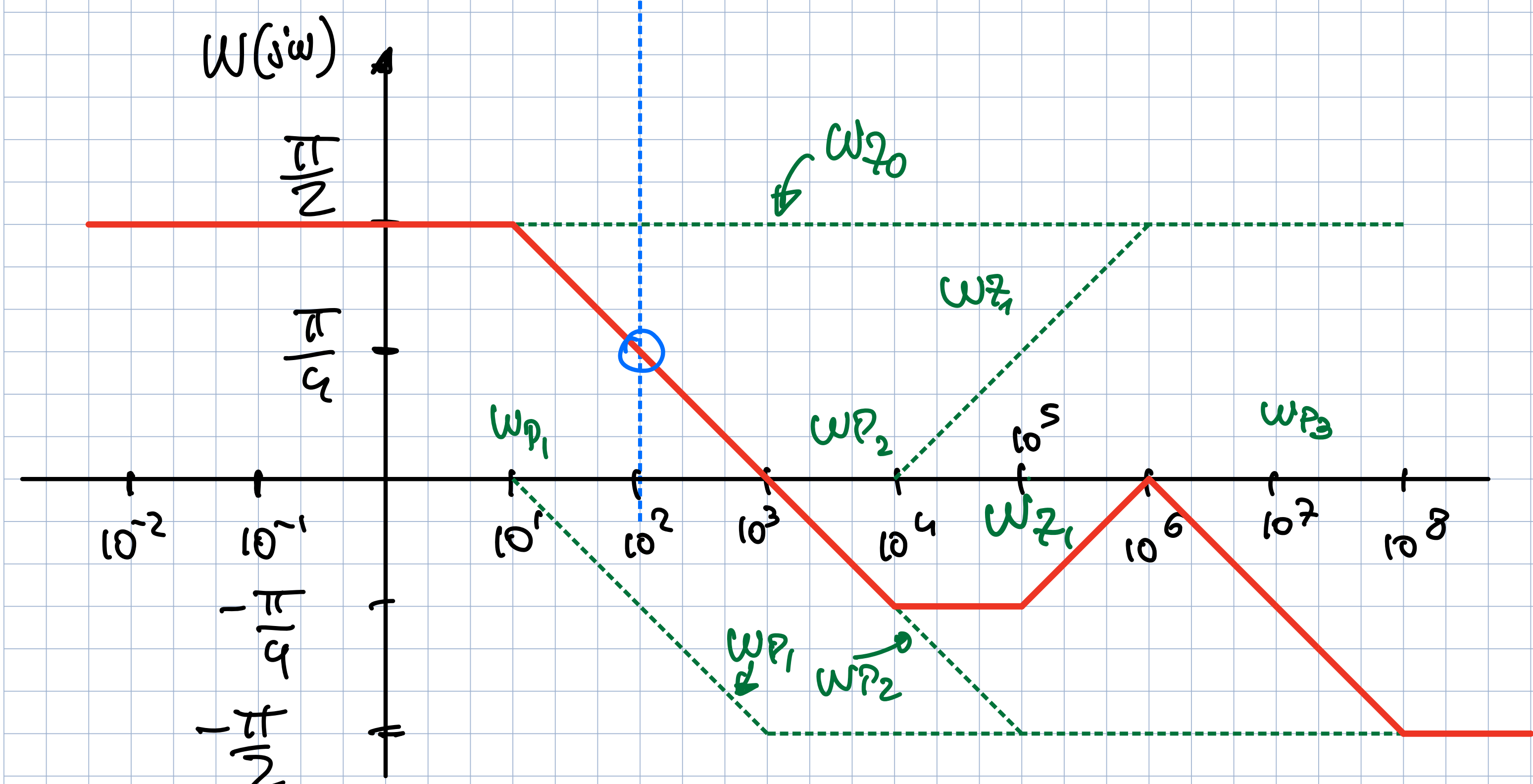
$$W(s) = \underbrace{\frac{\cancel{C_1}R_2}{\cancel{C_1}R_1}}_{A_{mid1}} \cdot \underbrace{\frac{s}{\frac{1}{C_1R_1} + s}}_{F_L(s)} \cdot \underbrace{\frac{(1+sC_4R_4)}{(1+sC_2R_2)[1+sC_4(R_3+R_4)]}}_{F_H(s)}$$

$$A_{mid1} = \frac{R_2}{R_1} = 10^2 = 40 \text{ dB}$$

$$A_{mid2} = \frac{R_2}{R_1} \cdot \frac{R_4}{R_3+R_4} = 10 = 20 \text{ dB}$$

2)





3) $v_s = 2V + 1V \sin(\omega_0 t)$ $\quad \omega_0 = 100$ rad/sec

$|W(j\omega_0)| = 40\,dB = 100$ $\quad$ (meglio se $\frac{100}{\sqrt{2}} = 70{,}7$)

$\angle W(j\omega_0) = \frac{\pi}{4}$

7

INOLTRE $W(0) = 0$

$$v_o(t) = 2V \cdot W(0) + |W(j\omega_0)| \cdot 1V \cdot \sin\left(\omega_0 t + \angle W(j\omega_0)\right)$$

$$= 100V \sin\left(\omega_0 t + \frac{\pi}{4}\right)$$

$\left(\text{o meglio } v_o(t) = 70{,}7V \sin\left(\omega_0 t + \frac{\pi}{2}\right)\right)$

4) PER ANNULLARE ZERO/POLO USANDO C_2

$$W(s) = \frac{v_o}{v_s} = \frac{sC_1R_2 \cdot (1+sC_4R_4)}{(1+sC_1R_1)(1+sC_2R_2)[1+sC_4(R_3+R_4)]}$$

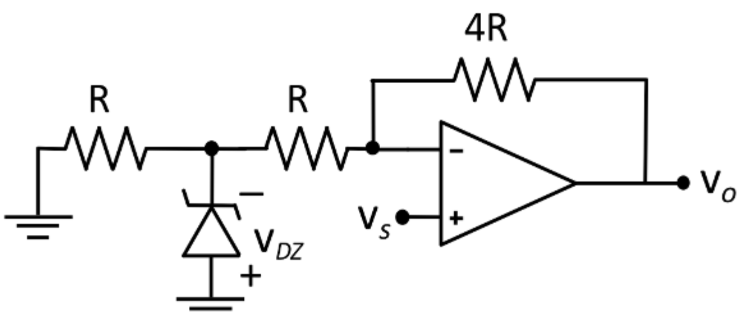
DEVO FAR SÌ CHE $C_4R_4 = C_2R_2$

$$\Rightarrow C_{2new} = C_4 \frac{R_4}{R_2} = 0{,}05\,nF = 50\,pF$$

PROBLEMA Q1

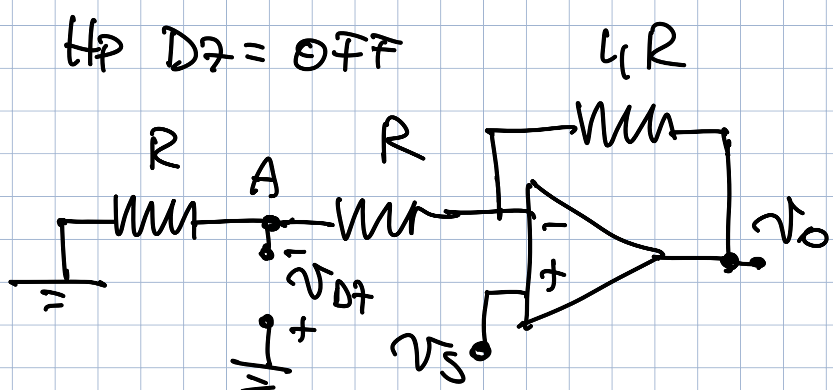
L'amplificatore in figura è realizzato con un amplificatore operazionale ideale e un diodo Zener ideale.

1) Determinare i valori della tensione di ingresso per la quale il diodo è ON, OFF e in Breakdown.
2) Determinare v_o quando $v_s = -5$ V.
3) (*facoltativo*) tracciare la transcaratteristica del circuito.



Dati: $R = 1\ k\Omega$, $V_{ON} = 0$, $V_Z = 5V$

Hp DZ = OFF



$$V_A = v_s \cdot \frac{R}{R+R} = \frac{v_s}{2}$$

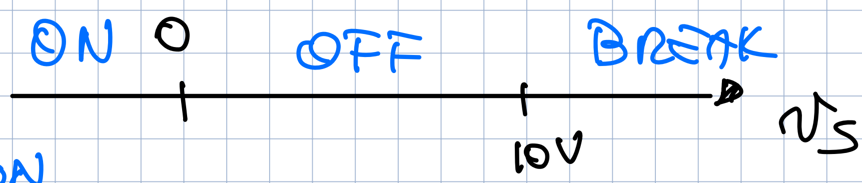
$$v_{DZ} = 0 - V_A = -\frac{v_s}{2}$$

$D_Z = ON \quad v_{DZ} \geq 0 \Rightarrow -\frac{v_S}{2} \geq 0 \Rightarrow v_S < 0$

$D_Z = BREAK \quad v_{DZ} < -V_Z \Rightarrow -\frac{v_S}{2} < -V_Z \Rightarrow v_S > 2V_Z$

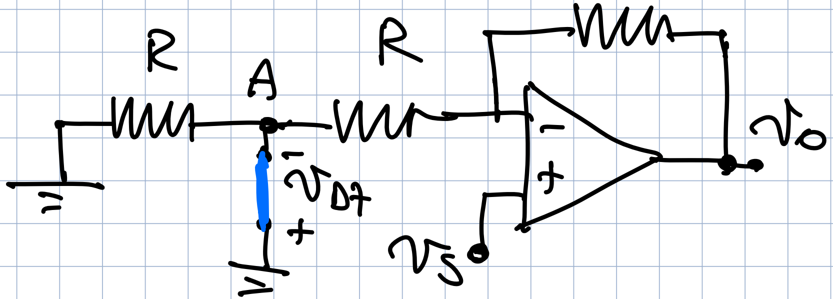
$v_S > 10V$

$D_Z = OFF \quad 0 \leq v_S \leq 10V$



2) $V_S = -5V \Rightarrow D_Z = ON$

Hp $D_Z = ON$



$$v_O = v_S\left(1 + \frac{4R}{R}\right) \overset{!}{=} 5v_S = -25V$$

3) FACOLTATIVO

Con $v_S < 0 \Rightarrow D_Z =$ "ON" $\Rightarrow v_O = 5v_S$ (vedi sopra)

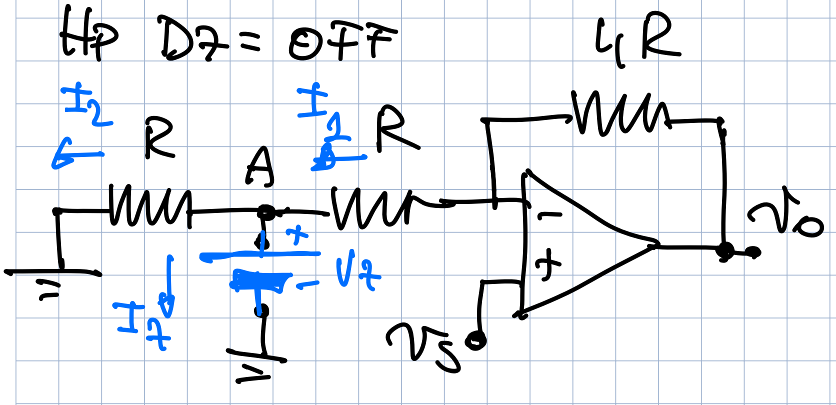
Con $0 \leq v_S \leq 10V \quad D_Z = OFF$

$$v_O = v_S\left(1 + \frac{4R}{2R}\right) = 3v_S$$

RACCORDO x $v_S = 0 \quad v_O(0^-) = 0 \quad v_O(0^+) = 0 \quad$ OK

Caso $v_S > 10\,V$

Hp D_Z = OFF



$$I_1 = \frac{v_S - V_Z}{R}$$

$$v_o = v_S + I_1\,4R$$

$$= v_S + \frac{v_S 4R}{R} - \frac{V_Z}{R}4R$$

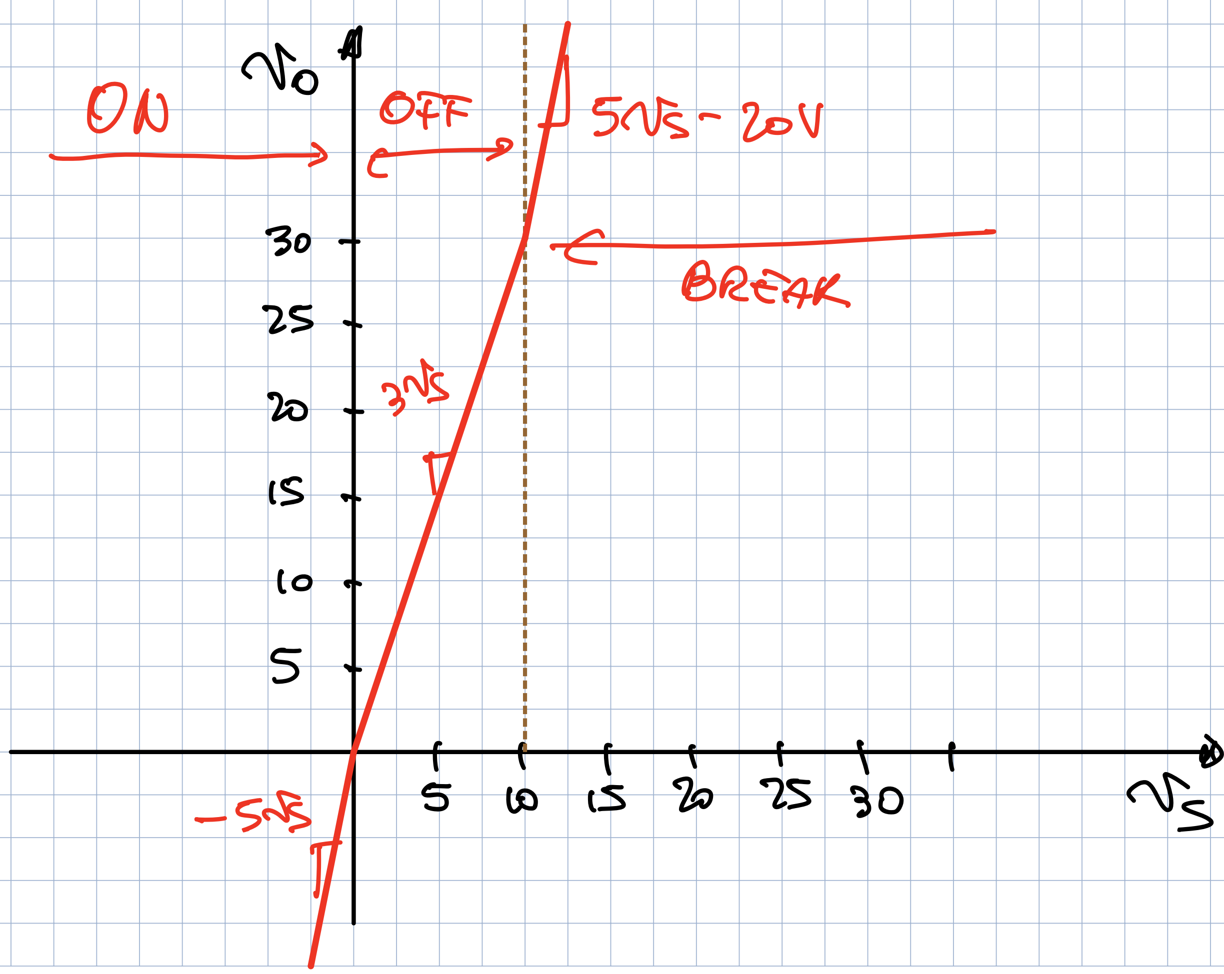
$$= 5v_S - 4V_Z$$

RACCORDO

$$v_o(10^-) = 3v_S = 30V$$

$$v_o(10^+) = 5v_S - 4V_Z = 50V - 20V = 30V$$

OK



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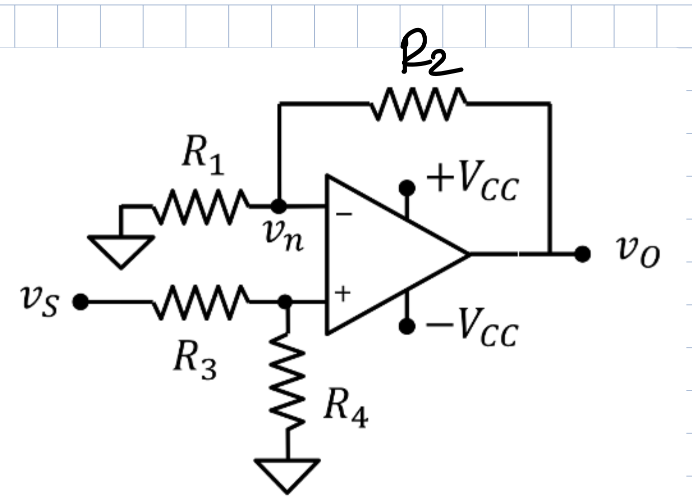
PROBLEMA Q2

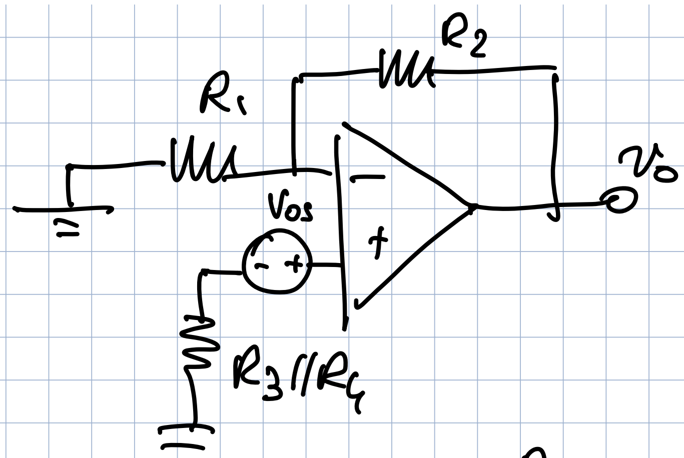
L'amplificatore in figura è realizzato usando un amplificatore operazionale reale con V_{OS} = 5mV e alimentato con tensione +/- V_{CC}. calcolare la tensione di uscita e la tensione del morsetto negativo v_n con:

1) $v_s = 0$ V,
2) $v_s = 4$V.



Dati: R_1 = 1 kΩ, R_2 = 10 kΩ, R_3 = 1 kΩ,
R_4 = 3 kΩ, V_{CC} = 10V.

1) $v_s = 0$



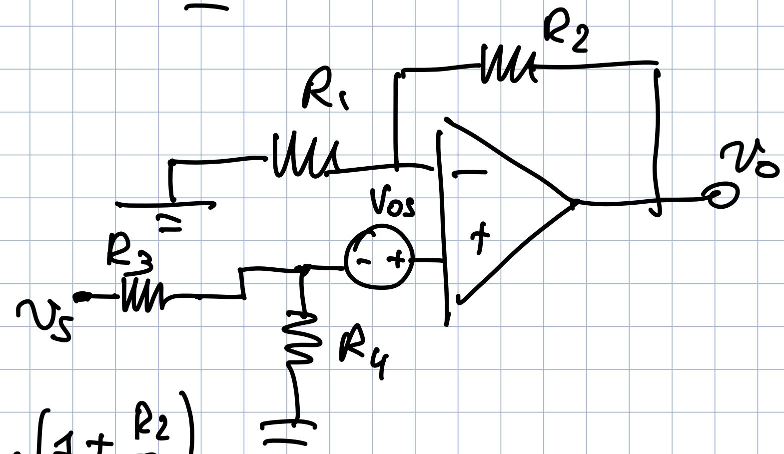
$v_+ = V_{os}$

$\Rightarrow v_{o_1} = V_{os}\left(1 + \frac{R_2}{R_1}\right) = 55\,mV$

$v_n = V_{os} = 5\,mV$

VALE $v_{id} = 0$

2) $v_s = 4V$



SOVRAPP. ~~EFFETTI~~

$$v_{o_2} = V_{os}\left(1 + \frac{R_2}{R_1}\right) + v_s \frac{R_4}{R_3 + R_4} \cdot \left(1 + \frac{R_2}{R_1}\right) = 55\,mV + 33\,V = 33{,}055\,mV > +V_{CC} \Rightarrow v_{o_2} = V_{CC} = 10V$$

SATURAZIONE DELL'A.O. $v_{id} \neq 0$!

$$v_n = v_O \cdot \frac{R_1}{R_1 + R_2} = V_{CC} \cdot \frac{R_1}{R_1 + R_2} = 0{,}909$$

$v_n \neq v_p$

NON VALE $v_{id} = 0$!

$$v_p = v_s \cdot \frac{R_4}{R_3 + R_4} + V_{os} \cong 3V$$

PROBLEMA Q3

Data la seguente mappa di Karnaugh

1) Trovare una F minimizzata
2) Disegnare la rete logica minimizzata tramite porte logiche fondamentali.

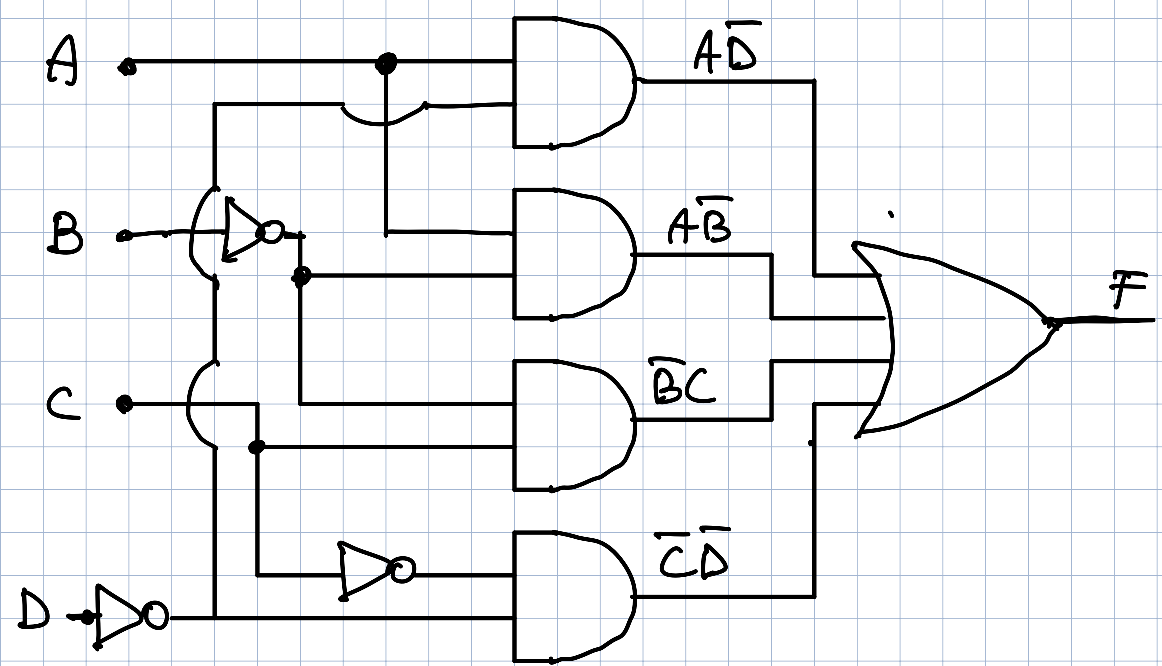
AB \ CD	00	01	11	10
00	1	0	1	1
01	1	0	0	0
11	X	0	0	1
10	1	1	X	1

$A\bar{D}$ $A\bar{B}$ $\bar{B}C$ $\bar{C}\bar{D}$

$F = A\bar{D} + A\bar{B} + \bar{B}C + \bar{C}\bar{D}$ (a)

$= \bar{B}(A+C) + \bar{D}(A+\bar{C})$ (b)

a)



b)