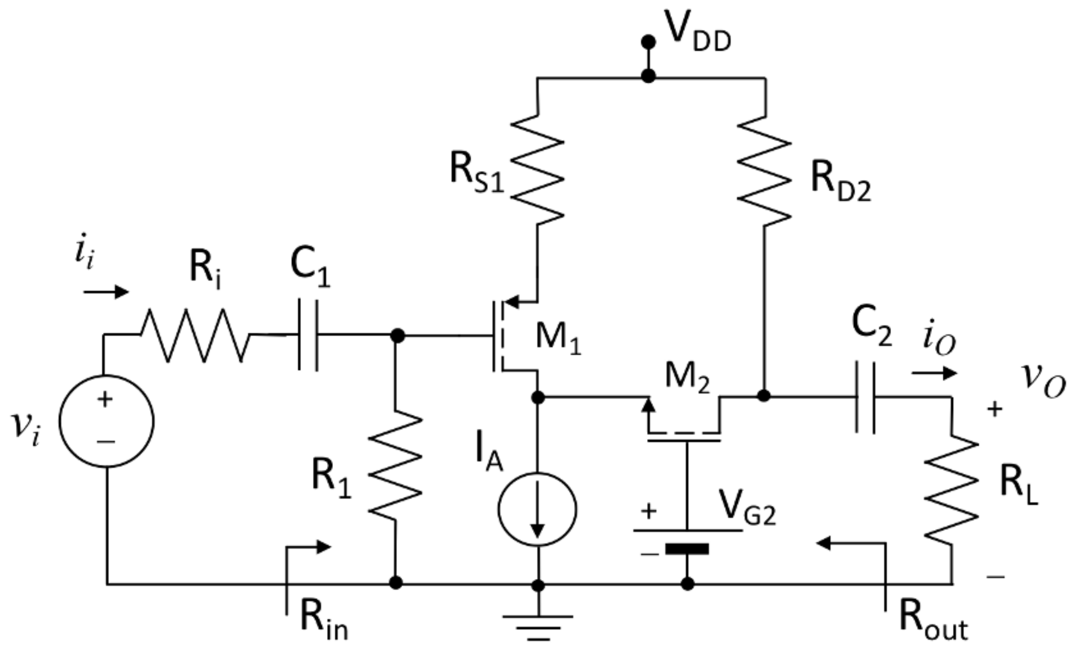
**PROBLEMA P1**

Dato il circuito riportato nella figura sottostante, determinare:

1) il punto di lavoro dei transistor $M_1$ e $M_2$ ;
2) la potenza erogata dal generatore di corrente $I_A$ ;
3) le resistenze di ingresso e uscita ai piccoli segnali ac $R_{in}$ e $R_{out}$ ;
4) il guadagno di tensione ai piccoli segnali ac $A_v = v_o/v_i$ ;
5) il guadagno di corrente ai piccoli segnali ac $A_i = i_o/i_i$ ;

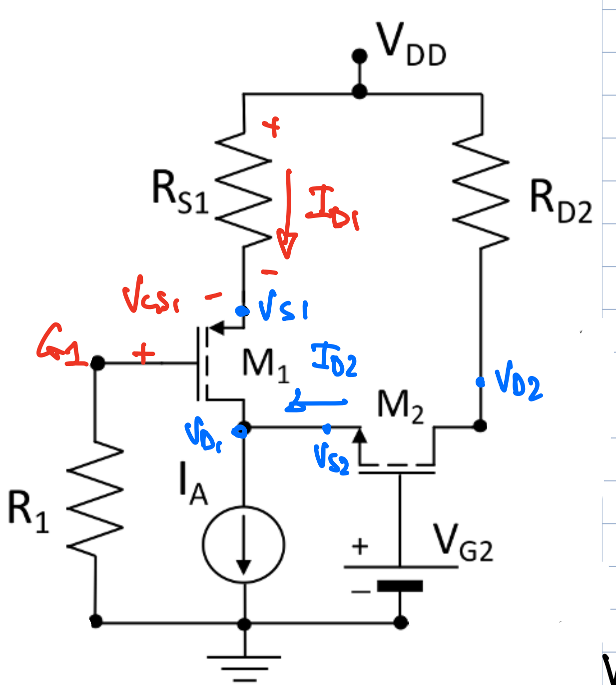



**Dati:**
$V_{DD}$=12 V,
$V_{G2}$=4 V,
$I_A$=16 mA
$R_i$ = 10 kΩ,
$R_1$ = 500 kΩ,
$R_{S1}$ =1 kΩ,
$R_{D2}$ =1 kΩ,
$R_L$ = 1 kΩ,

$M_1$: $k_{p1}$=4 mA/V$^2$,
$V_{TP1}$ = -2 V,
$\lambda_{p1}$=0 V$^{-1}$;

$M_3$: $k_{n2}$=4 mA/V$^2$,
$V_{TN2}$ = 2 V,
$\lambda_{n2}$ = 0 V$^{-1}$.

POLARIZZAZIONE




$I_{G1} = 0 \Rightarrow V_{G1} = 0$

$$\begin{cases} V_{DD} = I_{D1} R_{S1} - V_{GS1} \\ I_{D1} = \frac{K_{P1}}{2}\left(V_{GS1} - V_{TP1}\right)^2 \end{cases}$$

$$I_{D1} = \frac{V_{DD} + V_{GS1}}{R_{S1}}$$

$$\frac{2V_{DD}}{K_{P1}R_{S1}} + \frac{2V_{GS1}}{K_{P1}R_{S1}} = V_{GS1}^2 + V_{TP1}^2 - 2V_{GS}V_{TP1}$$

$$V_{GS1}^2 + V_{GS1}\left(-\frac{2}{K_{P1}R_{S1}} - 2V_{TP1}\right) + V_{TP1}^2 - \frac{2V_{DD}}{K_{P1}R_{S1}} = 0$$

$a = 1$ $\quad b = 3{,}5$ $\quad c = -2$

$$V_{GS1} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} = \frac{-3{,}5 \pm 4{,}5}{2} \begin{cases} \nearrow -4\ V \quad \text{OK} \\ \searrow \cancel{+\frac{1}{2}} \end{cases}$$

$$I_{D1} = \frac{K_{P1}}{2}\left(V_{GS1} - V_{TP1}\right)^2 = 2\,mA/V^2 \left(2V\right)^2 = \underline{\underline{8\,mA}}$$

$$I_{D1} + I_{D2} = I_A \Rightarrow I_{D2} = I_A - I_{D1} = 8\,mA$$

$$V_{GS2} = V_{TN2} + \sqrt{\frac{2 I_{D2}}{K_{n2}}} = 2V + \sqrt{\frac{16\,mA}{4\,mA/V^2}} = +4\,V$$

$$\Rightarrow V_{S2} = V_{G2} - V_{GS2} = 4V - 4V = 0V$$

$$V_{D1} = V_{S2} = 0\,V$$

$$V_{S1} = V_{DD} - I_{D1} R_{S1} = 12V - 8\,mA \cdot 1\,k\Omega = 4\,V$$

$$V_{D2} = V_{DD} - I_{D2} R_{D2} = 12\,V - 8\,mA \cdot 1\,k\Omega = 4\,V$$

$$\Rightarrow \begin{cases} V_{DS1} = V_{D1} - V_{S1} = -4\,V < V_{GS1} - V_{TP1} = -2V & \text{OK SAT} \\ V_{DS2} = V_{D2} - V_{S2} = 4V > V_{GS2} - V_{TN} = 2V & \text{OK SAT} \end{cases}$$

$$\boxed{\begin{aligned} M_1 &: \left(I_{D1} = 8\,mA,\ V_{DS1} = -4V\right) \\ M_2 &: \left(I_{D2} = 8\,mA,\ V_{DS2} = +4V\right) \end{aligned}}$$

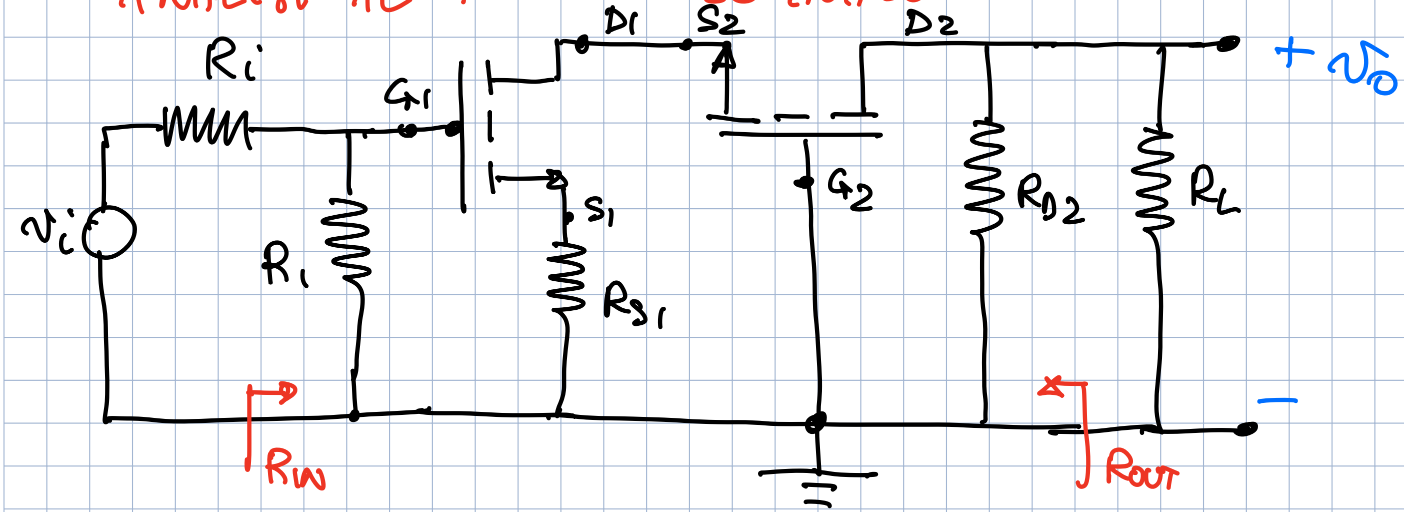
TENSIONE AI CAPI DI $I_A = 0 \Rightarrow \underline{P_{I_A} = 0 \cdot I_A = 0\,!}$

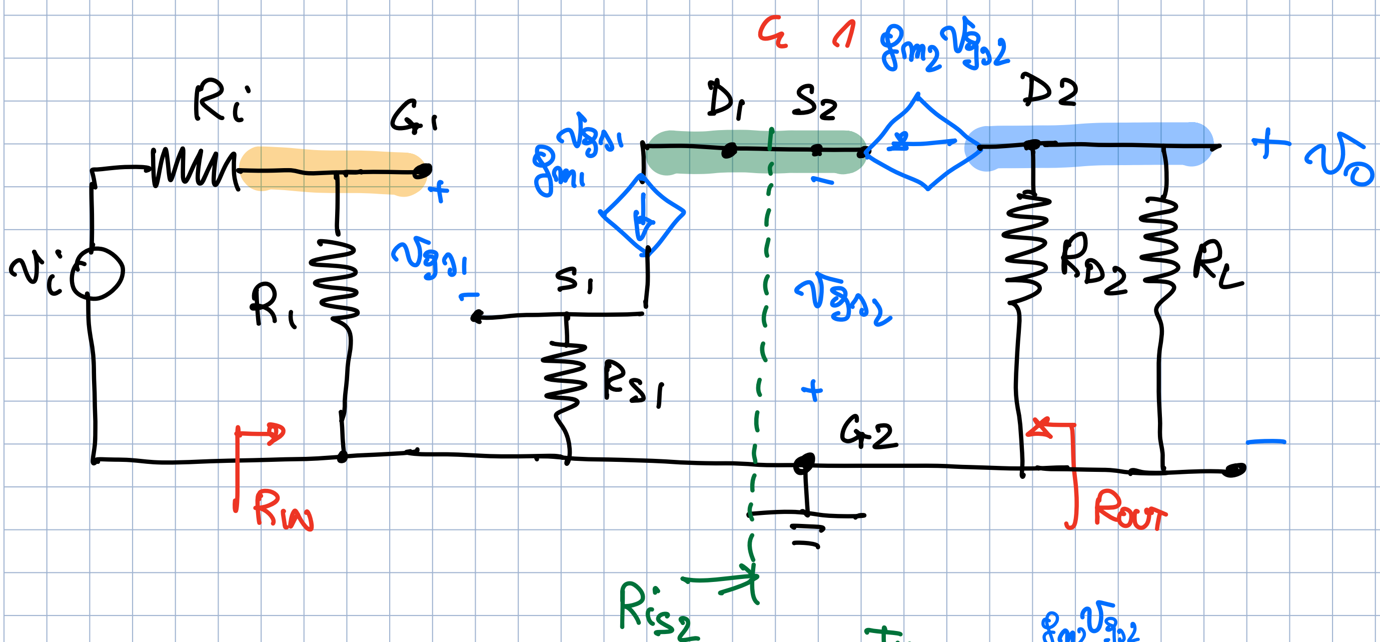
PARAMETRI AL PICCOLO SEGNALE

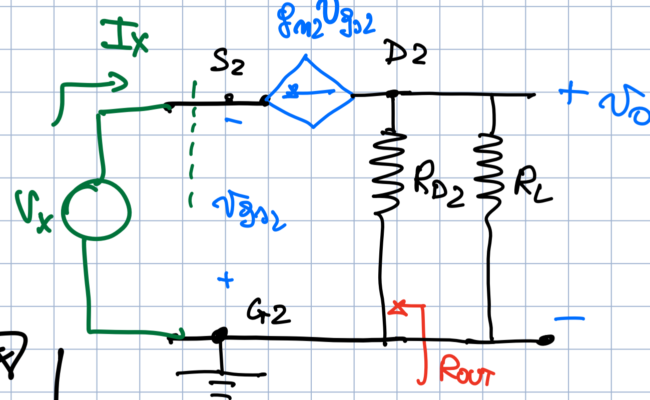
$$g_{m1} = \frac{2 I_{D1}}{|V_{GS1} - V_{TP1}|} = \frac{16\,mA}{2V} = 8\,mS = \sqrt{2 I_{D1} K_{P1}}$$

$$g_{m2} = \frac{2 I_{D2}}{V_{GS2} - V_{TN2}} = \frac{16\,mA}{2V} = 8\,mS = \sqrt{2 I_{D2} K_{N2}}$$

# ANALISI AL PICCOLO SEGNALE




$R_{IN} = R_1 = 500\ k\Omega$

$R_{OUT} = R_{D2} = 1\ k\Omega$

$R_{is_2} = \dfrac{1}{g_{m2}} = 125\ \Omega$

$I_x = -g_{m2} v_{gs2}$

$V_x = -v_{gs2}$

$\boxed{\Rightarrow \dfrac{V_x}{I_x} = \dfrac{1}{g_{m2}}}$

$A_v = \dfrac{v_o}{v_i} = \dfrac{v_o}{v_{s2}} \cdot \dfrac{v_{s2}}{v_{G1}} \cdot \dfrac{v_{G1}}{v_i}$

$v_o = v_{D2}$

$v_{s2} = v_{D1}$

$$A_V = \frac{v_{D2}}{v_{S2}} \cdot \frac{v_{D1}}{v_{G1}} \cdot \frac{v_{G1}}{v_i} = \underbrace{\overset{CG}{A_{VE}} \cdot \overset{CS+RS}{A_{VE}} \cdot \frac{v_{G1}}{v_i}}$$

$$\overset{CG}{A_{VE}} = \frac{v_{D2}}{v_{S2}} = \frac{-g_{m2} v_{gs2} R_{D2} // R_L}{-v_{gs2}} = +g_{m2} R_{D2} // R_L = 4$$

$$\overset{CS+RS}{A_{VE}} = \frac{v_{D1}}{v_{G1}} = \frac{-g_{m1} v_{gs1} \cdot R_{iS2}}{v_{gs1}(1+g_{m1} R_{S1})} = -\frac{g_{m1} R_{iS2}}{1+g_{m1} R_{S1}} = -0{,}111$$

$$\frac{v_{G1}}{v_i} = \frac{R_1}{R_1 + R_i} = 0{,}98$$

$$\Rightarrow \boxed{A_V = -0{,}436}$$

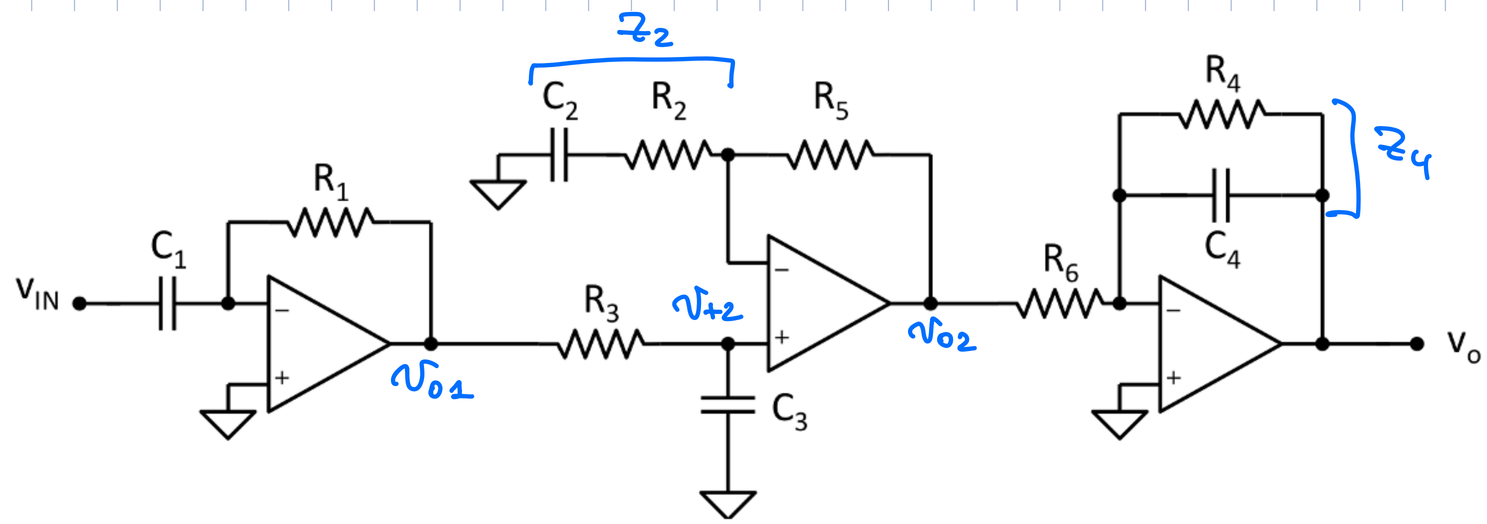
$$\left(\frac{510}{1} = 51\right)$$

$$A_I = \frac{i_o}{i_i} = \frac{\frac{v_o}{R_L}}{\frac{v_i}{R_i + R_1}} = -A_V \cdot \frac{R_i + R_1}{R_L} = -222{,}2$$

**PROBLEMA P2**

Sia dato il circuito nella figura di pagina seguente che usa amplificatori operazionali e componenti passivi ideali. Le resistenze hanno valore $R_1 = R_2 = R_3 = R_4 = R_6 = 10k\Omega$ e $R_5 = 90k\Omega$. Le capacità valgono: $C_1 = 10nF$, $C_2 = 1\mu F$, $C_3 = 100nF$ e $C_4 = 0.1nF$.

1) ricavare l'espressione della funzione di trasferimento $W(\omega)=v_o(\omega)/v_{in}(\omega)$;
2) tracciare il diagramma di Bode asintotico dell'ampiezza e della fase di W, usando, nel caso della fase, l'approssimazione senza discontinuità.
3) Modificare in modo opportuno il valore di $C_1$ affinché il diagramma di Bode del modulo (asintotico) calcolato in $\omega = 10^5$ rad/s sia pari a 40dB.




$$Z_2 = \frac{1}{sC_2} + R_2 = \frac{1+sC_2R_2}{sC_2} \qquad Z_4 = \frac{\frac{1}{sC_4}\cdot R_4}{\frac{1}{sC_4}+R_4} = \frac{R_4}{1+sC_4R_4}$$

$$v_{o1} = -V_{IN}\cdot\frac{R_1}{\frac{1}{sC_1}} = -sC_1R_1V_{IN}$$

$$v_{+2} = v_{o1}\cdot\frac{\frac{1}{sC_3}}{R_3+\frac{1}{sC_3}} = \frac{-sC_1R_1}{1+sC_3R_3}V_{IN}$$

$$v_{o2} = v_{+2}\cdot\left(1+\frac{R_5}{Z_2}\right) = v_{+2}\left(1+\frac{sC_2R_5}{1+sC_2R_2}\right)$$

$$= -\frac{sC_1R_1}{1+sC_3R_3}\cdot\frac{1+sC_2(R_2+R_5)}{1+sC_2R_2}V_{IN}$$

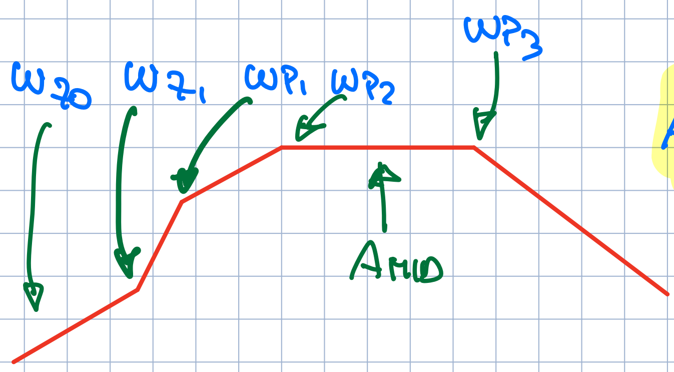
$$V_o = v_{o2}\cdot -\frac{Z_4}{R_6} = -v_{o2}\cdot\frac{R_4}{R_6}\cdot\frac{1}{1+sC_4R_4}$$

$$\Rightarrow W(s) = \frac{v_o}{V_{IN}} = \boxed{\frac{R_4}{R_6}\cdot\frac{(sC_1R_1)\left[1+sC_2(R_2+R_5)\right]}{(1+sC_2R_2)(1+sC_3R_3)(1+sC_4R_4)}}$$

$$\omega_{z0} = \frac{1}{R_1C_1} = 10^4 \text{ rad/sec} \qquad \omega_{P1} = \frac{1}{R_2C_2} = 10^2 \text{ rad/sec}$$

$$\omega_{P2} = \frac{1}{R_3C_3} = 10^3 \text{ rad/sec}$$

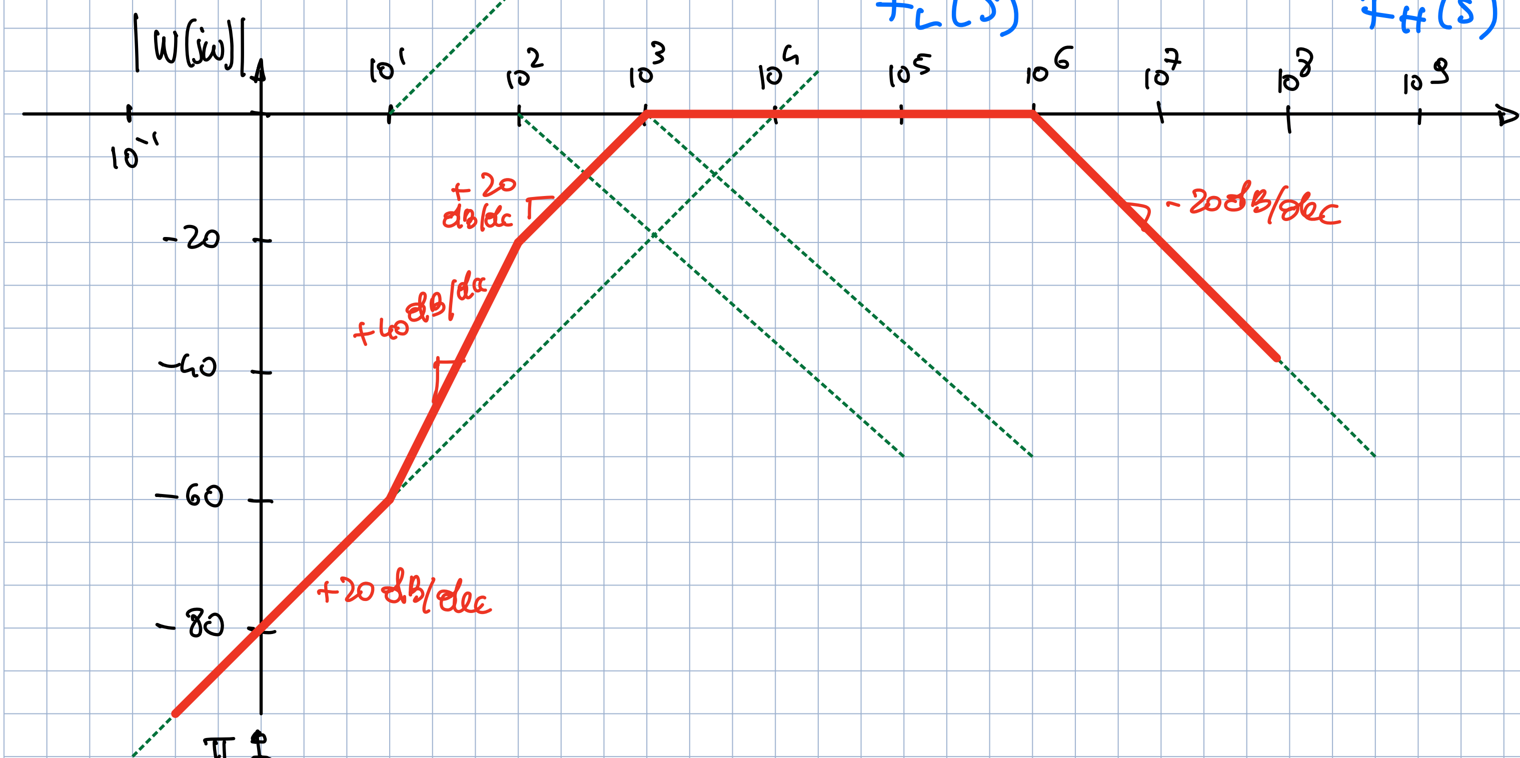
$$\omega_{z1} = \frac{1}{C_2(R_2+R_5)} = 10 \text{ rad/sec} \qquad \omega_{P3} = \frac{1}{R_4C_4} = 10^6 \text{ rad/sec}$$

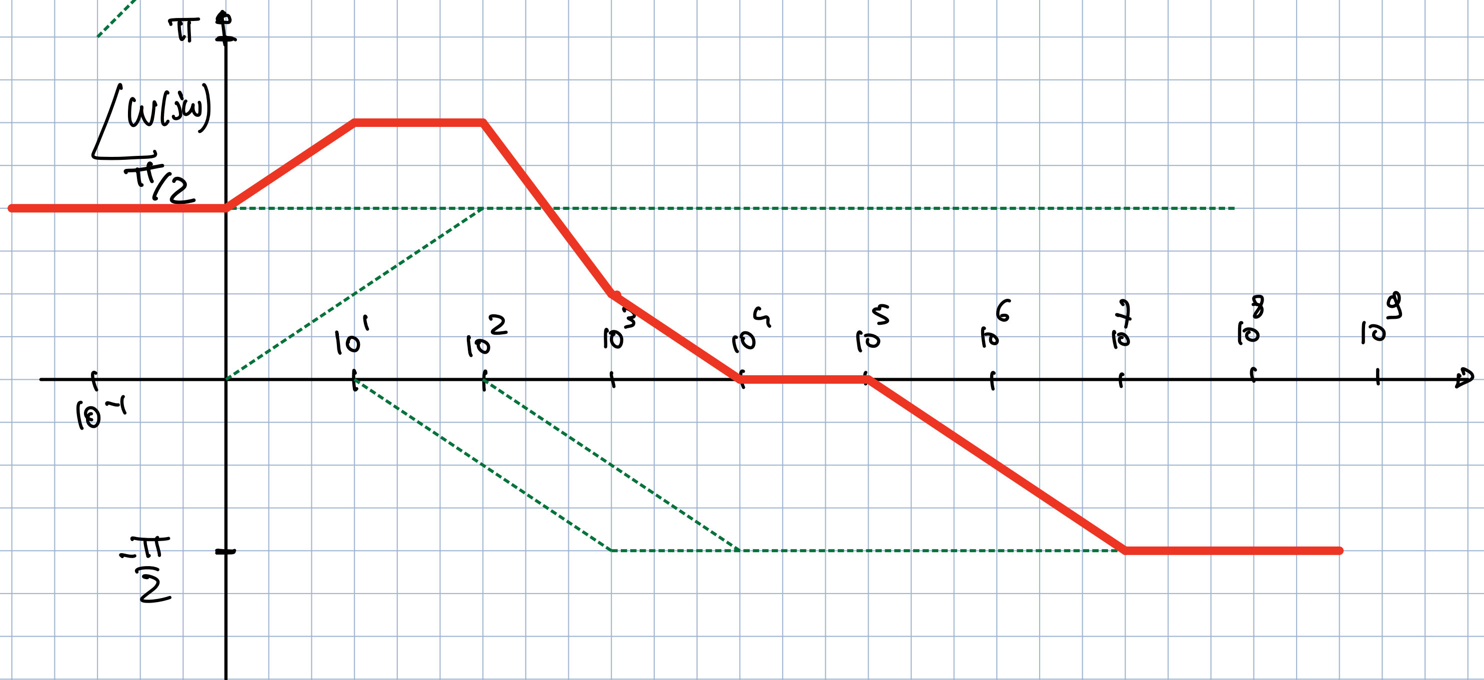



$$A_{MID} = \frac{C_1R_1 \cdot C_2(R_2+R_5)}{C_2R_2 \cdot C_3R_3} = 1$$

$C_{1NEW} = 100 \times C_1$ !

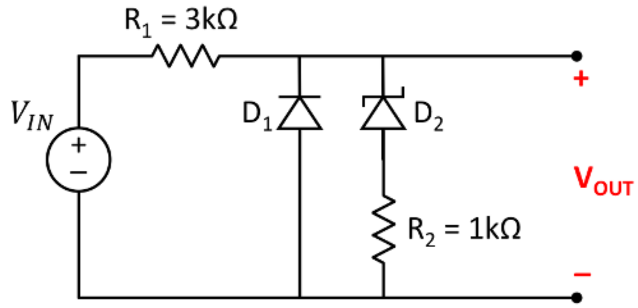
$$W(s) = \underbrace{\frac{C_1R_1 \cdot C_2(R_2+R_5)}{C_2R_2 \cdot C_3R_3}}_{A_{MID}} \cdot \underbrace{\frac{s \cdot \left[\frac{1}{C_2(R_2+R_5)} + s\right]}{\left(\frac{1}{C_2R_2} + s\right)\left(\frac{1}{C_3R_3} + s\right)}}_{F_L(s)} \cdot \underbrace{\frac{1}{1+sC_4R_4}}_{F_H(s)}$$



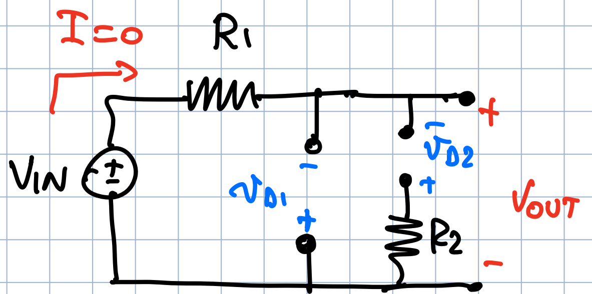



**PROBLEMA Q1**

Sia dato il circuito in figura composto da un diodo ideale $D_1$ ($V_{ON} = 0V$) ed uno diodo Zener $D_2$ ($V_{ON} = 0V$ e $V_Z = 2V$). Trovare le regioni di funzionamento dei diodi e tracciare la tensione di uscita $V_{OUT}$ per $V_{IN}$ compreso tra –10V e +10V.




HP D1 e D2 = OFF




$\Rightarrow v_{D1} = -V_{IN}$

$v_{D2} = -V_{IN}$

$\Rightarrow V_{IN} > 0 \Rightarrow v_{D1} < 0$ e $v_{D2} < 0 \Rightarrow \boxed{V_{OUT} = V_{IN}}$

TUTTAVIA D2 È ZENER $\Rightarrow$ QUANDO $v_{D2} < -V_Z$

$\Rightarrow$ D2 = BREAK //

$\Rightarrow v_{D2} < -V_Z \Rightarrow -V_{IN} < -V_Z \Rightarrow \underline{\underline{V_{IN} > V_Z}}$

QUANDO $V_{IN} > V_Z \Rightarrow$ D2 VA IN BREAK. ~~ZENER~~

$\Rightarrow$ ① $0 \leq V_{IN} \leq V_Z$ D1 e D2 = OFF

$V_{OUT} = V_{IN}$ $(m = 1,\ q = 0)$

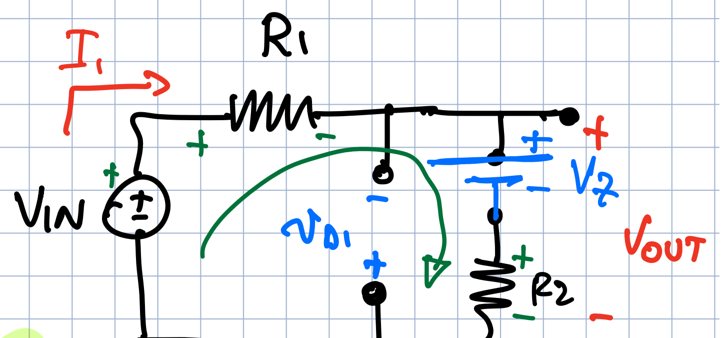
RACCORDI: $V_{OUT}(0) = 0$ $V_{OUT}(V_Z) = V_Z = 2V$

$\Rightarrow$ ② $V_{IN} > V_Z$

D1 = OFF D2 = BREAK.

$-V_{IN} + R_1 I_1 + V_Z + R_2 I_1 = 0$

$\Rightarrow I_1 = \dfrac{V_{IN} - V_Z}{R_1 + R_2}$




$V_O = V_Z + R_2 I_1$

$$V_o = V_{IN}\frac{R_2}{R_1+R_2} + V_Z - V_Z\frac{R_2}{R_1+R_2}$$

$$= V_{IN}\frac{R_2}{R_1+R_2} + V_Z\frac{R_1}{R_1+R_2} = \frac{1}{4}V_{IN} + \frac{3}{4}V_Z$$

$$= 0{,}25\,V_{IN} + 1{,}5\,V \qquad (V_{IN} > V_Z)$$

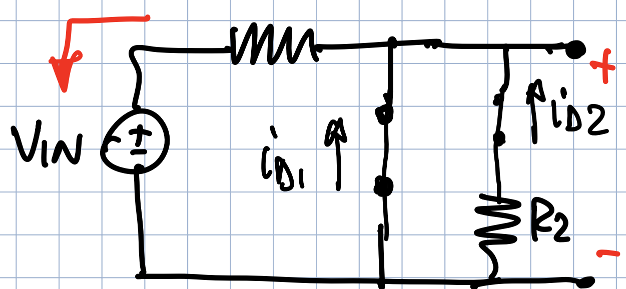
$m = 0{,}25 \qquad q = 1{,}5$

RACCORDO $V_O(V_Z) = V_O(2) = (0{,}5+1{,}5)\,V = 2\,V$

OK RACCORDO

(3) CON $V_{IN} < 0$ $\qquad D_1 = D_2 = ON$

$\boxed{V_{OUT} = 0}$ $\qquad m = 0$, $q = 0$



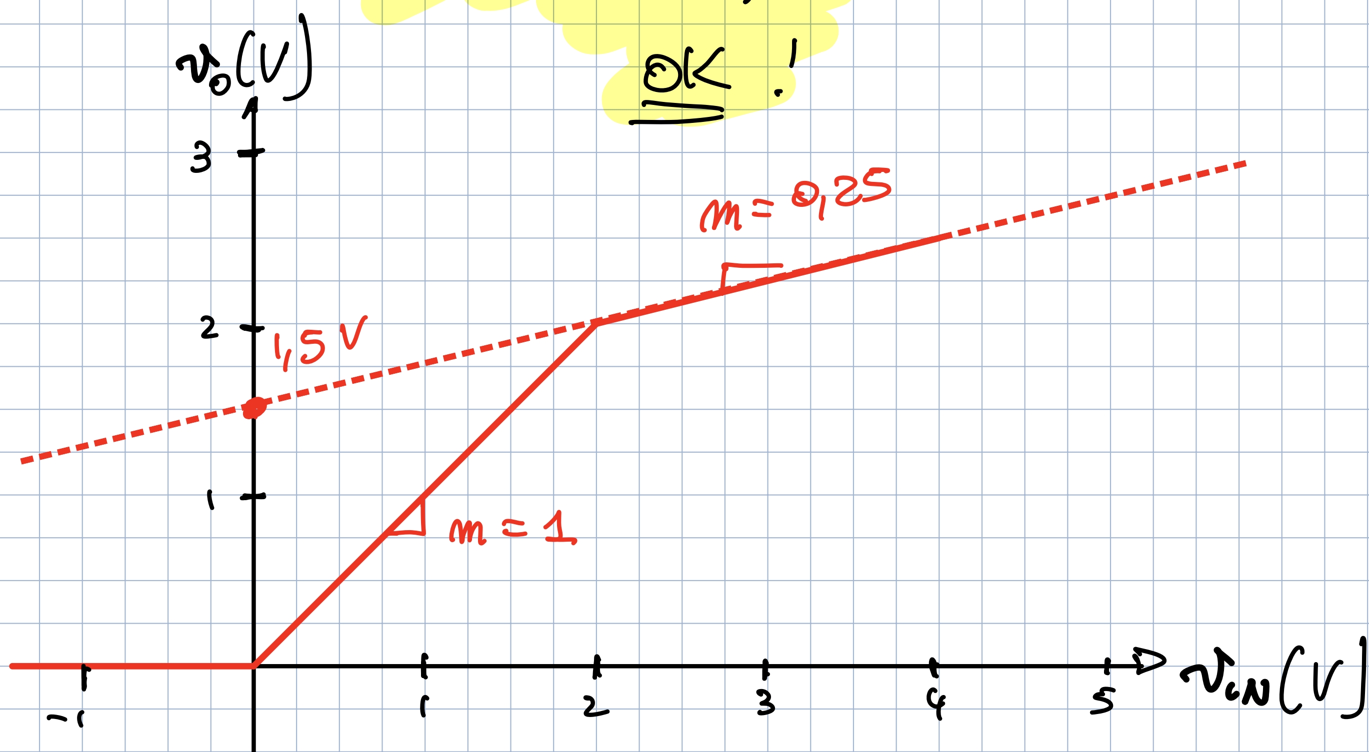

$\Rightarrow i_{D2} = 0 \quad (i_{R_2} = 0)$

$i_{D1} = -\frac{V_{IN}}{R_1} > 0$

OK $D_1 = ON$

RACCORDO $V_o(0) = 0$

OK !



## PROBLEMA Q2

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 | X | | 1 | 1 |
| 01 | | X | 1 | 1 |
| 11 | 1 | 1 | X | |
| 10 | 1 | X | 1 | X |

$\bar{A}C$

$A\bar{C}$

$CD$

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