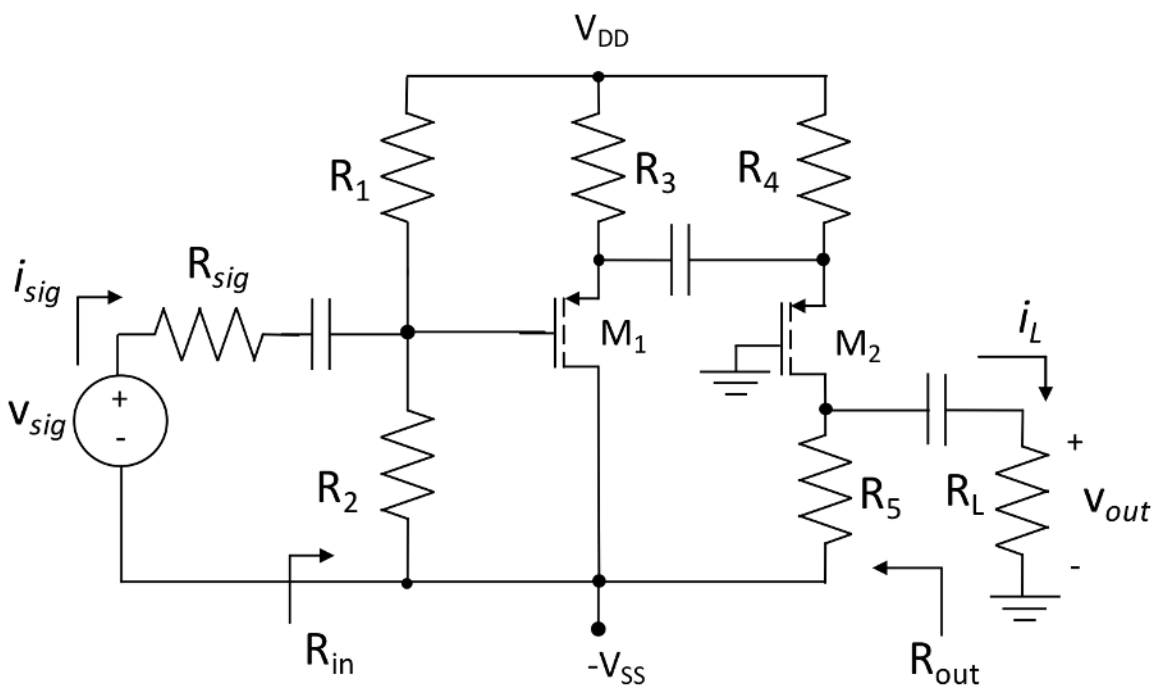
PROBLEMA P1

Dato il circuito riportato nella figura sottostante, determinare:

1) il valore della resistenza R_3 in modo che la corrente di drain di M_1 valga I_{D1} = 5 mA;
2) il punto di lavoro dei transistor M_1, M_2,
3) il guadagno di tensione ai piccoli segnali ac $A_v = v_{out}/v_{sig}$;
4) Il guadagno di corrente $A_i = i_L/i_{sig}$;
5) le resistenze di ingresso e uscita ai piccoli segnali ac R_{in} e R_{out}.



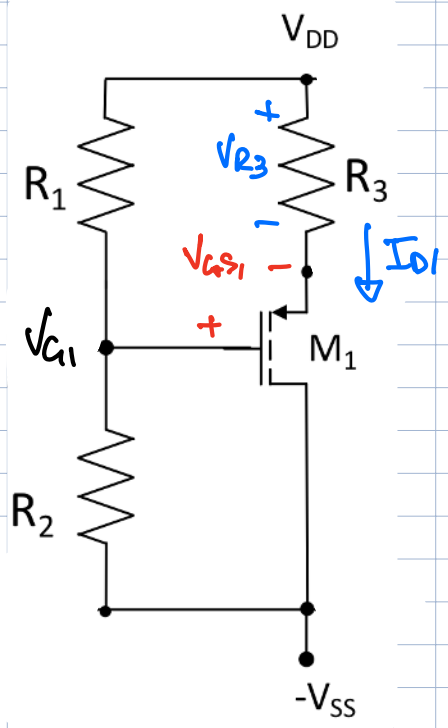
Dati:

V_{DD}=12 V
V_{SS}=12 V
R_1=200 kΩ,
R_2=200 kΩ,
R_4=2 kΩ,
R_5=1.0 kΩ,
R_L=1.0 kΩ,
R_{sig}= 1.0 kΩ,

M_1: k_{p1}=10 mA/V^2,
V_{TP1} = -1 V,
λ_{p1}=0 V^{-1};

M_2: k_{p2}=5 mA/V^2,
V_{TP2} = -2 V,
λ_{p2}=0 V^{-1};

POLARIZZAZIONE:



$$V_{G1} = V_{DD} \cdot \frac{R_2}{R_1+R_2} - V_{SS} \frac{R_1}{R_1+R_2} = \frac{V_{DD}}{2} - \frac{V_{SS}}{2} = 0\,V$$

$$I_{D1} = \frac{K_{P1}}{2}\left(V_{GS1} - V_{TP1}\right)^2$$

$$\Rightarrow V_{GS1} = V_{TP2} - \sqrt{\frac{2I_{D1}}{K_P}} = -1V - 1V = -2V$$

$$V_{GS1} = V_{G1} - V_{S1} = -V_{S1} \quad (V_{G1}=0)$$

$$\Rightarrow V_{S1} = -V_{GS1} = 2V$$

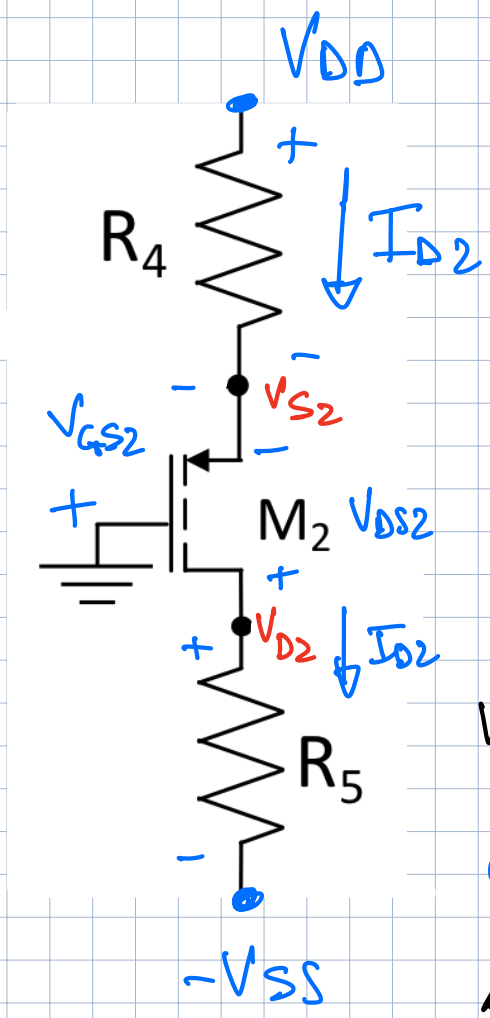
$$V_{S1} = V_{DD} - V_{R3} = V_{DD} - R_3 I_{D1} \Rightarrow \boxed{R_3 = \frac{V_{DD} - V_{S1}}{I_{D1}} = \frac{10V}{5mA} = 2k\Omega}$$

$$\boxed{V_{DS1} = -V_{SS} - V_{S1} = -14\,V}$$

$V_{DS1} < V_{GS1} - V_{TP1}$?

$-14\,V < -1\,V$ OK

M1 IN SATURAZ.



$$V_{DD} = R_4 I_{D2} - V_{GS2}$$

$$\Rightarrow \begin{cases} I_{D2} = \dfrac{V_{DD} + V_{GS2}}{R_4} \\ I_{D2} = \dfrac{K_{P2}}{2}\left(V_{GS2} - V_{TP2}\right)^2 \end{cases}$$

$$\frac{2(V_{DD} + V_{GS2})}{R_4 K_P} = V_{GS2}^2 + V_{TP2}^2 - 2V_{GS2}V_{TP2}$$

$$V_{GS2}^2 + V_{GS2}\left(-\frac{2}{R_4 K_{P2}} - 2V_{TP2}\right) + V_{TP2}^2 - \frac{2V_{DD}}{R_4 K_{P2}} = 0$$

$a = 1$ $\quad b = 3{,}8$ $\quad c = 1{,}6$

$$\Delta = (3{,}8)^2 - 4 \times 1{,}6 = 8{,}04$$

$$\boxed{V_{GS2} = \frac{-b - \sqrt{\Delta}}{2a} = \frac{-3{,}8 - 2{,}84}{2}\,V = -3{,}32\,V}$$

$$\boxed{I_{D2} = \frac{K_{P2}}{2}\left(V_{GS2} - V_{TP2}\right)^2 = 4{,}34\,mA}$$

$$V_{S2} = V_{DD} - R_4 I_{D2} = 3{,}32\,V$$

$$V_{D2} = -V_{SS} + R_5 I_{D2} = -7{,}66\,V$$

$$\boxed{V_{DS2} = V_{D2} - V_{S2} = -10{,}98\,V} < V_{GS2} - V_{TP2} \ ?$$

$-10{,}98 < -1{,}32\,V$

OK M2 IN SATURAZ

M_1: $I_{D_1} = 5\,mA$, $V_{DS_1} = -14\,V$, $V_{GS_1} = -2\,V$.

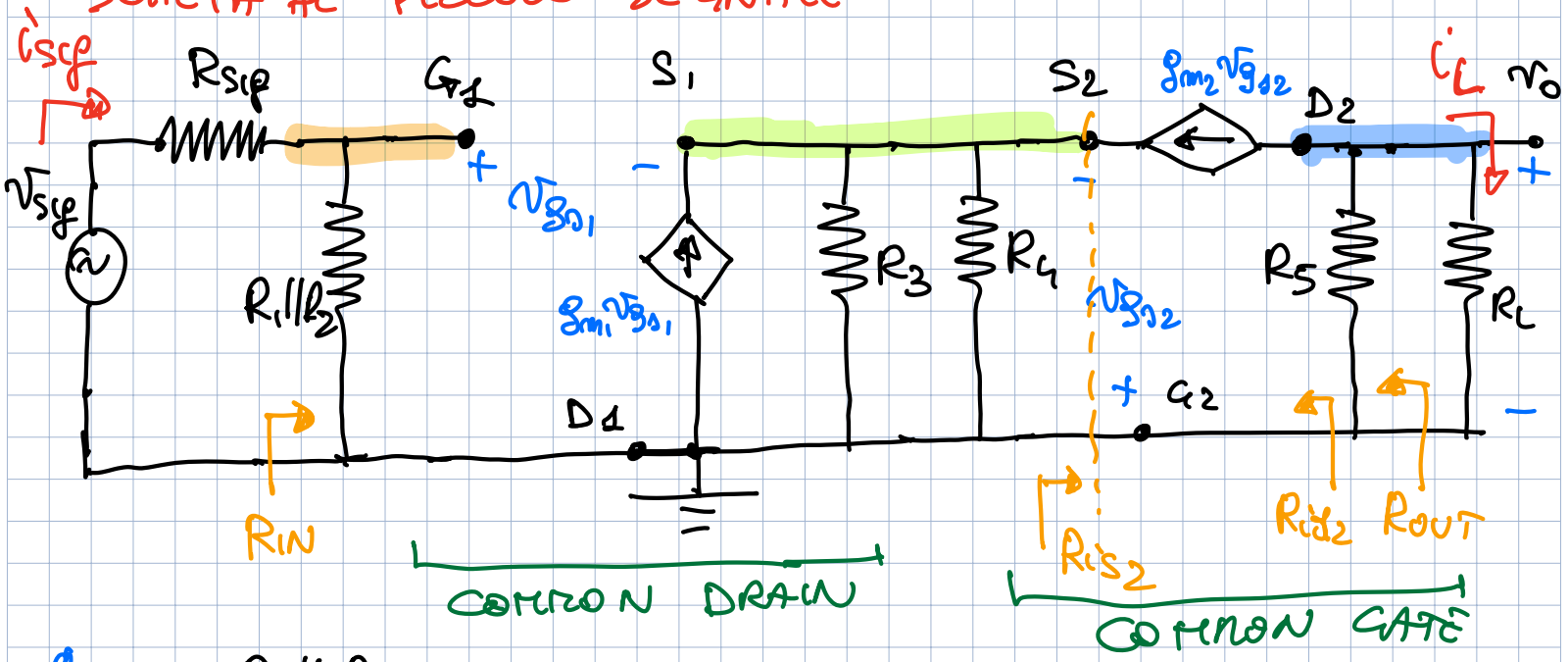
M_2: $I_{D_2} = 4{,}34\,mA$, $V_{DS_2} = -10{,}98\,V$, $V_{GS_2} = -3{,}32\,V$.

ANALISI AL PICCOLO SEGNALE

$$g_{m_1} = \frac{2I_{D_1}}{V_{GS_1} - V_{TP_1}} = \sqrt{2I_{D_1}K_{P_1}} = 10\,mS \;;\; r_{o_1} = \infty$$

$$g_m = \frac{2I_{D_2}}{V_{GS_2} - V_{TP_2}} = \sqrt{2I_{D_2}K_{P_2}} = 6{,}59\,mS \;;\; r_{o_2} = \infty$$

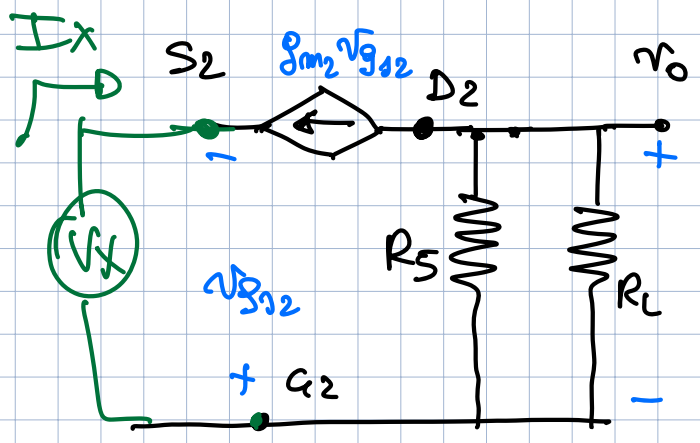
SCHEMA AL PICCOLO SEGNALE



$R_{IN} = R_1 // R_2$

$R_{OUT} = R_5$ (IN QUANTO $R_{id_2} = \infty$ con $r_o = \infty$)

$R_{is_2} = 1/g_{m2}$



$I_x = -g_{m_2} v_{gs2}$

$V_x = -v_{gs2}$

$$\frac{V_x}{I_x} = \frac{1}{g_{m2}}$$

$$R_{L1} = R_3 // R_4 // R_{is2} = R_3 // R_4 // \frac{1}{g_{m2}} = 131{,}8\ \Omega$$

$$R_{L2} = R_5 // R_L = 0{,}5\ k\Omega$$

$$A_v = \frac{v_o}{v_{sig}} = \frac{v_{D2}}{v_{S2}} \cdot \frac{v_{S2}}{v_{G1}} \cdot \frac{v_{G1}}{v_{sig}} \qquad v_{S2} = v_{S1}$$

$$= \overset{CG}{A_v} \cdot \overset{CD}{A_v} \cdot \alpha$$

$$\alpha = \frac{R_1 // R_2}{R_{sig} + R_1 // R_2} = \underline{\underline{0{,}99}}$$

$$\overset{CD}{A_v} = ? \qquad v_{S2} = g_{m1} v_{gs1} R_{L1}$$

$$v_{G1} = v_{gs1} + g_{m1} v_{gs1} R_{L1}$$

$$\Rightarrow \overset{CD}{A_v} = \frac{v_{S2}}{v_{G1}} = \frac{g_{m1} R_{L1}}{1 + g_{m1} R_{L1}} = \underline{\underline{0{,}569}}$$

$$\overset{CG}{A_v} = ? \qquad v_{D2} = -g_{m2} v_{gs2} R_{L2}$$

$$v_{S2} = -v_{gs2}$$

$$\Rightarrow \overset{CG}{A_v} = \frac{v_{D2}}{v_{S2}} = g_{m2} R_{L2} = \underline{\underline{3{,}284}}$$

$$\Rightarrow \boxed{A_v = \overset{CG}{A_v} \cdot \overset{CD}{A_v} \cdot \alpha = 1{,}854}$$

$$A_i = \frac{i_L}{i_{sig}} = \frac{\frac{v_o}{R_L}}{\frac{v_{sig}}{R_{sig}+R_1 \| R_2}} = A_v \cdot \frac{\overbrace{R_{sig}+R_1\|R_2}^{=101}}{R_L} = 187{,}3$$

IN ALTERNATIVA:

$$i_L = -g_{m2} v_{gs2} \frac{R_S}{R_S+R_L}$$

$$v_{gs2} = -g_{m1} v_{gs1} \cdot R_{L1}$$

$$v_{gs1} = i_{sig} \cdot R_1\|R_2 - g_{m1} v_{gs1} R_{L1}$$

$$v_{gs1}(1+g_{m1}R_{L1}) = i_{sig} R_1\|R_2$$

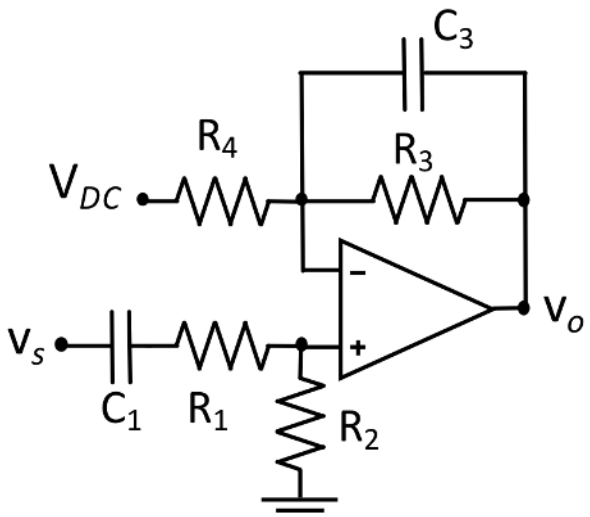
$$v_{gs1} = \frac{i_{sig} R_1\|R_2}{1+g_{m1}R_{L1}}$$

$$\frac{i_L}{i_{sig}} = R_1\|R_2 \cdot \frac{g_{m1}R_{L1}}{1+g_{m1}R_{L1}} \cdot g_{m2} \frac{R_S}{R_S+R_L} = 187{,}3$$

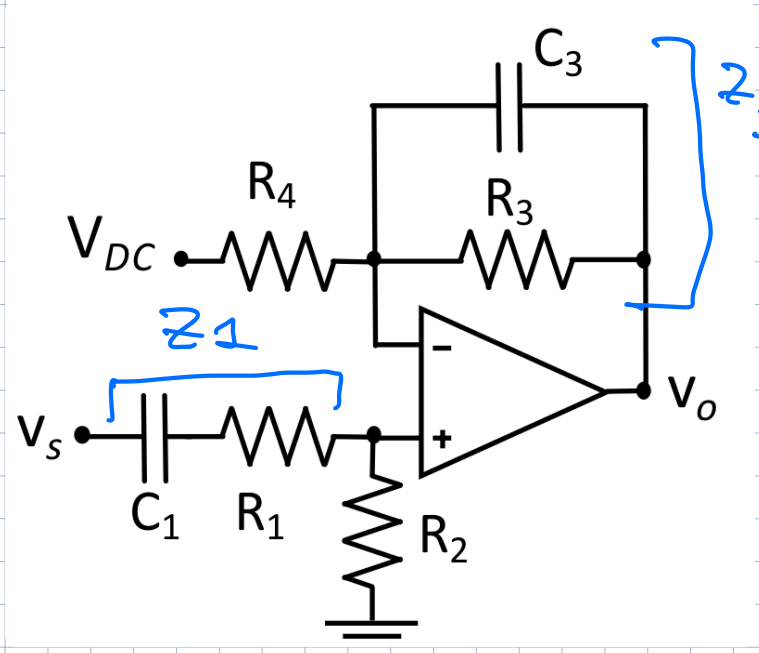
PROBLEMA P2

Sia dato il circuito in figura che usa un amplificatore operazionale ideale. Le resistenze hanno valore R_1 = 9 kΩ, R_2 = 1 kΩ, R_3 = 990 Ω, R_4 = 10 Ω. Le capacità valgono: C_1 = 10μF, C_3 = 101nF. V_{DC}= 1 V.

1) ricavare l'espressione della funzione di trasferimento $W(s)=v_o(s)/v_s(s)$;
2) tracciare il diagramma di Bode asintotico dell'ampiezza e della fase di W, (per la fase non usare l'approssimazione a gradino).
3) Calcolare $v_o(t)$ sapendo che $v_s = 2V + 5V*\sin(\omega_o t)$ con ω_o = 10 rad/s.



1) $W(s) = \dfrac{v_o}{v_s}$ (non si considera V_{DC}!)



$$Z_1 = R_1 + \frac{1}{sC_1} = \frac{1+sC_1R_1}{sC_1}$$

$$Z_3 = \frac{R_3 \cdot \frac{1}{sC_3}}{R_3 + \frac{1}{sC_3}} = \frac{R_3}{1+sC_3R_3}$$

$$v_+ = v_s \cdot \frac{R_2}{R_2 + Z_1} = \frac{R_2}{R_2 + \frac{1+sC_1R_1}{sC_1}} v_s = \frac{sC_1R_2}{1+sC_1(R_1+R_2)} v_s$$

$$v_o = v_+\left(1 + \frac{Z_3}{R_4}\right) = v_+\left(\frac{R_4 + Z_3}{R_4}\right) = \frac{R_4 + \frac{R_3}{1+sC_3R_3}}{R_4} v_+$$

$$= \frac{R_4 + sC_3R_3R_4 + R_3}{R_4(1+sC_3R_3)} v_+ = \frac{R_3+R_4}{R_4} \cdot \frac{1+sC_3R_3/\!/R_4}{1+sC_3R_3} v_+$$

$$\Rightarrow \boxed{W(s) = \frac{v_o}{v_s} = \frac{R_3+R_4}{R_4} \cdot \frac{sC_1R_2}{1+sC_1(R_1+R_2)} \cdot \frac{1+sC_3\,R_3//R_4}{1+sC_3R_3}}$$

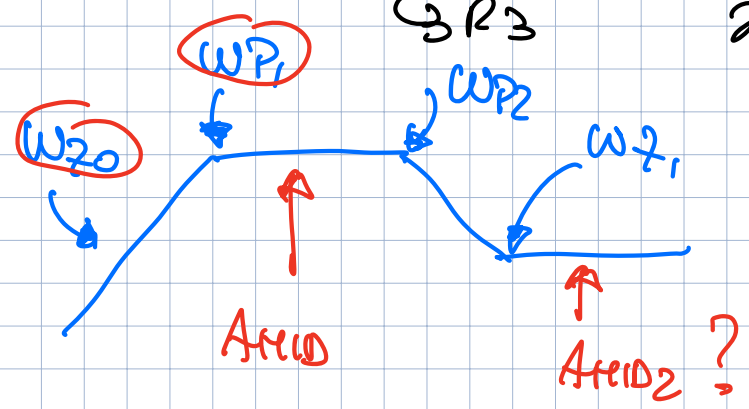
$$\omega_{z_0} = \frac{1}{C_1R_2} = 10^2 \text{ rad/sec} \qquad \omega_{P_1} = \frac{1}{C_1(R_1+R_2)} = 10 \frac{\text{rad}}{\text{sec}}$$

$$\omega_{z_1} = \frac{1}{C_3\,R_3//R_4} = 10^6 \text{ rad/sec} \qquad \omega_{P_2} = \frac{1}{C_3R_3} = 10^4 \frac{\text{rad}}{\text{sec}}$$

$$\underbrace{\frac{R_3+R_4}{R_4} = 100 = 40\,\text{dB}}$$

NON È $W(0)$

NON È A_{MID}

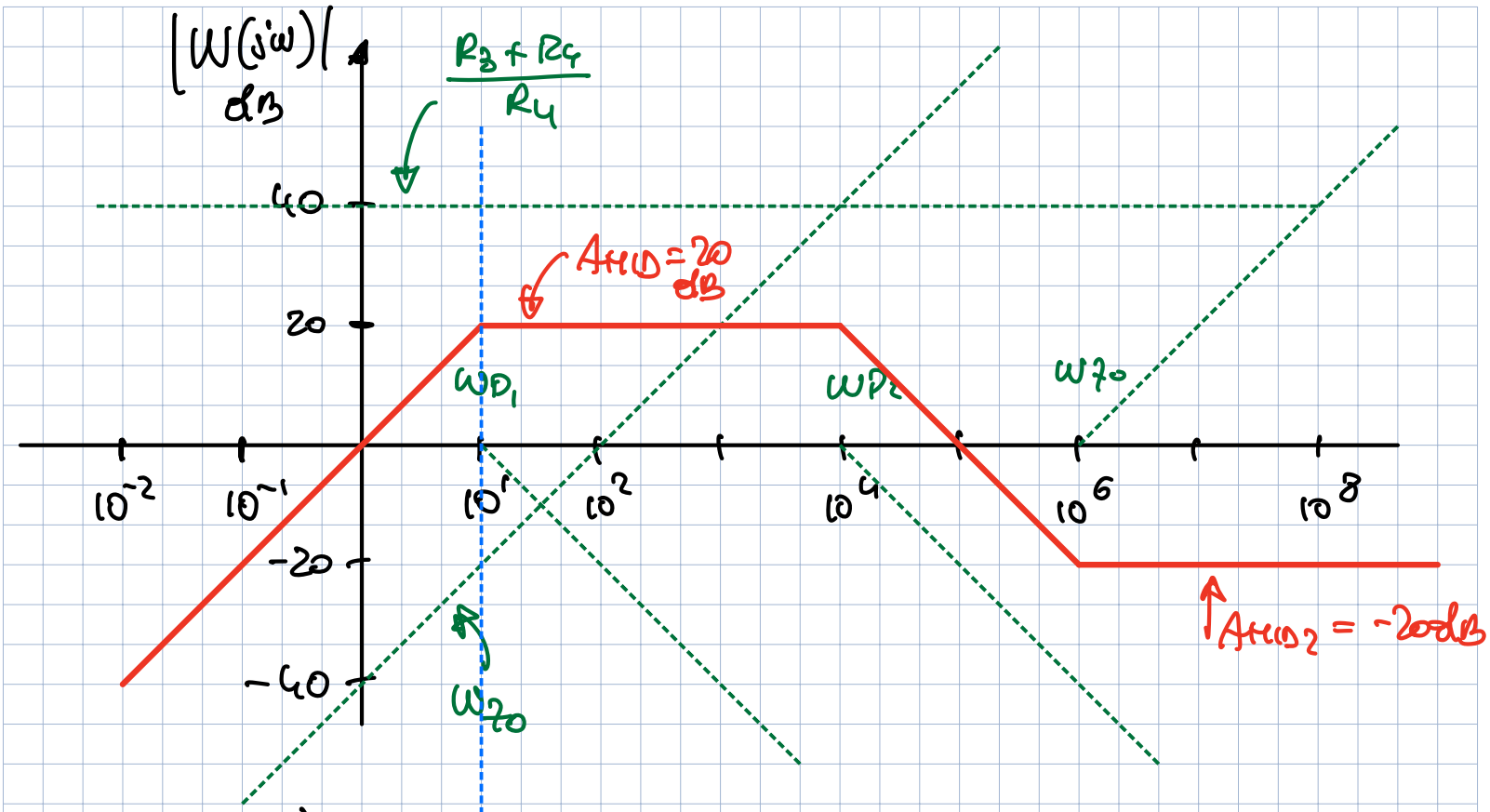


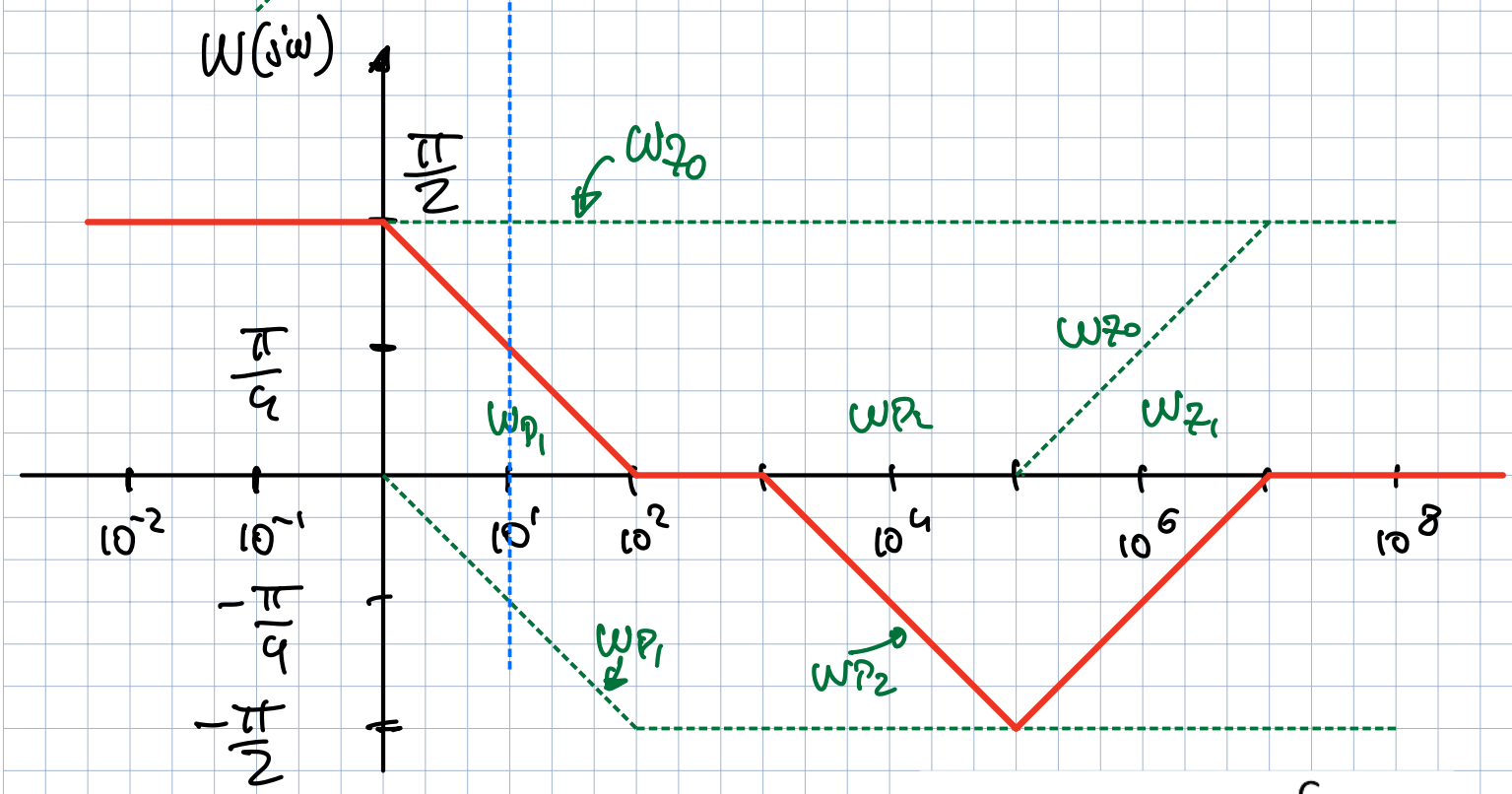
PER A_{MID} "RACCOLGO" ω_{z_0} e ω_{P_1} e li SCRIVO COME $(s+\omega)$ invece che $1+\frac{s}{\omega}$

$$W(s) = \underbrace{\frac{R_3+R_4}{R_4} \cdot \frac{R_2}{R_1+R_2}}_{A_{MID}} \cdot \underbrace{\frac{s}{\frac{1}{C_1(R_1+R_2)}+s}}_{F_L(s)} \cdot \underbrace{\frac{1+sC_3\,R_3//R_4}{1+sC_3R_3}}_{F_H(s)}$$

$$A_{MID} = 10 = 20\,\text{dB}$$

$$A_{MID_2} = \frac{R_3+R_4}{R_4} \cdot \frac{R_2}{R_1+R_2} \cdot \frac{R_3//R_4}{R_3} = \frac{R_2}{R_1+R_2} = 0{,}1 = -20\,\text{dB}$$

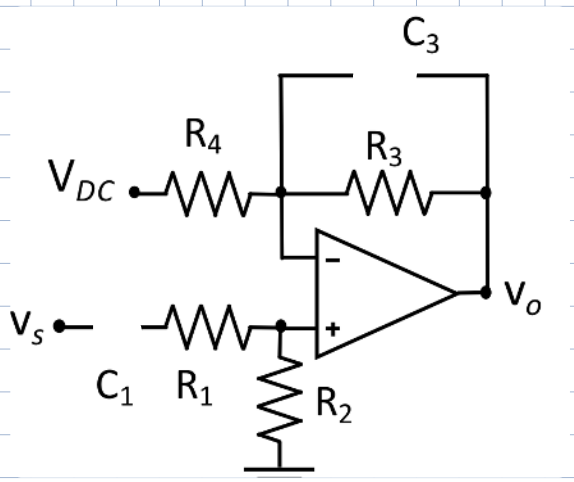




CALCOLO DELLE V_O

CONSIDERO ORA LA VDC!

IN CONTINA I "C" SONO RIRCUITI APERTI



V_S viene ANNULLATO (SOVRAPP. EFFETTI)
Comunque il FATTO CHE C_1 è "OPEN" V_S non avrebbe avuto nessun effetto!

$V_+ =$ MASSA (NON CIRCOLA CORRENTE SU R_1 e R_2)

$$V_0 = V_{DC}\left(-\frac{R_3}{R_4}\right) = -99 V_{DC} = -99V = V_{0DC}$$

PER $\omega_0 = 10$ rad/sec

$$|W(j\omega_0)| = 20\,dB = 10$$

(VISTO CHE SONO NELLO SPEZZAMENTO POSSO DIRE $|A(j\omega_0)| = \frac{10}{\sqrt{2}} = 7{,}07$)

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

$$W(0) = 0$$

NOTA BENE, C'È ZERO NELL'ORIGINE!

$$V_S = 2V + 5V \sin(\omega_0 t)$$

$$V_0 = V_{0DC} + 2V \cdot W(0) + 5V \cdot |W(j\omega_0)| \sin\left(\omega_0 t + \angle W(j\omega_0)\right)$$

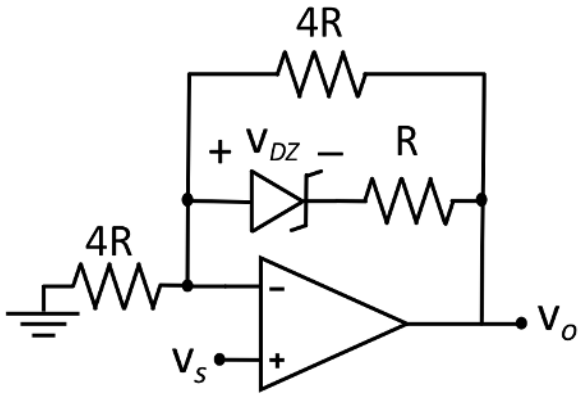
$$= -99V + 50V \sin\left(\omega_0 t + \frac{\pi}{4}\right)$$

OPPURE $\frac{50V}{\sqrt{2}} = 35{,}35V$

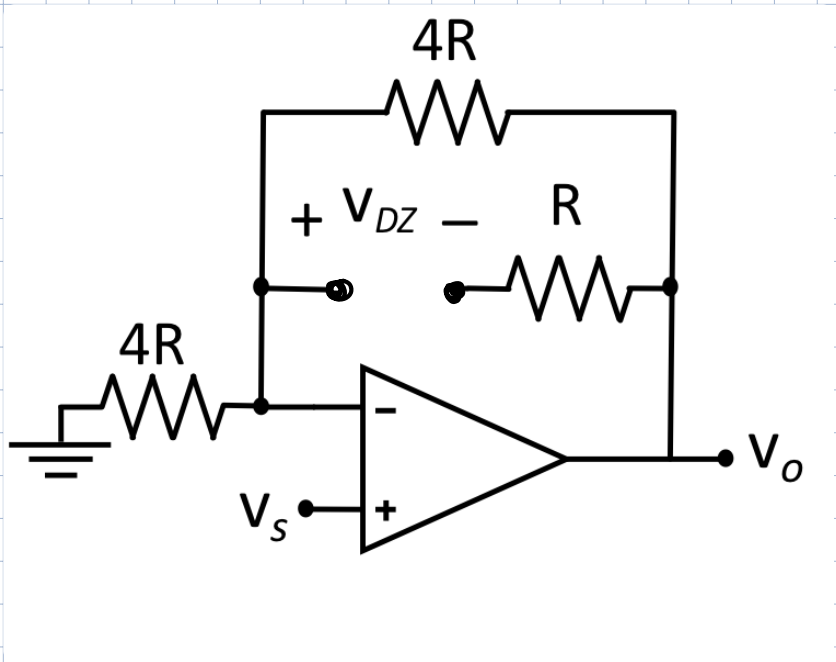
PROBLEMA Q1

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: $R_1 = 1\ k\Omega$, $V_{ON} = 0$, $V_Z = 5V$



Hp D_Z = OFF

$$\boxed{v_o = v_s\left(1 + \frac{4R}{4R}\right) = 2v_s}$$

$$v_{DZ} = v_- - v_o = v_s - 2v_s = -v_s$$

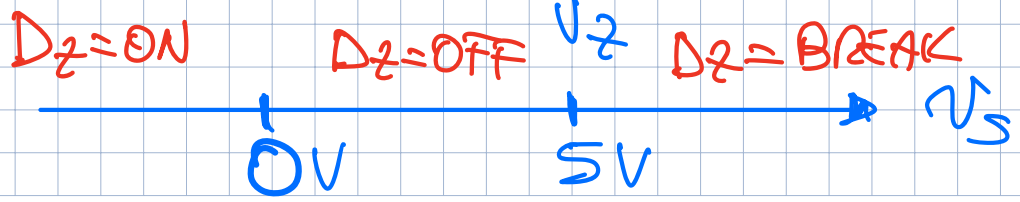
DIODO ON $v_{DZ} > 0 \Rightarrow -v_s > 0 \Rightarrow v_s < 0$

DIODO BREAK. $v_{DZ} < -V_Z$ $\quad -v_s < -V_Z$

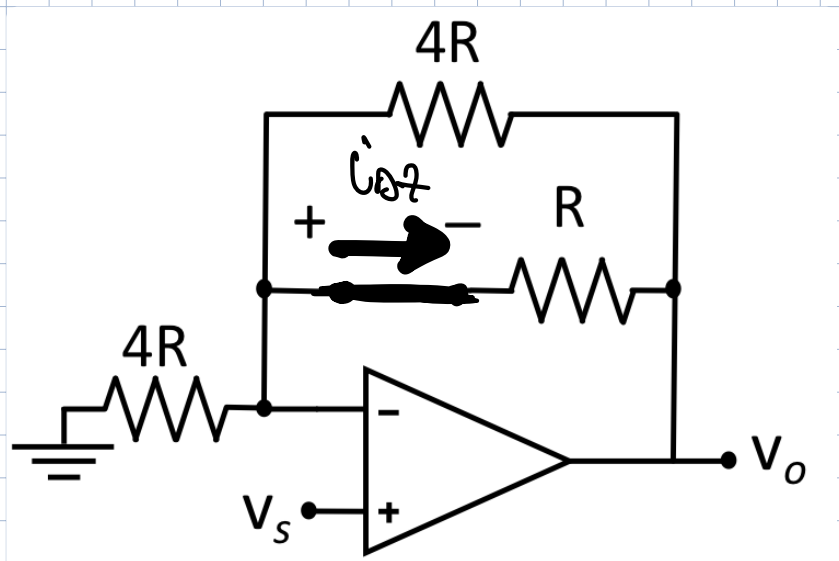
$\Rightarrow v_s > V_Z$

DIODO OFF $-V_Z \le v_{DZ} \le 0$

$\Rightarrow 0 \le v_s \le V_Z$



2) CON $v_S = -5V \Rightarrow D_Z =$ "ON"



$$4R // R = \frac{4R^2}{5R} = \frac{4}{5}R$$

$$v_O = v_S\left(1 + \frac{\frac{4}{5}R}{4R}\right) = v_S\left(1 + \frac{1}{5}\right)$$

PER VERIFICA, PROVARE CHE $i_{DZ} > 0$

$$\boxed{v_O = \frac{6}{5} v_S = -6V}$$

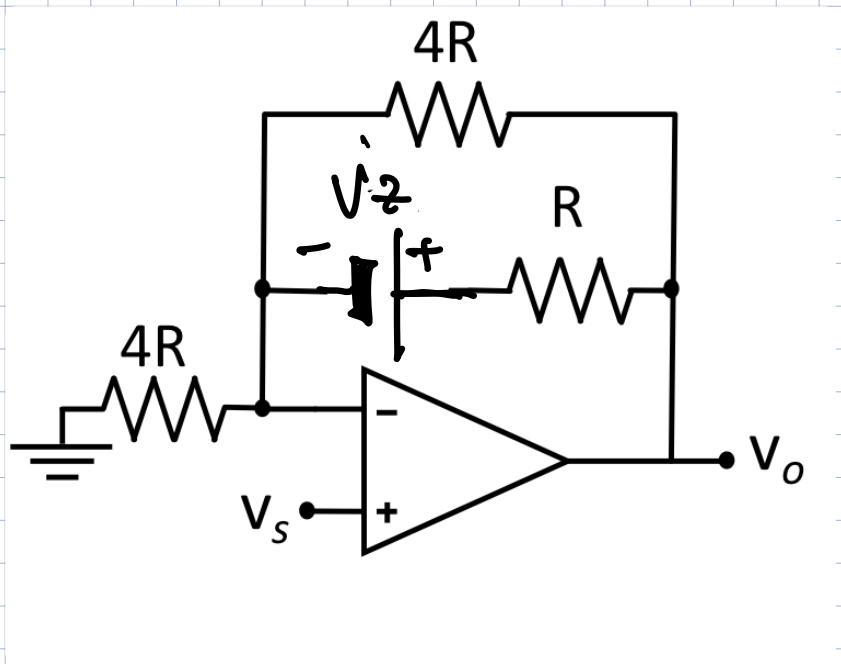
FACOLTATIVO

HO GIÀ CALCOLATO:

a) DIODO OFF $v_O = 2v_S$ $\quad 0V \leq v_S \leq 5V$

b) DIODO ON $v_O = \frac{6}{5} v_S = 1{,}2 v_S$ $\quad v_S < 0V$

c) DIODO BREAKDOWN $\quad v_S > 5V$

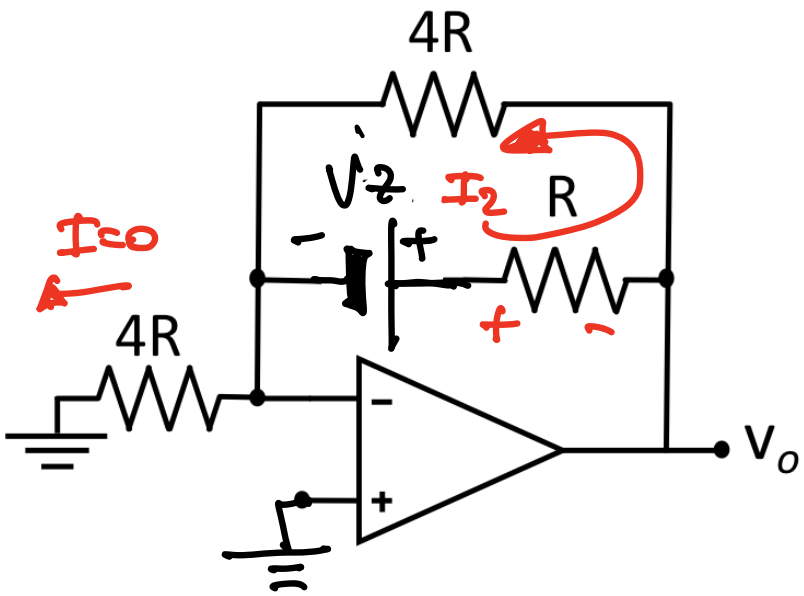


CONVIENE USARE SOVRAPP. EFFETTI

1) Con v_S e $V_Z=0$ HO LA CONDIZIONE DIODO "ON"

$$\Rightarrow v_o' = \frac{6}{5} v_S$$

2) Con $v_S=0$ e V_Z ATTIVO



$$I_2 = \frac{V_Z}{R+4R} = \frac{5V}{5R} = 1\,mA$$

$$v_o'' = V_Z - I_2 R = V_Z - \frac{V_Z}{5} = \frac{4}{5} V_Z = 4V$$

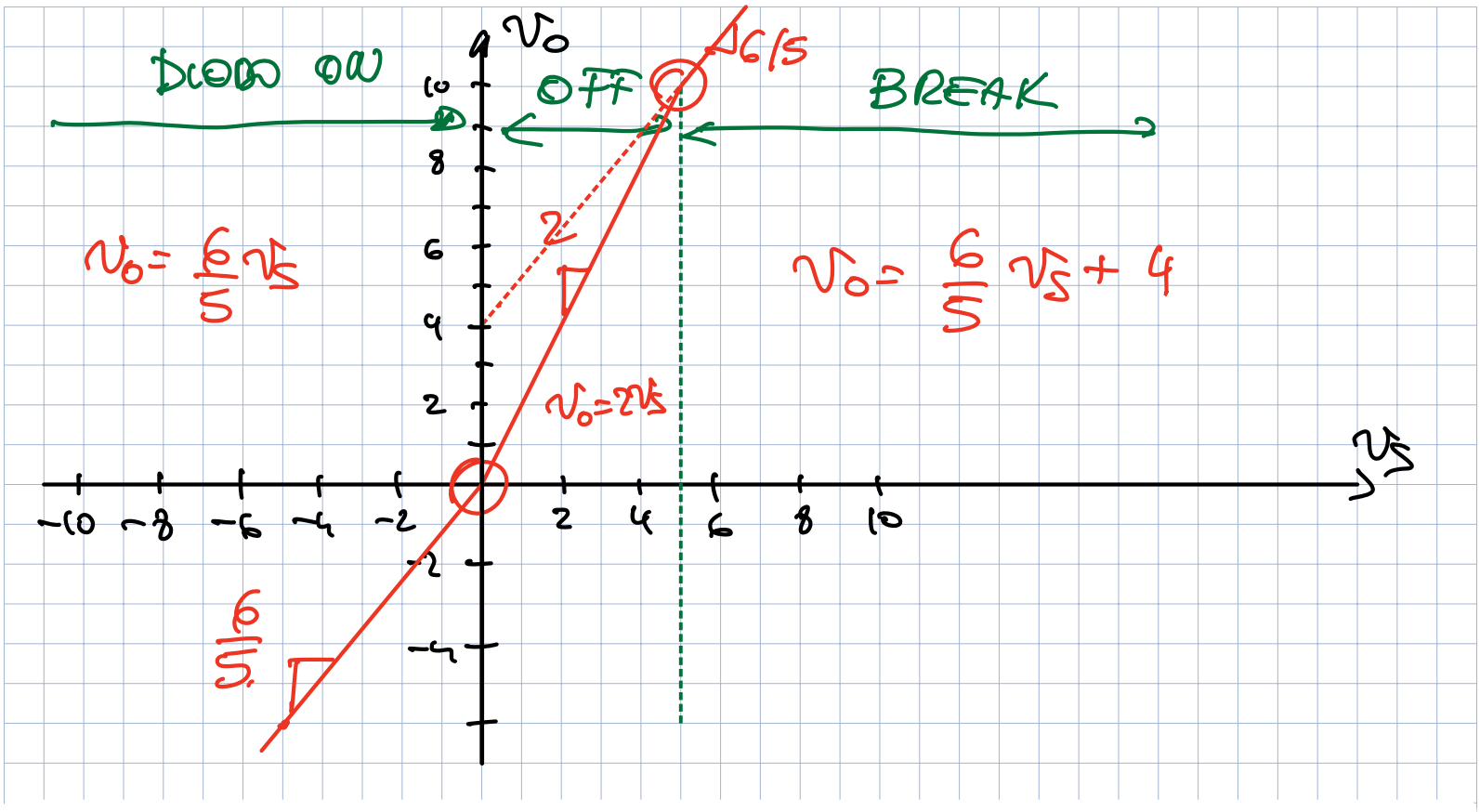
CON DIODO BREAK:

$$\Rightarrow v_o = \frac{6}{5} v_S + 4V$$

RACCORDI:

$v_S=0$ → $2v_S=0$, $\frac{6}{5}v_S=0$ OK

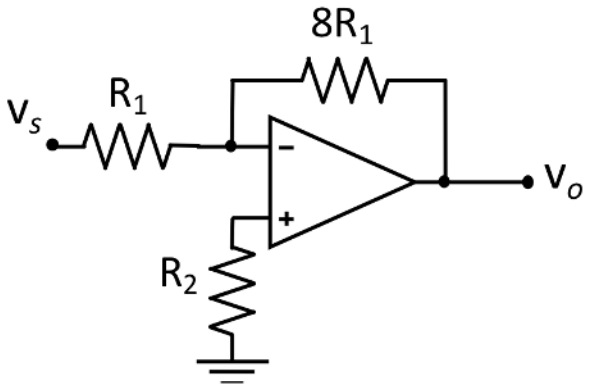
$v_S=5V$ → $v_o=2v_S=10V$, $v_o=\frac{6}{5}5+4V=10V$



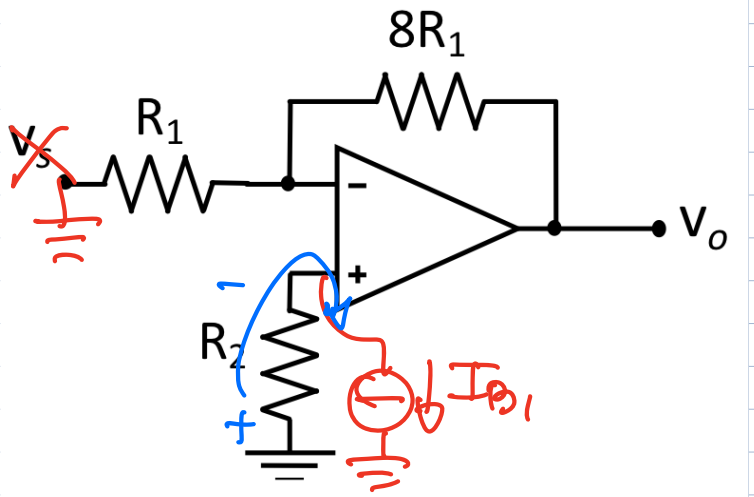
PROBLEMA Q2

Il circuito di figura impiega un AO quasi ideale con correnti di polarizzazione pari a I_{B1}=120nA (morsetto non invertente), I_{B2}=80nA (morsetto invertente).

1) Calcolare v_o considerando l'effetto delle sole correnti di polarizzazione (v_s=0). Trovare il valore di R_2 che annulla l'effetto delle correnti di BIAS.
2) Calcolare il valore di v_o considerando la sola tensione v_s = +2 V sapendo che l'AO è alimentato con +/- Vcc e determinare il valore della tensione del morsetto invertente, v_-.



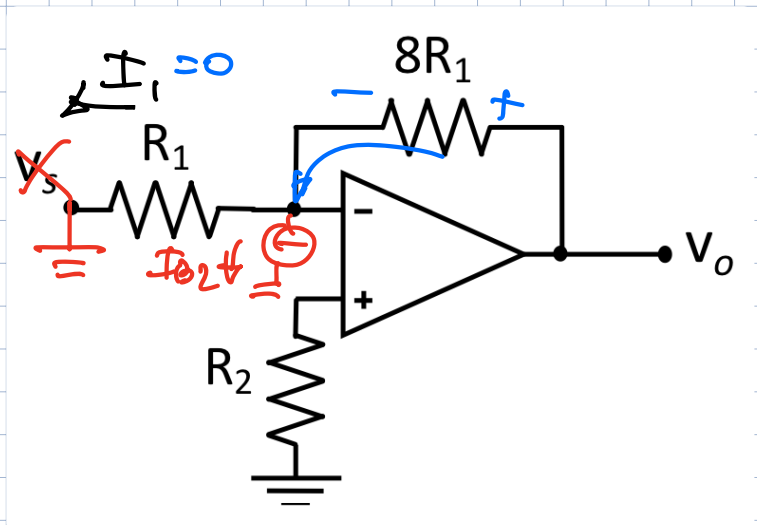
Dati: R_1 = 1 kΩ, R_2 = 1 kΩ v_s = +2 V, Vcc= 10V.



EFETTO DI I_{B1}

$$v_+ = -I_{B1} R_2$$

$$v_o' = v_+ \left(1 + \frac{8R_1}{R_1}\right) = -9 I_{B1} R_2 = -1{,}08\,mV$$



$$v_o'' = 8R_1 I_{B2} = 0{,}64\ mV$$

$$\Rightarrow v_o = v_o' + v_o'' = -0{,}44\ mV$$

X ANNULLARE EFFETTO $I_{B1,2}$:

$$8R_1 I_{B2} - 9 I_{B1} R_2 = 0 \Rightarrow R_{2_{new}} = \frac{8}{9}\frac{I_{B2}}{I_{B1}} R_1 = 592{,}6\ \Omega$$

2) Con $v_s = 2V$

$$v_o = v_s\left(-\frac{8R_1}{R_1}\right) = -8v_s = -16V$$

VISTO CHE AO È ALIMENTATO A $\pm 10V$

$\Rightarrow$ v_o SATURA A $-10V$

$\Rightarrow v_o = -10V$

QUANDO A.O. SATURA $\Rightarrow v_{id}$ NON È PIÙ TRASCURABILE e NON VALE PIÙ LA TRASSA VIRTUALE

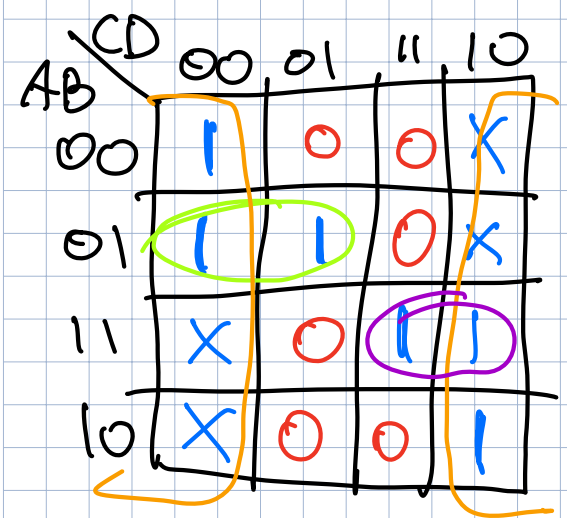
$$v_- = v_s \cdot \frac{8R_1}{R_1+8R_1} - V_{cc}\cdot\frac{R_1}{R_1+8R_1} = 1{,}78V - 1{,}11V = 0{,}67V$$

PROBLEMA Q3

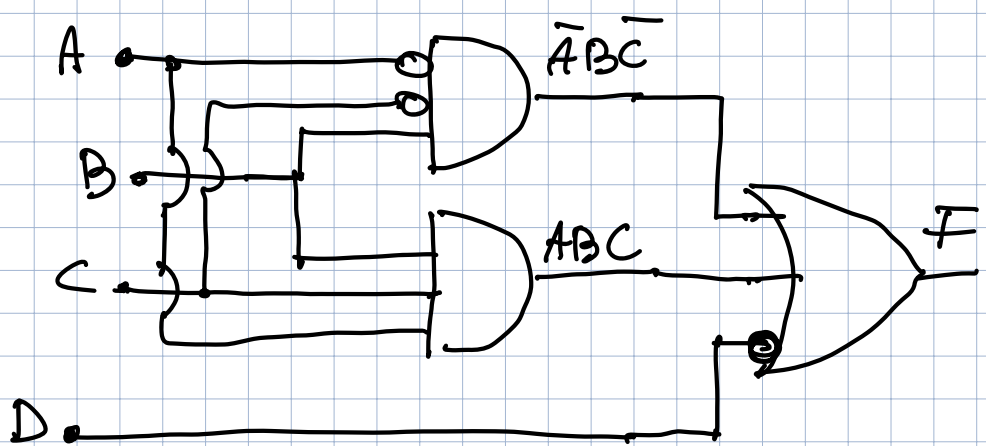
Data la seguente mappa di Karnaugh

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

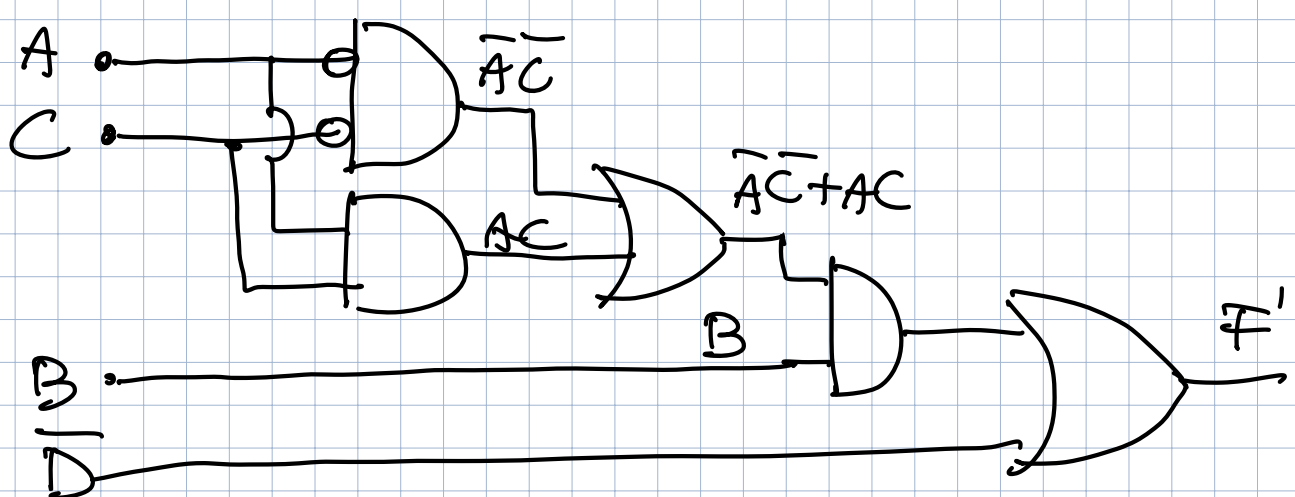
AB \ CD	00	01	11	10
00	1	0	0	X
01	1	1	0	X
11	X	0	1	1
10	X	0	0	1



$$F = \bar{D} + \bar{A}B\bar{C} + ABC$$



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

$$\boxed{\text{N.B. } \bar{A}\bar{C} \neq \overline{AC}}$$

$$(\overline{AC} + AC = 1)$$