Problema 1

DATI: $R_1 = 8k\Omega$, $R_i = 250\Omega$, $R_L = 750\Omega$, $V_B = 4V$, $V_{DD} = 10V$

Parametrati dei MOS: M_1: $k_{n1} = 0.5mA/V^2$, $V_{TN1} = 2V$, $\lambda_{n1} = 0$

M_2: $k_{n2} = 4mA/V^2$, $V_{TN2} = 2V$, $\lambda_{n2} = 0$

M_3: $k_{n3} = 0.5mA/V^2$, $V_{TN3} = 2V$, $\lambda_{n3} = 0.005V^{-1}$

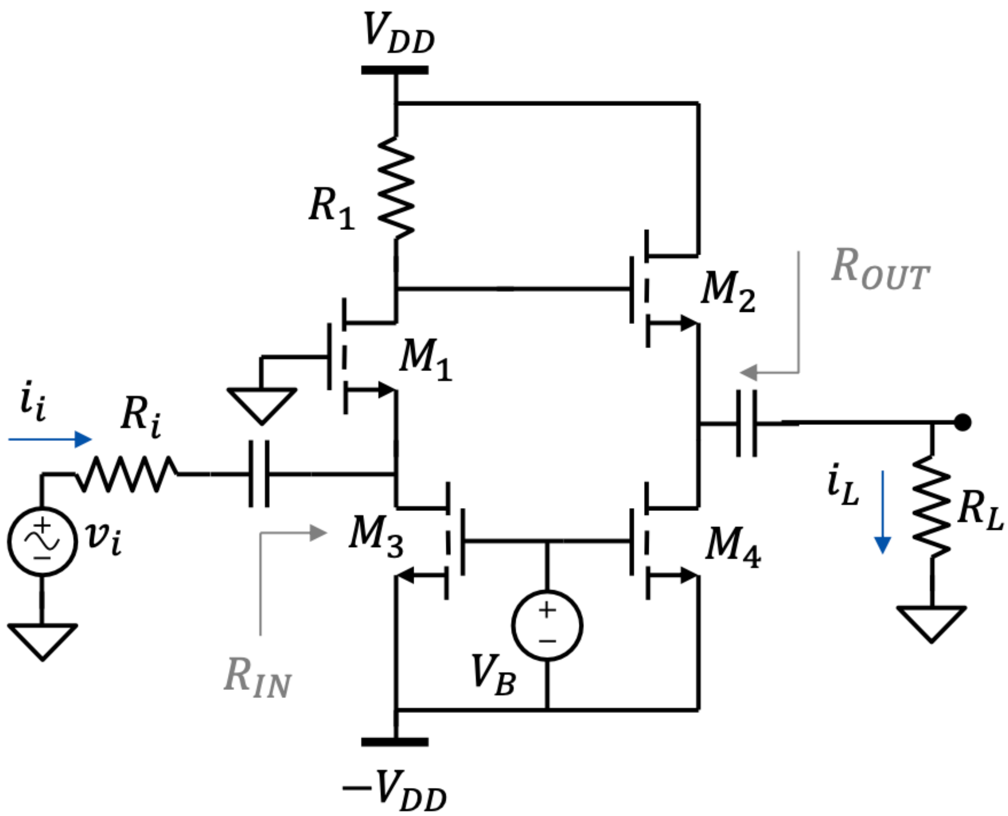
M_4: $k_{n4} = 1mA/V^2$, $V_{TN4} = 2V$, $\lambda_{n4} = 0.005V^{-1}$

Dato il circuito in figura, calcolare:

1. Il punto di polarizzazione di tutti i MOSFET
2. Disegnare il modello ai piccoli segnali e calcolare la transconduttanza g_{m1} e g_{m2} di M_1 e M_2.

Dal modello ai piccoli segnali calcolare:

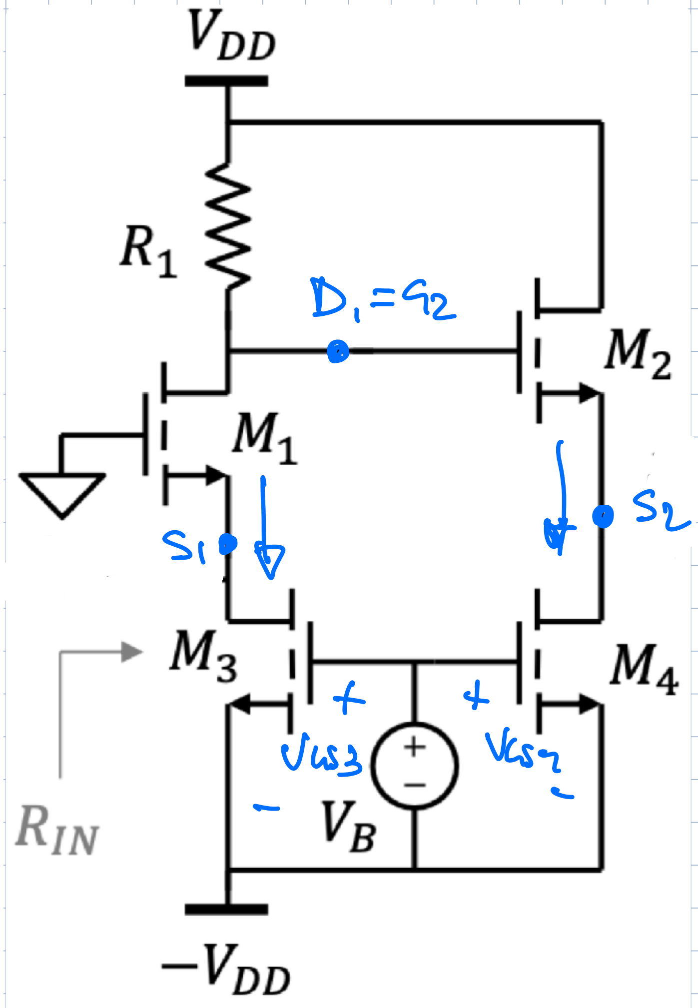
3. La resistenza di ingresso
4. La resistenza di uscita
5. Il guadagno di tensione dall'ingresso v_i all'uscita v_o.
6. (*facoltativo*) il guadagno di corrente i_L/i_i.



$$V_{GS3} = V_{GS4} = V_B = 4V$$

$$\Rightarrow I_{D3} = \frac{K_{n3}}{2}(V_{GS3} - V_{TN3})^2 = 1mA$$

$$I_{D4} = \frac{K_{n4}}{2}(V_{GS4} - V_{TN4})^2 = 2mA$$



$I_{D1} = I_{D3} = 1\,mA$

$I_{D2} = I_{D4} = 2\,mA$

$V_{GS1} = V_{TN1} + \sqrt{\dfrac{2 I_{D1}}{K_{n1}}} = 4V$

$V_{GS2} = V_{TN2} + \sqrt{\dfrac{2 I_{D2}}{K_{n2}}} = 3V$

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

$V_{D1} = V_{DD} - R_1 I_{D1} = 2V$

$V_{S2} = V_{D1} - V_{GS2} = -1V$

$V_{DS1} = V_{D1} - V_{S1} = 6V > V_{GS1} - V_{TN1} = 2V$ OK SAT

$V_{DS2} = V_{DD} - V_{S2} = 11V > V_{GS2} - V_{TN2} = 1V$ OK SAT

$V_{DS3} = V_{S1} + V_{DD} = 6V > V_{GS3} - V_{TN3} = 2V$ OK SAT

$V_{DS4} = V_{S2} + V_{DD} = 9V > V_{GS4} - V_{TN4} = 2V$ OK SAT

M_1: $I_{D1} = 1\,mA$, $V_{DS1} = 6V$

M_2: $I_{D2} = 2\,mA$, $V_{DS2} = 11V$

M_3: $I_{D3} = 1\,mA$, $V_{DS3} = 6V$

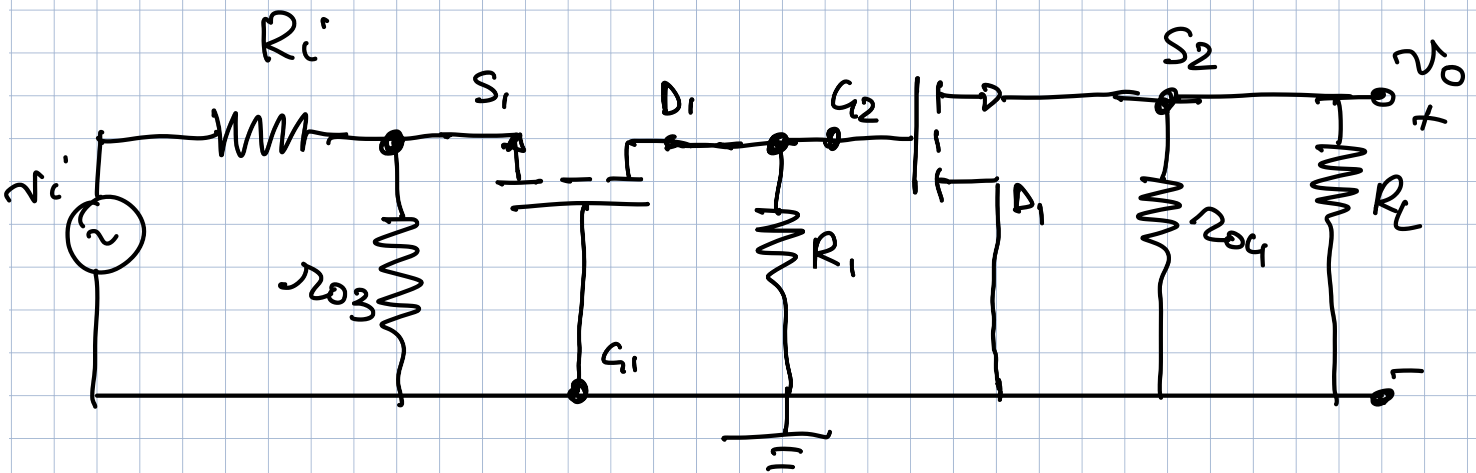
M_4: $I_{D4} = 2\,mA$, $V_{DS4} = 9V$

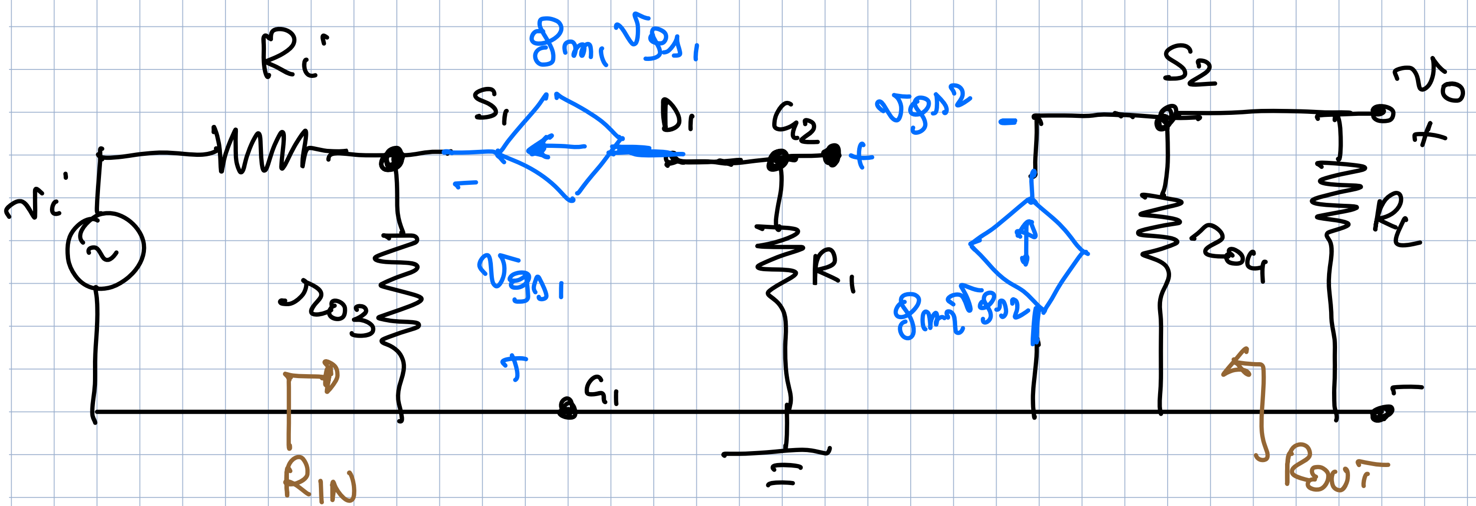
CALCOLO PARAMETRI PICCOLO SEGNALE

$$g_{m1} = \frac{2 I_{D1}}{V_{GS1} - V_{TN1}} = 1\ mS \qquad r_{o3} = \frac{\frac{1}{\lambda_{n3}} + V_{DS3}}{I_{D3}} = 206\ k\Omega$$

$$g_{m2} = \frac{2 I_{D2}}{V_{GS2} - V_{TN2}} = 4\ mS \qquad r_{o4} = \frac{\frac{1}{\lambda_{n4}} + V_{DS4}}{I_{D4}} = 104\ k\Omega$$

SCHEMA PICCOLO SEGNALE





$$R_{IN} = r_{o3} /\!/ \frac{1}{g_{m1}} = \frac{r_{o3}}{1 + g_{m1} r_{o3}} = 995{,}2\ \Omega$$

$$R_{OUT} = r_{o4} /\!/ \frac{1}{g_{m2}} = \frac{r_{o4}}{1 + g_{m2} r_{o4}} = 248{,}4\ \Omega$$

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

$$\frac{v_{S1}}{v_i} = \frac{R_{IN}}{R_{IN} + R_i} = 0,8$$

$$\frac{v_{G2}}{v_{S1}} = g_{m1} R_1 = 8$$

$$\frac{v_o}{v_{G2}} = \frac{g_{m2}\, r_{o4} /\!/ R_L}{1 + g_{m2}\, r_{o4} /\!/ R_L} = 0,75$$

$$\Rightarrow A_v = 4,8$$

GUADAGNO DI CORRENTE

$$A_i = \frac{i_L}{i_i} = \frac{v_o / R_L}{v_i / (R_i + R_{IN})} = A_v \cdot \frac{R_i + R_{IN}}{R_L} = 7,97$$

OPPURE

$$i_L = g_{m2} v_{gs2} \frac{r_{o4}}{r_{o4} + R_L}$$

$$v_{gs2} = v_{g2} - v_{s2} = - g_{m1} v_{gs1} R_1 - g_{m2} v_{gs2}\, r_{o4} /\!/ R_L$$

$$v_{gs2} = \frac{- v_{gs1}\, g_{m1} R_1}{1 + g_{m2}\, r_{o4} /\!/ R_L} \qquad v_{gs1} = - i_i \; R_{IN}$$

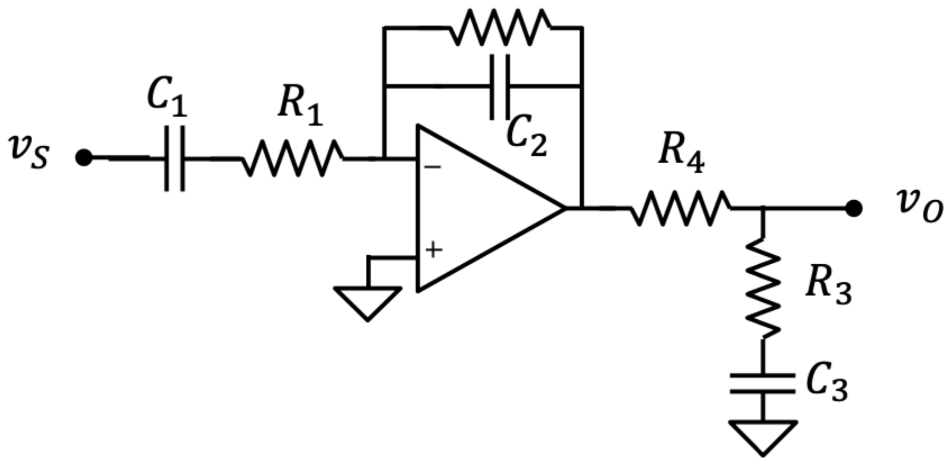
$$\Rightarrow A_i = \frac{i_L}{i_i} = g_{m2} \frac{r_{o4}}{r_{o4} + R_L} \cdot \frac{g_{m1} R_{in}}{1 + g_{m2}\, r_{o4} /\!/ R_L} \cdot R_1 = 7,97$$

Problema 2

Dato il filtro in figura realizzato con un amplificatore operazionale ideale:

1. Trovare la funzione di trasferimento del filtro
2. Tracciare il diagramma asintotico di Bode del modulo e della fase
3. Dato il segnale di ingresso $v_S = V_{S0} + V_{S1}\sin(\omega_S t + \phi_S)$ con V_{S0} = 1V, V_{S1} = 0.1V ϕ_S = 30° trovare il segnale di uscita nei due casi:
   a. $\omega_{S1} = 10^3$rad/s,
   b. $\omega_{S2} = 10^5$rad/s

DATI: R_1 = 2kΩ, R_2 = 20kΩ, R_3 = 10kΩ, R_4 = 90kΩ, C_1 = 5uF, C_2 = 50pF, C_3 = 1nF.



$$Z_1 = \frac{1}{SC_1} + R_1 = \frac{1+SR_1C_1}{SC_1}$$

$$Z_2 = \frac{1}{SC_2} \parallel R_2 = \frac{\frac{1}{SC_2}\cdot R_2}{\frac{1}{SC_2}+R_2} = \frac{R_2}{1+SC_2R_2}$$

$$Z_3 = \frac{1}{SC_3} + R_3 = \frac{1+SR_3C_3}{SC_3}$$

$$V_1 = -\frac{Z_2}{Z_1} = \frac{SC_1R_2}{(1+SC_1R_1)(1+SC_2R_2)} V_S$$

$$v_0 = \frac{Z_3}{Z_3 + R_4} v_1 = \frac{\dfrac{1 + sR_3C_3}{sC_3}}{\dfrac{1+sR_3C_3}{sC_3} + R_4} v_1$$

$$= -\frac{1 + sR_3C_3}{1 + sC_3(R_3+R_4)} \cdot \frac{sC_1R_2}{(1+sC_1R_1)(1+sC_2R_2)} v_S$$

$$W(s) = -\frac{(sC_1R_2)(1+sR_3C_3)}{(1+sR_1C_1)(1+sR_2C_2)\left[1+s(R_3+R_4)C_3\right]}$$

$$\omega_{z0} = \frac{1}{C_1R_2} = 10 \text{ rad/sec}$$

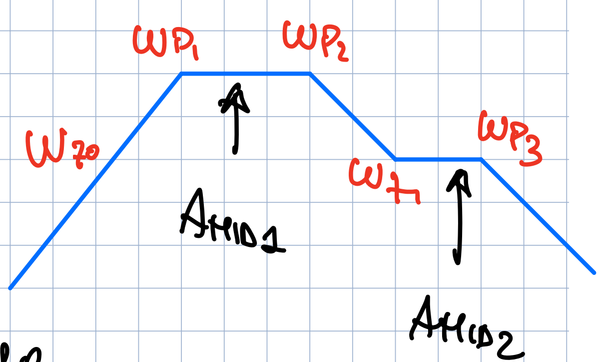
$$\omega_{z1} = \frac{1}{R_3C_3} = 10^5 \text{ rad/sec}$$

$$\omega_{P1} = \frac{1}{C_1R_1} = 10^2 \text{ rad/sec}$$

$$\omega_{P2} = \frac{1}{(R_3+R_4)C_3} = 10^4 \text{ rad/sec}$$

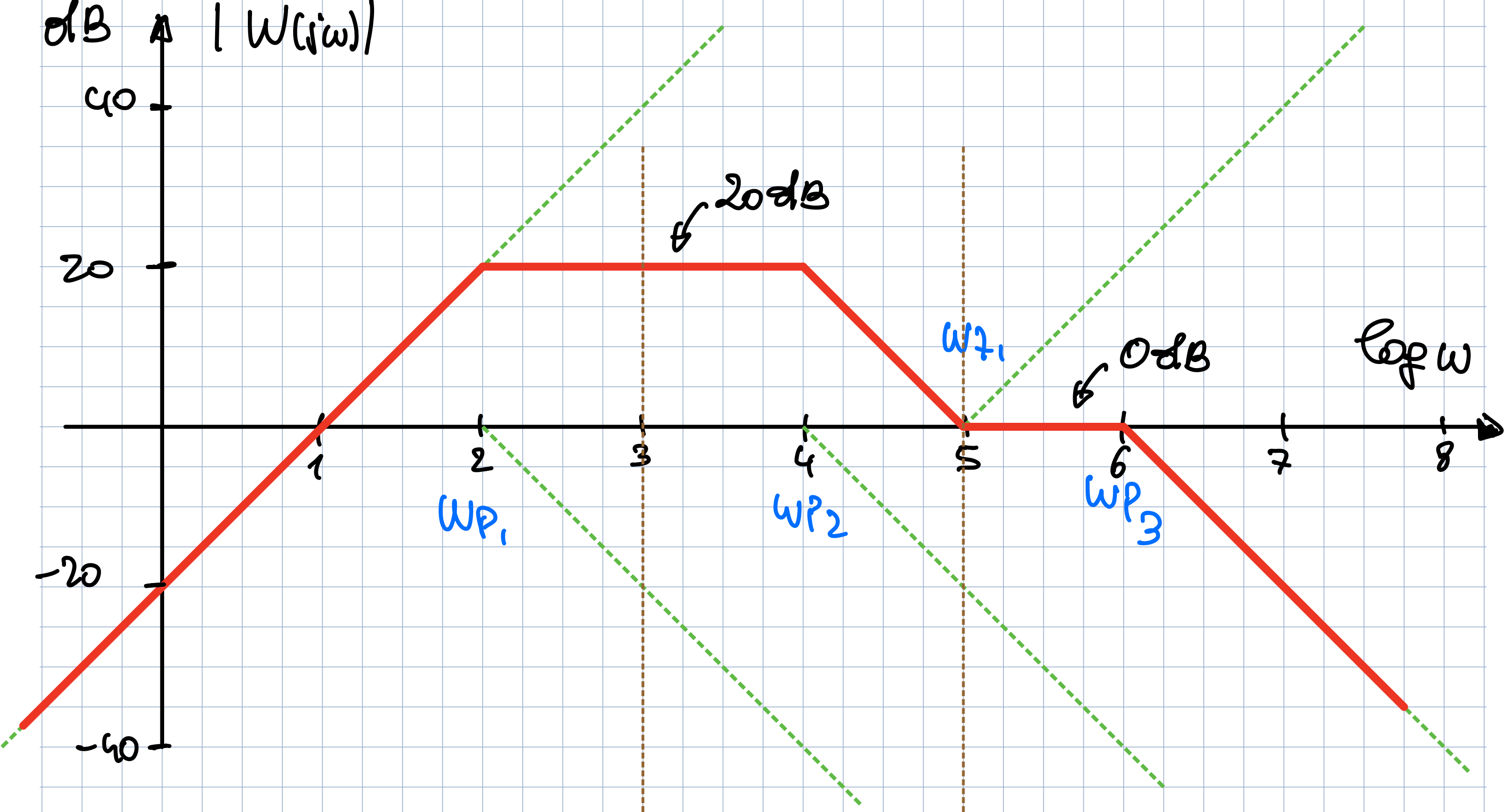
$$\omega_{P3} = \frac{1}{C_2R_2} = 10^6 \text{ rad/sec}$$

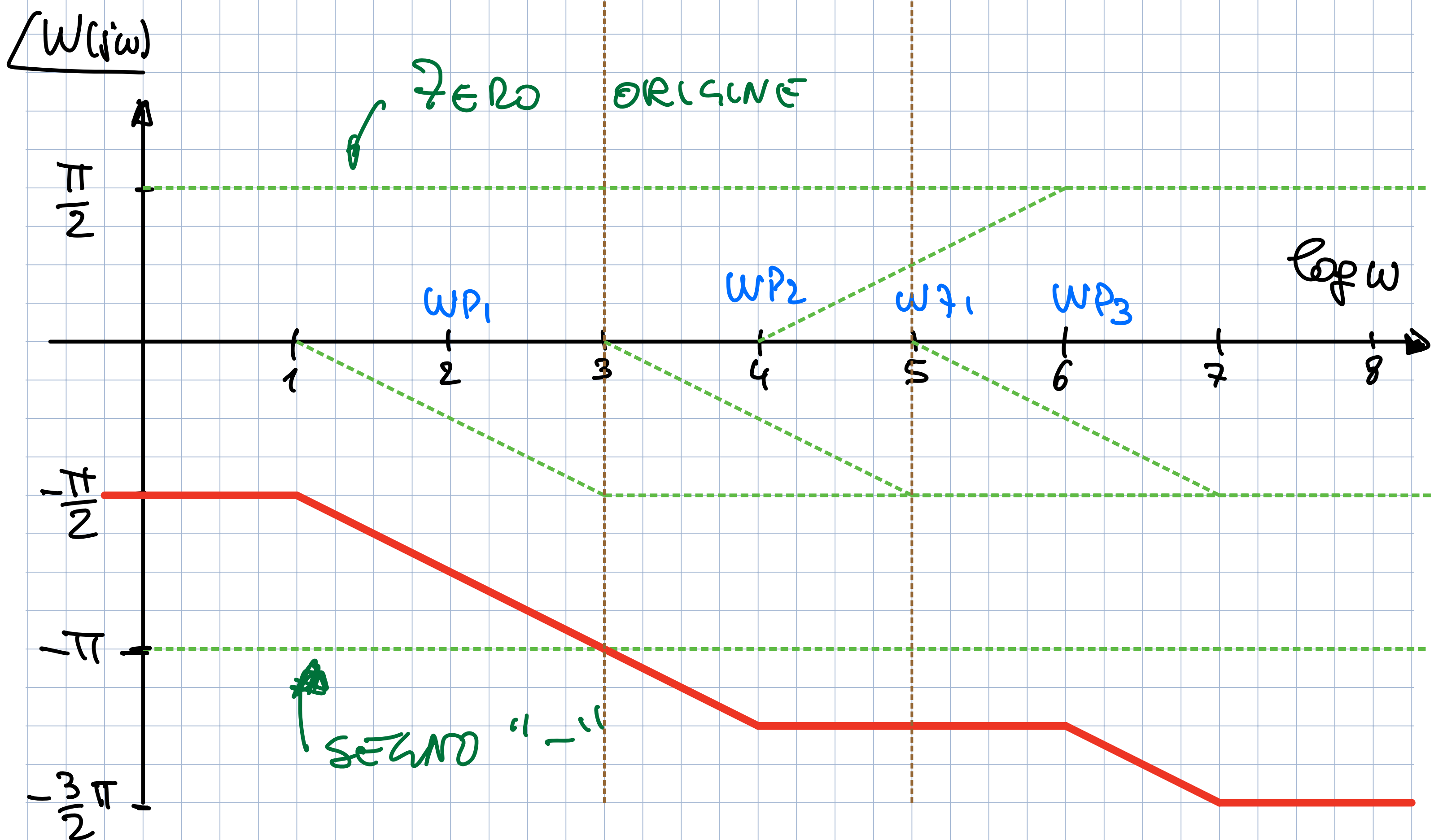
ω_{z0}
$\hookrightarrow \omega_{P1}$
$\hookrightarrow \omega_{P2}$
$\hookrightarrow \omega_{z1}$
$\hookrightarrow \omega_{P3}$



$$A_{MID1} = \left|\frac{C_1R_2}{C_1R_1}\right| = \frac{R_2}{R_1} = 10 = 20\text{dB}$$

$$A_{MID2} = \frac{\cancel{C_1}R_2\,\cancel{C_3}R_3}{\cancel{C_1}R_1\,\cancel{C_3}(R_3+R_4)} = 1 = 0 \text{ dB}$$


dB
|W(jω)|
40
20
-20
-40
20dB
0dB
log ω
1
2
3
4
5
6
7
8
ωp₁
ωp₂
ωz₁
ωp₃


∠W(jω)
ZERO ORIGINE
π/2
-π/2
-π
-3/2 π
log ω
ωp₁
ωp₂
ωz₁
ωp₃
1
2
3
4
5
6
7
8
SEGNO "–"

$\omega_{s_1} = 10^3 \Rightarrow |W(j\omega)| = 20\,dB = 10$

$\angle W(j\omega) = -\pi = -180^\circ$

$\omega_{s_2} = 10^5 \quad |W(j\omega)| = 0\,dB = 1$

meglio: $= \sqrt{2} = 1{,}41$

$\angle W(j\omega) = -\frac{5}{4}\pi = -225^\circ$

inoltre $W(0) = 0$

$V_{s0} = 1V$

$V_{s1} = 0{,}1V$

$\phi_s = 30^\circ = \frac{\pi}{6}$

$v_s = V_{s0} + V_{s1} \sin(\omega_s t + \phi_s)$

$v_o(\omega_1) = 1V \sin\left(\omega_{s_1} t - \frac{5}{6}\pi\right)$

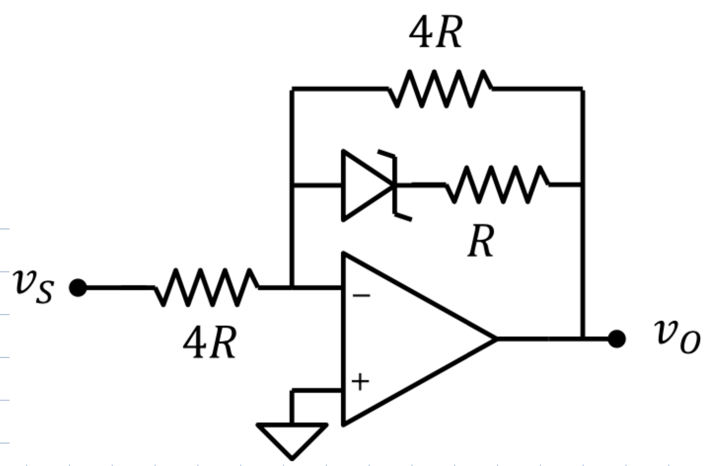
$v_o(\omega_2) = 0{,}1 \sin\left(\omega_{s_2} t - \frac{13}{12}\pi\right)$

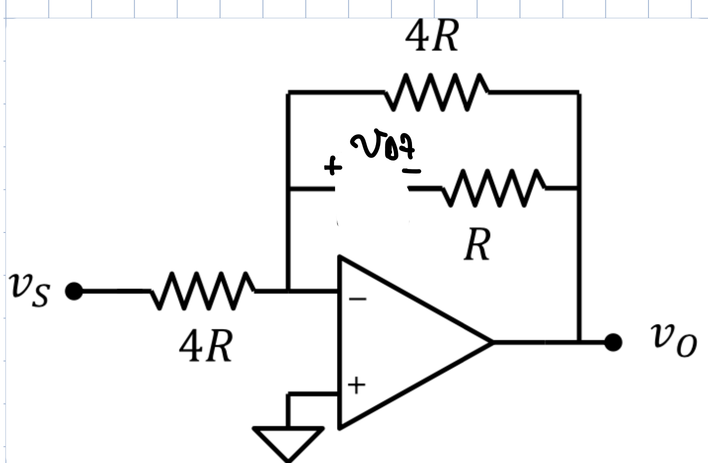
$-\frac{5}{4}\pi + \frac{\pi}{6} = \frac{-15 + 2\pi}{12} = -\frac{13}{12}\pi$

Problema 3

Dato il circuito in figura realizzato con un amplificatore operazionale ideale e un diodo zener con V_{ON} = 0V e V_Z = 8V:

1. Tracciare la transcaratteristica di v_O in funzione di v_S calcolando e indicando chiaramente nel piano v_S - v_O le coordinate dei punti di spezzamento della curva
2.
3. Calcolare il valore di v_O con:
    a. v_S = 2.5V
    b. v_S = -2V
    c. v_S = -9V





Hp DZ = OFF

$$v_O = -\frac{4R}{4R} v_S = -v_S$$

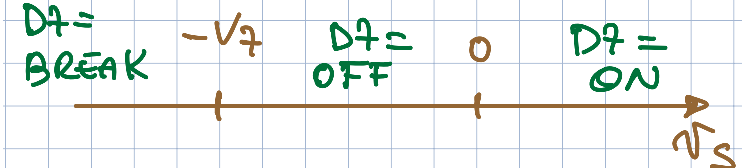
$$v_{DZ} = 0 - v_O = v_S$$

PER ZENER "OFF" $\Rightarrow -V_Z \leq v_{DZ} \leq 0$

$$\Rightarrow -V_Z \leq v_S \leq 0$$

$v_S < -V_Z$
$\Rightarrow$ VDZ BREAK

$v_S > 0$
v_{DZ} = ON



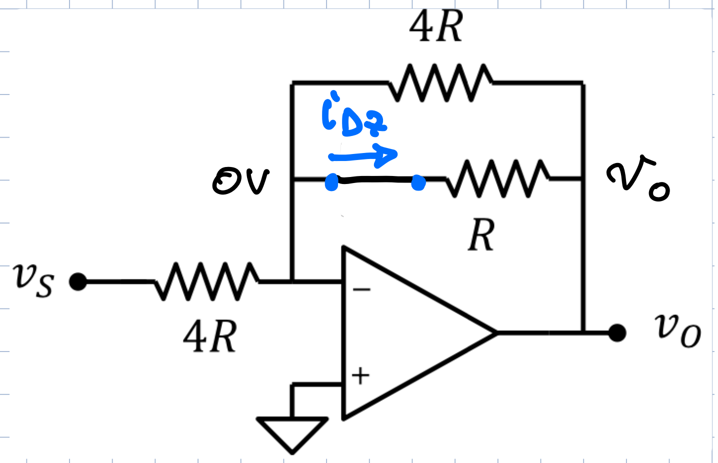
$\Rightarrow -V_Z \leq v_S \leq 0$

$\Rightarrow$ DZ = OFF $\quad v_O = -v_S \quad$ $m = -1$, $q = 0$

RACCORDI $\quad v_O(-V_Z) = 8V$

$v_O(0) = 0$

$\Rightarrow$ $v_S \geq 0$ $\Rightarrow$ $D_7 =$ "ON"



$R_F = 4R // R = \frac{4R \cdot R}{4R + R} = \frac{4}{5} R$

$$\Rightarrow v_0 = -\frac{\frac{4}{5}R}{4R} v_S = -\frac{1}{5} v_S$$

verifico $i_{D7} = \frac{0 - v_0}{R} = \frac{1}{5}\frac{v_S}{R} > 0$

$\times\ v_S > 0$

RACCORDO $v_0(0) = 0$ OK RACCORDO OK $D_7 =$ ON

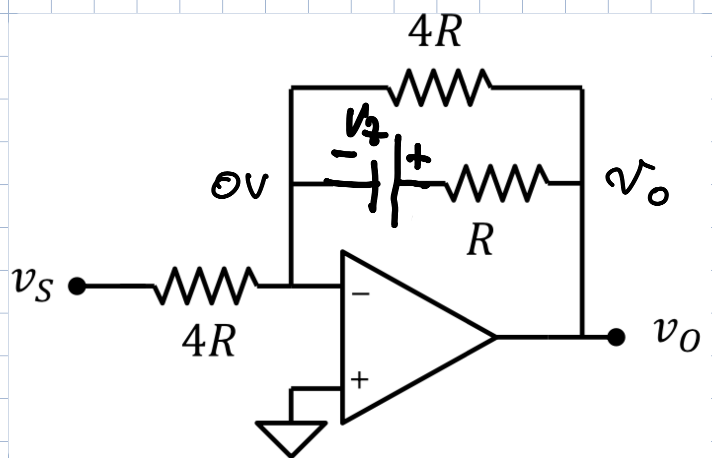
$v_S < -V_7$ $\Rightarrow$ D_7 BREAK.

USO SOVRAPP. ~~EFFETTI~~:

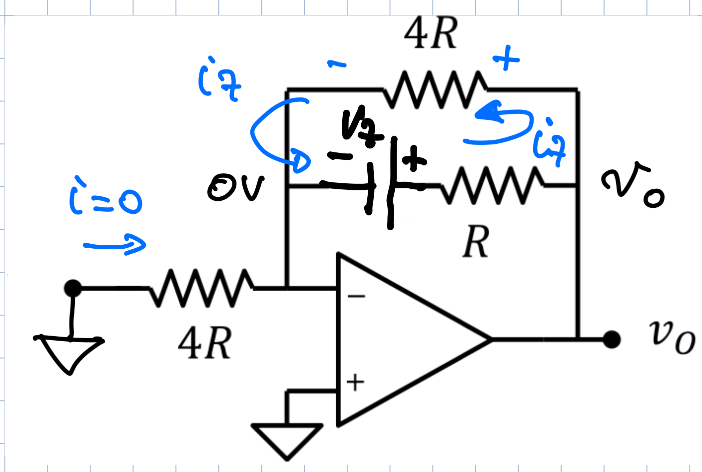
1) $v_S \neq 0$ $\quad V_7 = 0$

(VEDI DIODO "ON")

$\Rightarrow v_0' = -\frac{v_S}{5}$



2) $v_S = 0$ $\quad V_7 \neq 0$



$i_7 = \frac{V_7}{5R}$

$\Rightarrow v_0'' = i_7 \cdot 4R = \frac{4}{5} V_7$

$v_0 = v_0' + v_0'' =$

$= -\frac{v_S}{5} + \frac{4}{5} V_7 = -\frac{v_S}{5} + \frac{32}{5} V$

RACCORDO $v_o(-8V) = -\left(\frac{-8V}{5}\right) + \frac{32}{5}V = \frac{40}{5}V = 8V$

OK RACCORDO

VERIFICA $i_D < 0$:

$$i'_{D7} = \frac{v_S}{5R} \qquad i''_{D7} = \frac{V_7}{5R} \Rightarrow i_{D7} = \frac{v_S}{5R} + \frac{V_7}{5R} < 0$$

$$\Rightarrow v_S < -\frac{V_7}{5R} \cdot 5R \Rightarrow \underline{\underline{v_S < -V_7 \quad \text{OK!}}}$$