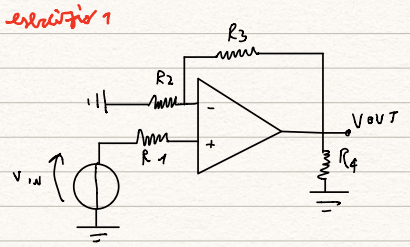
esercizio 1




$$G_{reale} = \frac{G_{id}}{1 - \frac{1}{G_{loop}}}$$

$R_2 = 10\,K\Omega$
$R_3 = 100\,K\Omega$
$R_4 = 100\,K\Omega$
$A_{diff} = 120\,dB\ (= 10^6)$

$O_{PAMP}$ ideale $A_{diff} \longrightarrow \infty$

RETROAZIONE NEGATIVA

1) Trasferimento reale $\frac{V_{OUT}}{V_{IN}}$

- $G_{id}$ (HP: Opamp non ideale)
- $G_{loop}$

Calcolo $G_{id}$:

$i_{R_1} = 0 \longrightarrow V^+ = V_{IN}$

$V^- = V^+$

$V_{R_2} = V^- = V_{IN}$

$i_{R_2} = \frac{V_{R_2}}{R_2} = \frac{V_{IN}}{R_2}$

$i_{R_3} = i_{R_2} \longrightarrow V_{R_3} = i_{R_3} \cdot R_3 = \frac{V_{IN}}{R_2} R_3$

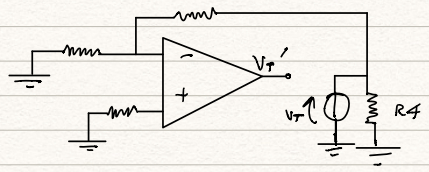
$V_{OUT} = V^- + V_{R_3} = V_{IN}\left(1 + \frac{R_3}{R_2}\right)$ $\qquad G_{id} = \left(1 + \frac{R_3}{R_2}\right) = 11$

esempio

$V_{IN} = 100\,mV$
$V_{OUT} = 1{,}1\,V$

$V_{out} = V_{diff} A_{diff}$

- $G_{loop}$




$$G_{loop} = \frac{V_T'}{V_T}$$

$$v^- = V_T \cdot \frac{R_2}{R_2+R_3}$$

$$v^+ = 0$$

$$v_T' = (v^+ - v^-)\, A_{diff} = -A_{diff} \frac{R_2}{R_2+R_3} \cdot V_T$$

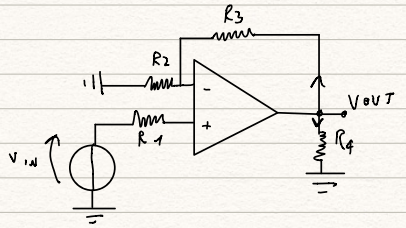
$$G_{loop} = -A_{diff} \frac{R_2}{R_2+R_3} = -90909$$

$$G_{reale} = \frac{G_{ID}}{1 - \frac{1}{G_{loop}}} = \frac{11}{1 - \frac{1}{(-90909)}} = 10{,}9998$$

3) Amplificatore rail to rail

$V_{dd} = +15\ V \qquad V_{ss} = -15V$

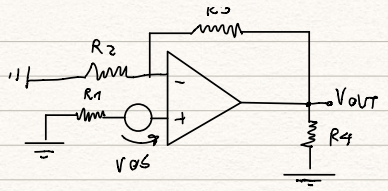
Quanto vale la max corrente di uscita?




CASO PESSIMO PER $V_{OUT} = +15V$

$$I_{OUT} = I_{R4} + I_{retroaz} = V_{OUT}\left(\frac{1}{R_4} + \frac{1}{R_3+R_2}\right) = 286{,}4\ \mu A$$

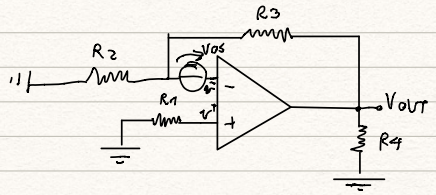
3) Valutare effetto su $V_{OUT}$ di $V_{OS} = \pm 3{,}5\ mV$




$v^+ = v_{os}$

$v^- = v^+$

$v_{OUT} = \pm v_{os}\left(1 + \frac{R_3}{R_2}\right)$




$v^+ = 0$

$v^- = v^+$

$v_{R2} = -v_{os} \rightarrow i_{R2} = -\frac{v_{os}}{R_2}$

$v_{R3} = -\frac{v_{os}}{R_2} \; R_3$

$v_{OUT} = \pm\left(v_{os}\left(1+\frac{R_3}{R_2}\right)\right) \simeq \pm 27{,}5\,mV$

4) Valutare effetto delle correnti di bias uscenti e dell'offset di corrente dell'op. amp. sull'uscita

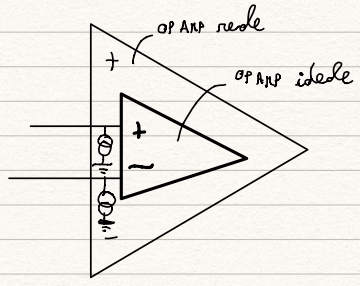
$I_{BIAS} = \frac{I^+ + I^-}{2}$

$I_{os} = |I^+ - I^-|$

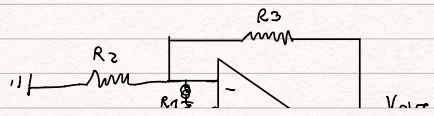
$I^+ = I_{BIAS} + \frac{I_{os}}{2}$

$I^- = I_{BIAS} - \frac{I_{os}}{2}$

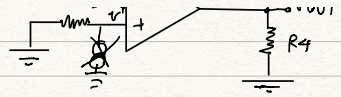
$-I_{BIAS}$




$I_B^+ = I_B^- = I_{BIAS}$




$v_{OUT}|_{I_{B+}} = I_B^+ R_1 \left(1+\frac{R_3}{R_2}\right)$



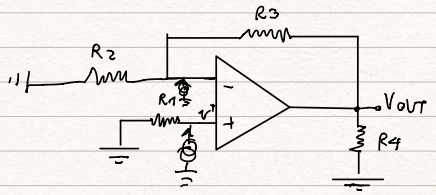

$V_{OUT}\big|_{I_B^-} = -I_B^- R_3$

$V_{OUT} = I_{BIAS}\left(R_1\left(1+\frac{R_3}{R_2}\right) - R_3\right)$

se $R_1\left(1+\frac{R_3}{R_2}\right) = R_3$

$V_{OUT}\big|_{I_{BIAS}} = 0$

$-I_{OS}$



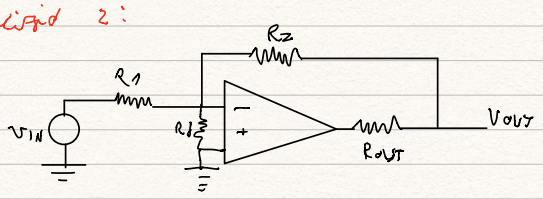

$V_{OUT}\big|_{I_{OS}^+} = +I_{OS}^+ R_1\left(1+\frac{R_3}{R_2}\right)$

$V_{OUT}\big|_{I_{OS}^-} = +I_{OS}^- R_3$

$|I_{OS}^+| = |I_{OS}^-| = \frac{I_{OS}}{2}$

$V_{OUT}\big|_{I_{OS}} = \pm\frac{I_{OS}}{2}\left(R_1\left(1+\frac{R_3}{R_2}\right) + R_3\right)$

esercizio 2:

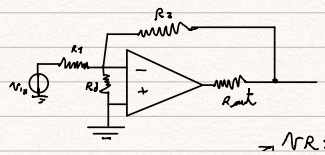



$R_1 = 10\ K\Omega$
$R_2 = 100\ K\Omega$
$R_L = 1M\Omega$
$R_{OUT} = 1K\Omega$
$A_{diff} = 100\ dB\ (10^5)$

RETROAZIONE NEGATIVA

1) $G_{reale} = \frac{V_{OUT}}{V_{IN}}\Big|_{reale}$

$G_{ID}$:




$I_{R_1} = \frac{V_{IN}}{R_1} = i_{R_2}$

$V_{OUT} = 0 + (-V_{R_2}) = -V_{IN}\frac{R_2}{R_1}$

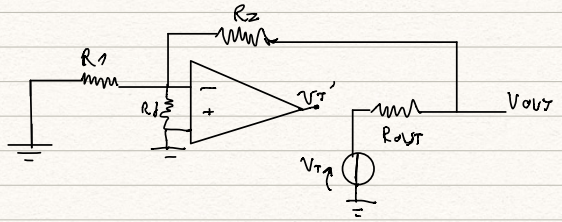
$-V_{R_1} = V_{IN}$

$v^- = v^+ = \emptyset$ ✓

$\rightarrow i_{Rd} = \emptyset$

$$\left.\frac{V_{OUT}}{V_{IN}}\right|_{ID} = -\frac{R_2}{R_1}$$

- Gloop




$$\frac{v_T'}{V_T} = G_{loop}$$

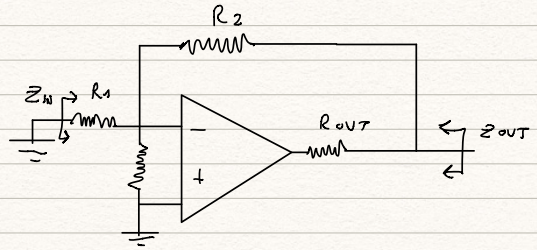
$$v^- = V_T \cdot \frac{R_1 // R_d}{(R_1 // R_d) + R_2 + R_{OUT}}$$

$$v_T' = -v^- A_{diff}$$

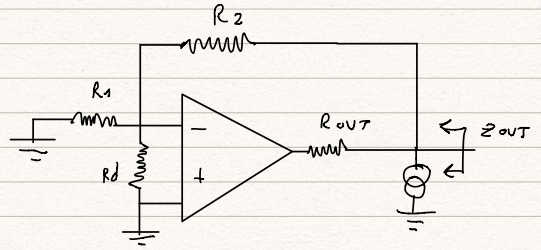
$$G_{loop} = -A_{diff} \frac{R_1 // R_d}{(R_1 // R_d) + R_2 + R_{OUT}} = -8927$$

$$G_{reale} = \frac{G_{id}}{1 - \frac{1}{G_{loop}}} = 9,9$$

2) Valutare $z_{in}$ e $z_{out}$




$z_{OUT}$

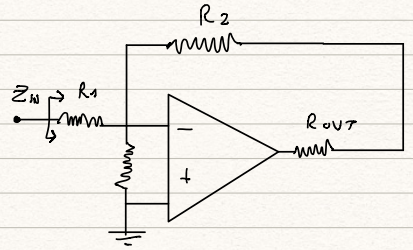


$$Z_{OUT} = \frac{Z_{OUT}^{0}}{1 - G_{loop}}$$

$$Z_{out}^{0} = R_{out} \,//\, \left[R_2 + (R_1 // R_d)\right] = 991\,\Omega$$

$$Z_{OUT} = \frac{991\,\Omega}{1 + 9927} = 0{,}11\,\Omega$$

$Z_{IN}$

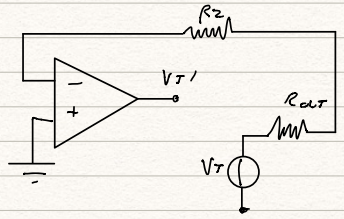



$$Z_{IN} = R_1 + R_d \,//\, Z^{*}$$

$$Z^{*} = \frac{Z^{*0}}{1 - G_{loop}^{*}}$$

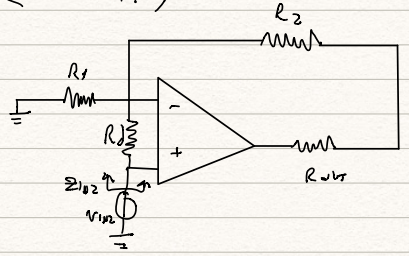
$$Z^{*0} = R_2 + R_{OUT}$$

$$G_{loop}^{*} = -A_{diff}$$




$$Z^{*} = \frac{R_2 + R_{OUT}}{1 + A_{diff}} = 1{,}01\,\Omega$$

$$Z_{IN} = R_1 + R_d \,//\, \left(\frac{R_2 + R_{OUT}}{1 + A_{diff}}\right)$$




retroazione $i_{Rd} \to 0$

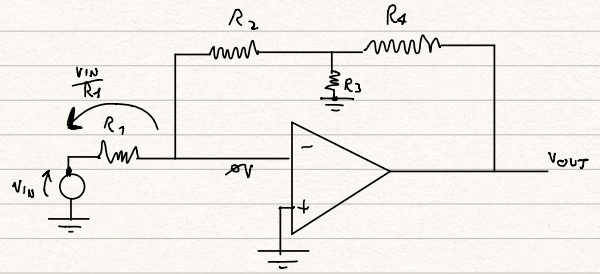
$$Z_{IN2} = Z_{IN2}^{0}\,(1 - G_{loop})$$

$$Z_{IN\,2^\circ} = R_d + \left[R_1 // (R_2 + R_{OUT})\right]$$

$$G_{loop} = -\frac{R_1 // R_d}{R_1 // R_d + R_2 + R_{OUT}} \qquad A_{diff} \simeq -8927$$

$$Z_{IN\,2} \simeq 1M\Omega\,(1 + 8927) = 8928M\Omega$$

esercizio 3:




$R_1 = 1M\Omega$
$R_2 = 1M\Omega$
$R_3 = 200K\Omega$
$R_4 = 1M\Omega$

1) $G_{ID}$

$$i_{R1} = i_{R2}$$

$$V_{R3} = -V_{IN}\frac{R_2}{R_1}$$

$$i_{R3} = \frac{-V_{IN}\frac{R_2}{R_1}}{R_3}$$

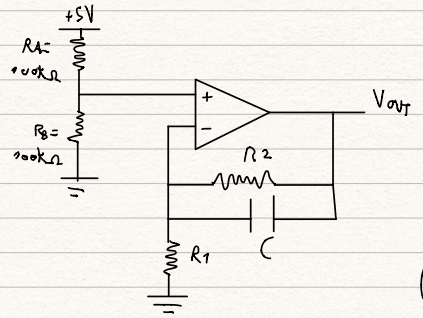
$$i_{R4} = i_{R2} - i_{R3} = \frac{V_{IN}}{R_1} - \left(-\frac{V_{IN}}{R_3}\frac{R_2}{R_1}\right) =$$

$$= V_{IN}\left(\frac{1}{R_1} + \frac{R_2}{R_3 R_1}\right)$$

$$V_{R4} = \frac{V_{IN}}{R_1}\left(1 + \frac{R_2}{R_3}\right)R_4$$

$$V_{OUT} = -V_{IN}\frac{R_2}{R_1} - \frac{V_{IN}R_4}{R_1}\left(1 + \frac{R_2}{R_3}\right) = -V_{IN}\left(\frac{R_2}{R_1} + \frac{R_4}{R_1} + \frac{R_4}{R_1}\cdot\frac{R_2}{R_3}\right)$$

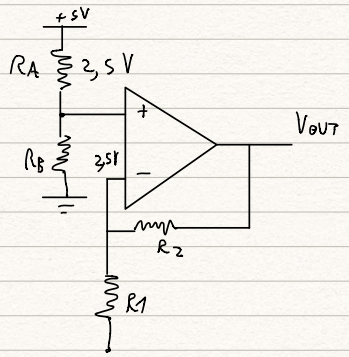
esercizio 4:




$R_2 = 2K\Omega$
$R_1 = 1K\Omega$
$C = 5\,pF$
$A_{diff} = 100\,dB\ (\rightarrow 10^5)$
$CMRR = 80\,dB$

$$\left(\frac{A_{diff}}{A_{CM}} = CMRR \longrightarrow \frac{10^5}{A_{CM}} = 10^8 \rightarrow A_{CM} = 10\right)$$

1) Con $i_{IN} = 0$
Valutare effetto su $V_{OUT}$ del modo comune di ingresso




$V_{OUT} = 2,5\ V \left(1 + \frac{R_2}{R_1}\right) = 7,5\ V$

$V_{CM} = +2,5\ V$