(1) $v^+ = \frac{R_5}{R_4+R_5} v_{in}$ $v^- = v^+$ per corto circuito virtuale

Poichè l'opamp è ideale in R_3 non passa corrente $\Rightarrow v_{(A)} = v^-$

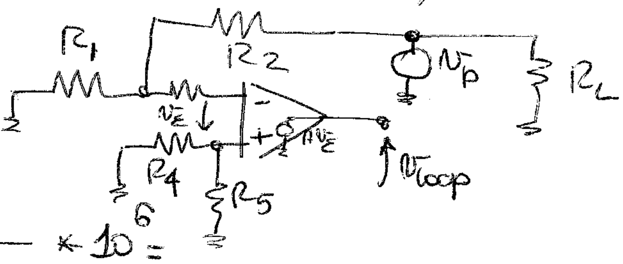
$v_{out} = i * (R_1+R_2) = \frac{v^-}{R_1}(R_1+R_2) = \frac{R_5}{R_4+R_5} * \left(1+\frac{R_2}{R_1}\right) v_{in}$

la resistenza R_L non influisce sul guadagno ideale

$\Downarrow$

$G_{id} = \frac{V_{out}}{V_{in}} = \frac{R_5}{R_4+R_5}\left(1+\frac{R_2}{R_1}\right) = \frac{50}{50+50}\left(1+\frac{100k}{10k}\right) = +5.5$

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

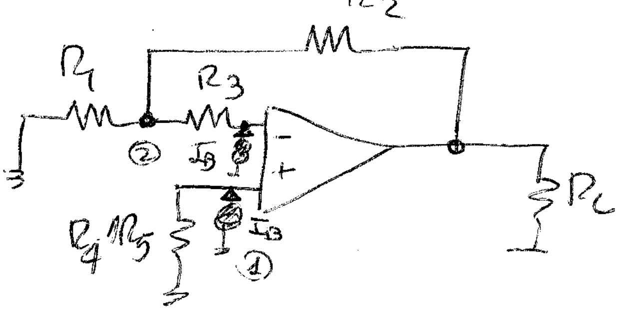


$G_{loop} = \frac{-R_1}{R_1+R_2} \cdot A = -\frac{10k}{10k+100k} * 10^6 =$

$= -9.1\ 10^4$

$\hookrightarrow G_{reale} = \frac{5.5}{1+\frac{1}{9.1\ 10^4}} = +5.4999$

(2)



$V_{out_{(1)}} = I_B * R_4 // R_5 * \left(1+\frac{R_2}{R_1}\right) = 1\mu A * 50 // 50 * \left(1+\frac{100k}{10k}\right) =$

$= 1\mu A * 25\Omega * 11 = 2.75\ 10^{-4} V = 0.275 mV$

$V_{out_{(2)}}$: $V_{(A)} = -I_B * R_3 \Rightarrow I_{R_1} = \frac{V_{(A)}}{R_1} = -I_B \frac{R_3}{R_1}$

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

$V_{out_{(2)}} = V_{(A)} - I_{R_2} * R_2 = -I_B * R_3 - I_B * \left(1+\frac{R_3}{R_1}\right) * R_2 =$

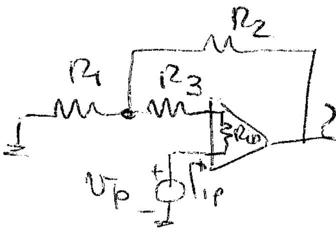
$= -I_B\left[R_3 + R_2\left(1+\frac{R_3}{R_1}\right)\right] = 1\mu A\left[220\Omega + 100k\left(1+\frac{220\Omega}{10k}\right)\right]$

③ Per compensare le correnti di bias:

$$R_{comp} + R_4 \parallel R_5 = R_3 + R_1 \parallel R_2$$

$\Downarrow$ $R_{comp} = R_3 + R_1 \parallel R_2 - R_4 \parallel R_5 = 220\,\Omega + 10k \parallel 100k - 25\,\Omega$

$= 9.295\,k\Omega$



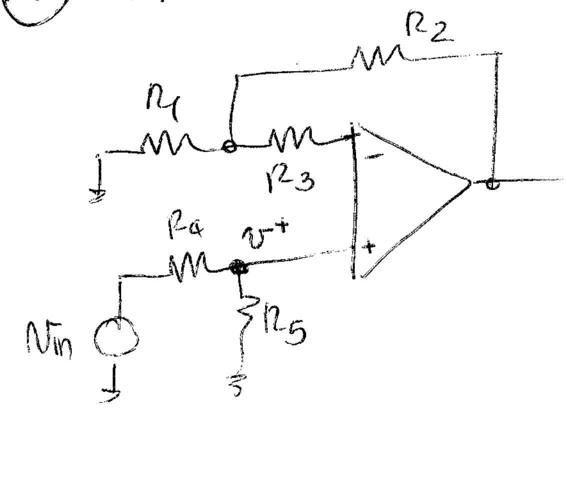
④ $R^*|_{id} = \infty \Rightarrow R^* = R_0^* (1 - G^*_{loop})$

$R_0^* = R_{ID} + R_3 + R_1 \parallel R_2 = 1M\Omega + 220\,\Omega + 10k \parallel 100k = 1.009$

$G^*_{loop} = -\dfrac{R_1 \parallel (R_3 + R_{ID})}{R_2 + R_1 \parallel (R_3 + R_{ID})} A_0 = -\dfrac{10k \parallel (220\,\Omega + 1M\Omega)}{100k + 10k \parallel (220\,\Omega + 1M\Omega)} * 10^6 = -9$

$\Downarrow$ $R^*_i = 1.009\,M\Omega * (1 + 9\,10^4) = 90.8\,G\Omega$

⑤ CMRR = 50 dB = 316 $\qquad$ 50 dB = 20 log CMRR



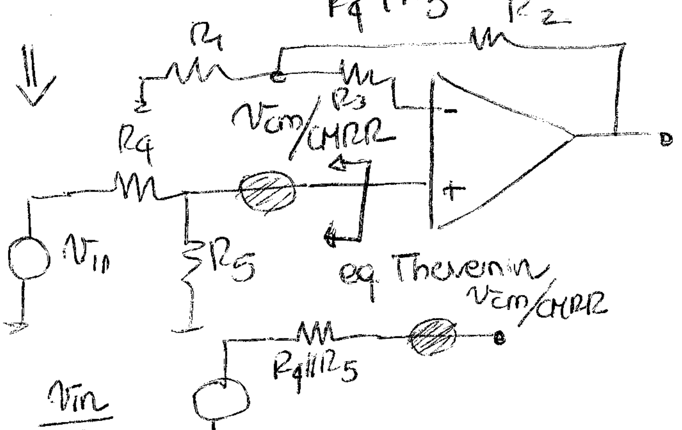
$$v^+ = \frac{R_5}{R_4 + R_5} \cdot v_{in}$$

$$v_{cm} = \frac{v_+ + v_-}{2}$$

$v^- \simeq v^+$ (nelle hp di $A_{dm} \to \infty$, poiché in R_3 non scorre corrente)

$\rightarrow$ $v_{cm} = \dfrac{R_5}{R_4 + R_5} v_{in}$

$\Downarrow$



$v_{out}|_{max} = \left[\dfrac{v_{in}}{2} \pm \dfrac{v_{cm}}{CMRR}\right] * \left(1 + \dfrac{R_2}{R_1}\right) =$

$= \left[\dfrac{150mV}{2} \pm \dfrac{150mV}{2} \cdot \dfrac{1}{316}\right] * \left(1 + \dfrac{100k}{10k}\right)$

$= \begin{cases} + \; 0.828V \\ - \; 0.822V \end{cases}$ invece di 0.825 V

(6) Errore statico di guadagno

$$\varepsilon = \left| \frac{G_{id} - G_{reale}}{G_{reale}} \right| = \left| \frac{G_{id} - \frac{G_{id}}{1 - 1/G_{loop}(0)}}{G_{id} / 1 - 1/G_{loop}(0)} \right| =$$

$$= \left| 1 - \frac{1}{1 - 1/G_{loop}(0)} \right| = \left| 1 - \frac{1}{G_{loop}(0)} - 1 \right| = \frac{1}{|G_{loop}(0)|} = 1.1 \; 10^{-5}$$

$\Downarrow$

$\varepsilon\% = 1.1 \; 10^{-3} \%$

(7) $I_{OUT} = \frac{V_{out}}{R_L} + \frac{V_{out}}{R_1 + R_2}$ (nel caso di op amp ideale)

$\Downarrow$

$$V_{out}\Big|_{max} = I_{out} \Big/ \left(\frac{1}{R_L} + \frac{1}{R_1 + R_2} \right) = 10mA \Big/ \left(\frac{1}{500\,\Omega} + \frac{1}{110\,k\Omega} \right) =$$

$$= 10mA * 498\,\Omega = 4.98V$$

(8) $SR = 0.75 V/\mu s$

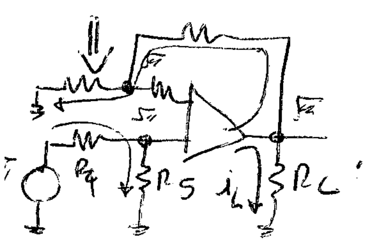
$$\frac{dV_{out}}{dt}\Big|_{MAX} = A_{in} * G * \omega * \cos\omega t \Big|_{max} = A_{in} * G * \omega$$

$\Downarrow$

$$A_{in}\Big|_{MAX} = \frac{SR}{G\omega} = \frac{0.75 V/\mu s}{\frac{1}{2} * 11 * 2 * \pi * 15kHz} = 1.45V$$

(9) $V_{in} = 200mV \Rightarrow V_{out} = V_{in} * \frac{R_5}{R_4 + R_5} \left(1 + \frac{R_2}{R_1} \right) = \frac{V_{in}}{2} * 11 =$

$= 1.1V$



$$i_L = \frac{V_{out}}{R_L} = \frac{1.1V}{500\,\Omega} = 2.2mA$$