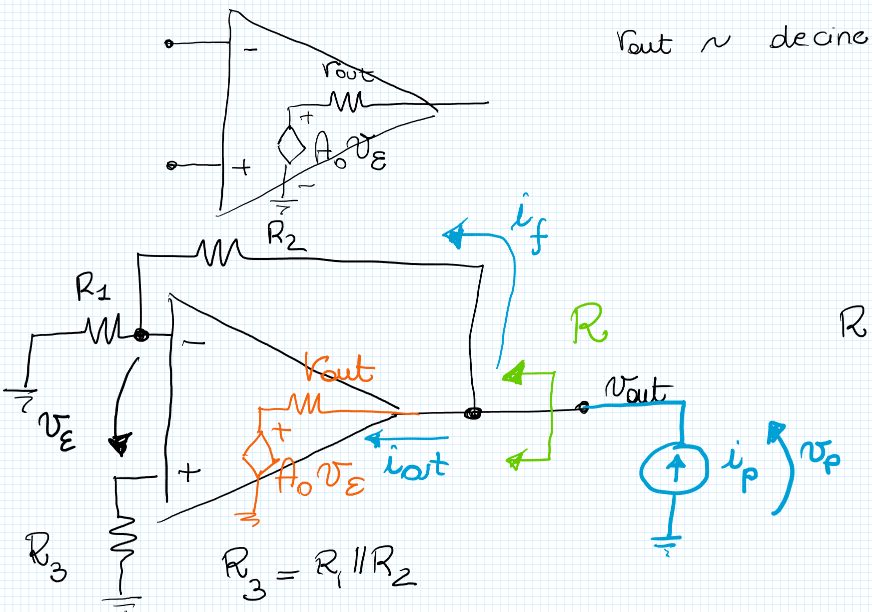
Amplificatore operazionale: resistenza di uscita non nulla, CMRR finito, SlewRate e limitazione corrente di uscita

Wednesday, May 5, 2021 10:22 AM

RESISTENZA DI USCITA NON NULLA



$r_{out} \sim$ decine di ohm

$R_3 = R_1 // R_2$

$R|_{ideale} = 0$

$R \triangleq \frac{v_p}{i_p}$

$$i_p = i_f + i_{out} \qquad i_{out} = \frac{v_p - A_0 v_\varepsilon}{r_{out}} \qquad i_f = \frac{v_p}{R_2 + R_1}$$

$$v_\varepsilon = -v^- = -\frac{R_1}{R_1 + R_2} v_p$$

$$i_p = \frac{v_p}{R_1 + R_2} + \frac{v_p}{r_{out}} + \frac{A_0}{r_{out}} \frac{R_1}{R_1 + R_2} v_p =$$

$$= v_p \left[\frac{1}{R_1 + R_2} + \frac{1}{r_{out}} + \frac{A_0}{r_{out}} \frac{R_1}{R_1 + R_2} \right]$$

$$R \triangleq \frac{v_p}{i_p} = \frac{1}{\frac{1}{R_1+R_2} + \frac{1}{r_{out}}\left(1 + A_0 \frac{R_1}{R_1+R_2}\right)} =$$

$$= (R_1 + R_2) // \frac{r_{out}}{1 + A_0 \frac{R_1}{R_1+R_2}} =$$

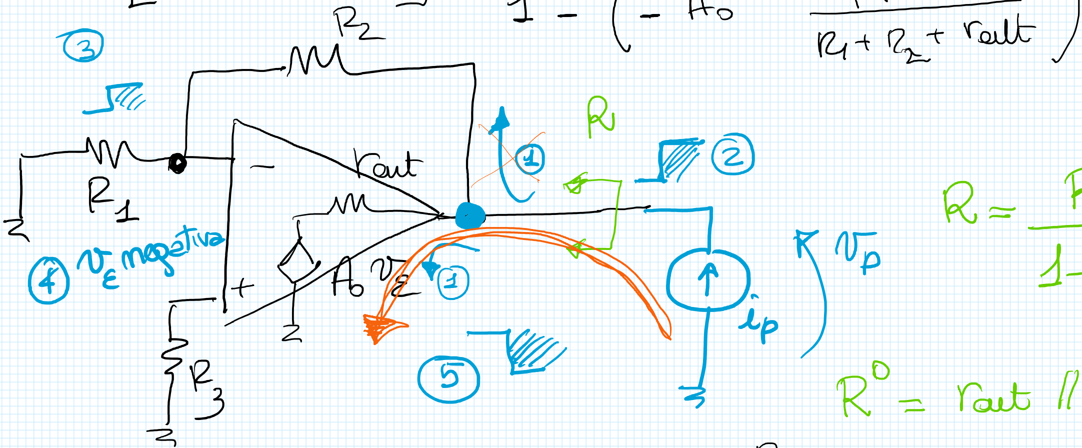
$$= \frac{(R_1+R_2) \cdot r_{out}}{1 + A_0 \frac{R_1}{R_1+R_2}} \cdot \frac{1}{(R_1+R_2) + \frac{r_{out}}{1 + A_0 \frac{R_1}{R_1+R_2}}} =$$

$$= \frac{(R_1+R_2) \cdot r_{out}}{\qquad} =$$

$$(R_1+R_2) + A_0 R_1 + r_{out}$$

$$= \frac{(R_1+R_2)\cdot r_{out}}{(R_1+R_2)+r_{out}} \cdot \frac{1}{1+A_0\dfrac{R_1}{R_1+R_2+r_{out}}} =$$

$$= \left[(R_1+R_2) \parallel r_{out}\right] \frac{1}{1-\left(-A_0\dfrac{R_1}{R_1+R_2+r_{out}}\right)}$$

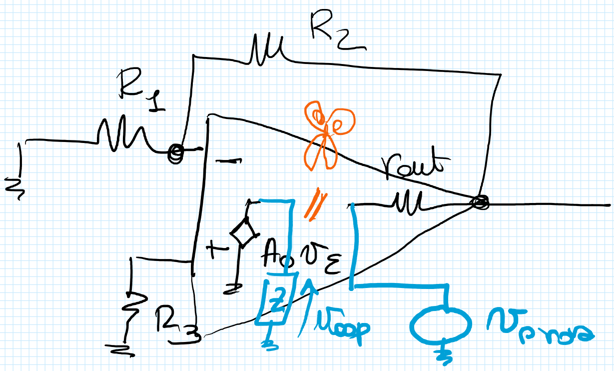


$$R = \frac{R^0}{1-G^*_{loop}}$$

$$R^0 = r_{out} \parallel (R_1+R_2)$$

$$G^*_{loop} \triangleq \frac{v_{loop}}{v_{prova}} =$$

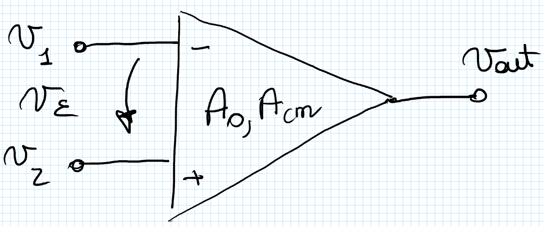
$$= -\frac{R_1}{R_1+R_2+r_{out}} \cdot A_0$$



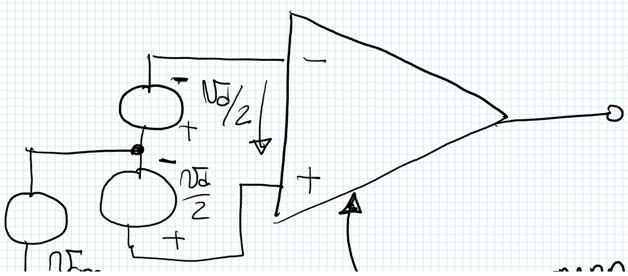
$$R = \frac{r_{out} \parallel (R_1+R_2)}{1+A_0\dfrac{R_1}{R_1+R_2+r_{out}}} \simeq \frac{r_{out}}{1+A_0\dfrac{R_1}{R_1+R_2}}$$

★ RAPPORTO DI REIEZIONE DEL MODO COMUNE FINITO.

$$CMRR \triangleq \left|\frac{A_{dm}}{A_{cm}}\right| = \left|\frac{A_0}{A_{cm}}\right|$$

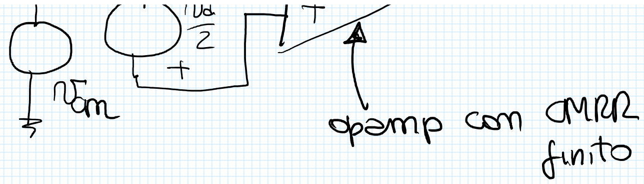


$$v_{out} = A_0(v_2 - v_1) + A_{cm}\frac{v_1+v_2}{2} = A_0 v_\varepsilon + A_{cm} v_{cm}$$

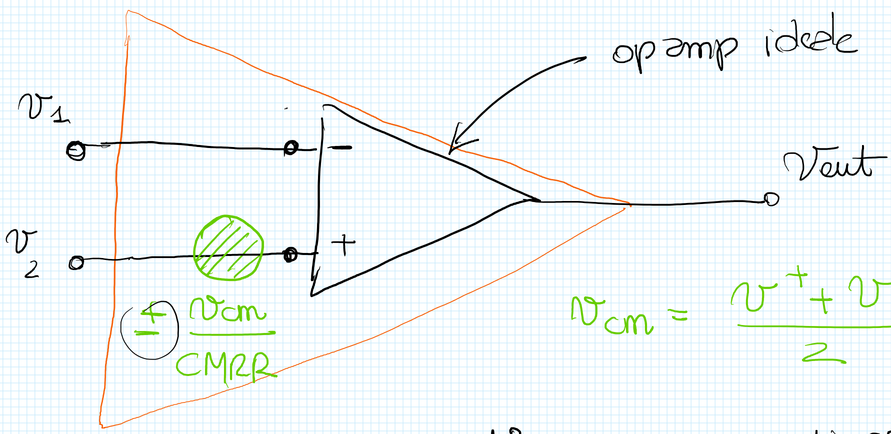


$$v_{out} = A_0 v_d + A_{cm} v_{cm} =$$

$$= A_0\left[v_d + \frac{A_{cm}}{A_0} v_{cm}\right] =$$



$$= A_0 \left[v_d \pm \frac{1}{CMRR} v_{cm} \right]$$



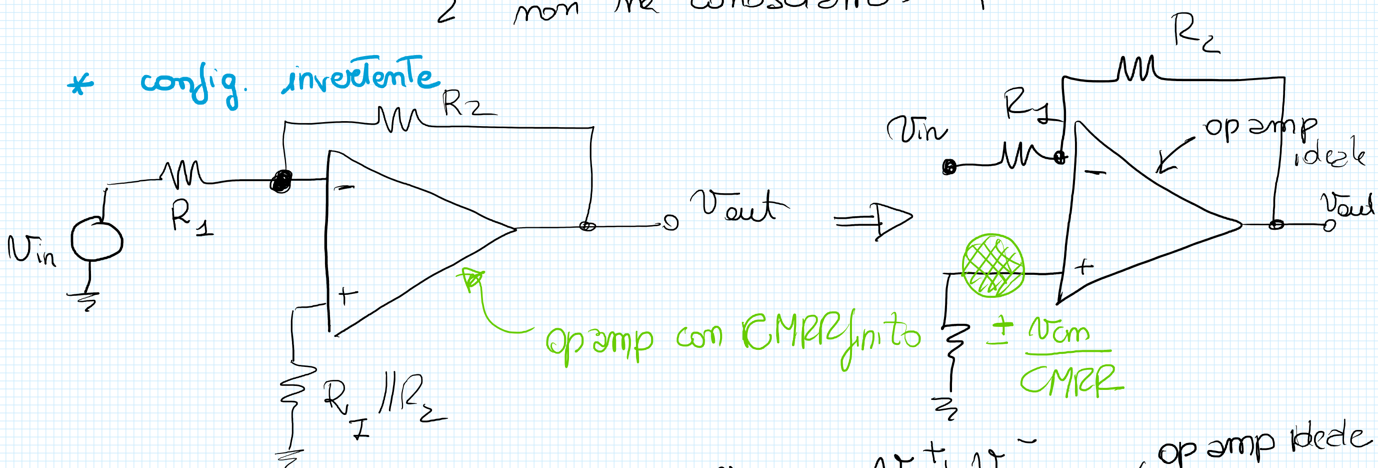
$$v_{cm} = \frac{v^+ + v^-}{2}$$

$40dB \leq CMRR \leq 120dB$

1° gen. equiv. di CMRR dipende dal segnale

2° non ne conosciamo la polarità

* config. invertente

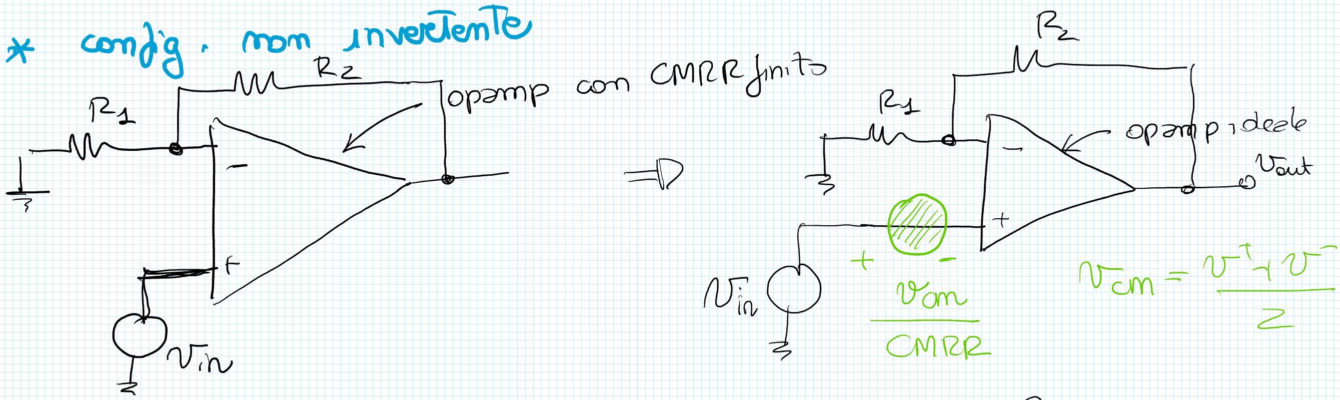


$$v_{cm} = \frac{v^+ + v^-}{2}$$

$v^+ = 0$ $\qquad v^- \simeq v^+ = 0$ (op amp ideale)

La config. invertente è insensibile al CMRR finito

* config. non invertente



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

$$\left. \begin{array}{l} v^+ = v_{in} \\ v^- = v^+ = v_{in} \end{array} \right\} v_{cm} = v_{in}$$

$v^- = v^+ = v_{in}$; ← approx. op-amp ideale

$$V_{out} = \left[v_{in} \pm \frac{v_{in}}{CMRR}\right]\left(1 + \frac{R_2}{R_1}\right) = v_{in}\left(1 + \frac{R_2}{R_1}\right)\left(1 \pm \frac{1}{CMRR}\right)$$

$R_2 = 100\,k\Omega$; $R_1 = 1\,k\Omega$; $CMRR = 40\,dB = 100$

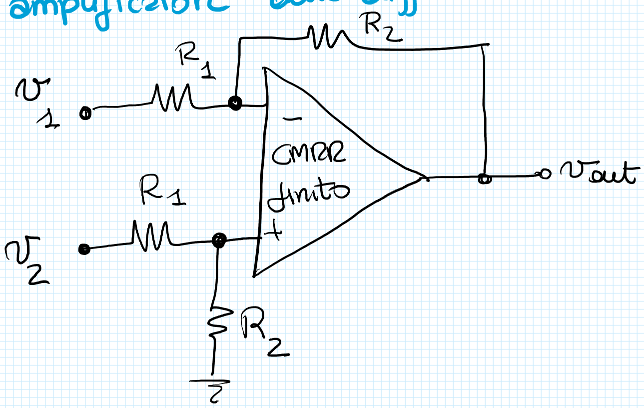
$v_{in} = 5\,mV \sin(\omega t)$ $\qquad G = 1 + \frac{R_2}{R_1} = 101$

$V_{out} = 505\,mV \sin \omega t$ ← ideale

$$V_{out}\Big|_{\text{reale con CMRR finito}} = \left[1 + \frac{R_2}{R_1}\right]\left[1 \pm \frac{1}{100}\right] 5mV \sin(\omega t) =$$

$= \begin{cases} 510\,mV \sin \omega t \\ 500\,mV \sin \omega t \end{cases}$

* amplificatore delle differenze



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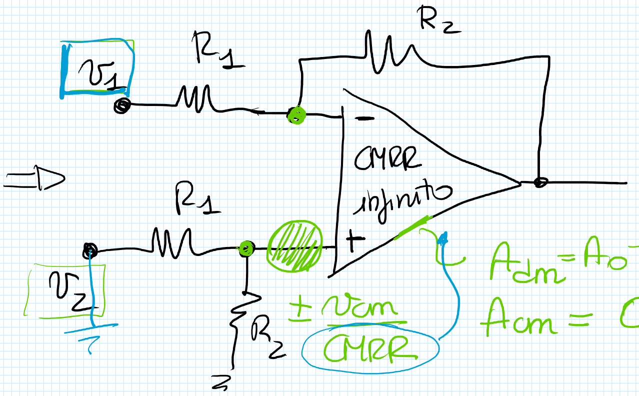
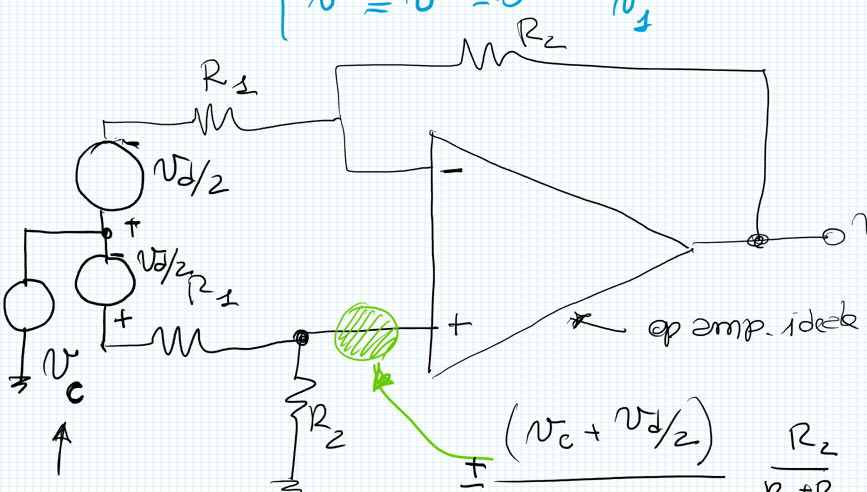


$$v_{cm} = \frac{v^+ + v^-}{2}$$

$v_2 \begin{cases} v^+ = \frac{R_2}{R_1+R_2} v_2 \\ v^- = v^+ \end{cases} \Rightarrow v_{cm}\Big|_{v_2} = \frac{R_2}{R_1+R_2}$ [illegible]

↑ hp idealità opamp

$v_1 \begin{cases} v^+ = 0 \\ v^- = v^+ = 0 \end{cases} \qquad v_{cm}\Big|_{v_1} = 0$



$$\pm \frac{(v_c + v_d/2)}{CMRR} \cdot \frac{R_2}{R_1+R_2}$$

V_{cm} : tens. di modo comune in ingresso all'opamp

V_c : tens. di modo comune in ingresso all'ampl. delle differenze

$v_1 = v_c - v_d/2$

$v_2 = v_c + v_d/2$

→∞

$\pm \frac{(\ \ )}{CMRR} \quad \frac{\ }{R_1+R_2} \quad (v_2 = v_c + v_d/2$

sovrapp. degli effetti

- v_c non dà contributi
- $v_d \rightarrow$ guadagno differenziale $\frac{R_2}{R_1}$
- $\pm \frac{v_c + v_d/2}{CMRR} \frac{R_2}{R_1+R_2} \rightarrow$ config. non invertente $G = \left(1 + \frac{R_2}{R_1}\right)$

$$v_{out} = v_d \frac{R_2}{R_1} \pm \left[\frac{(v_c + v_d/2)}{CMRR} \frac{R_2}{R_1+R_2}\right]\left(1 + \frac{R_2}{R_1}\right) =$$

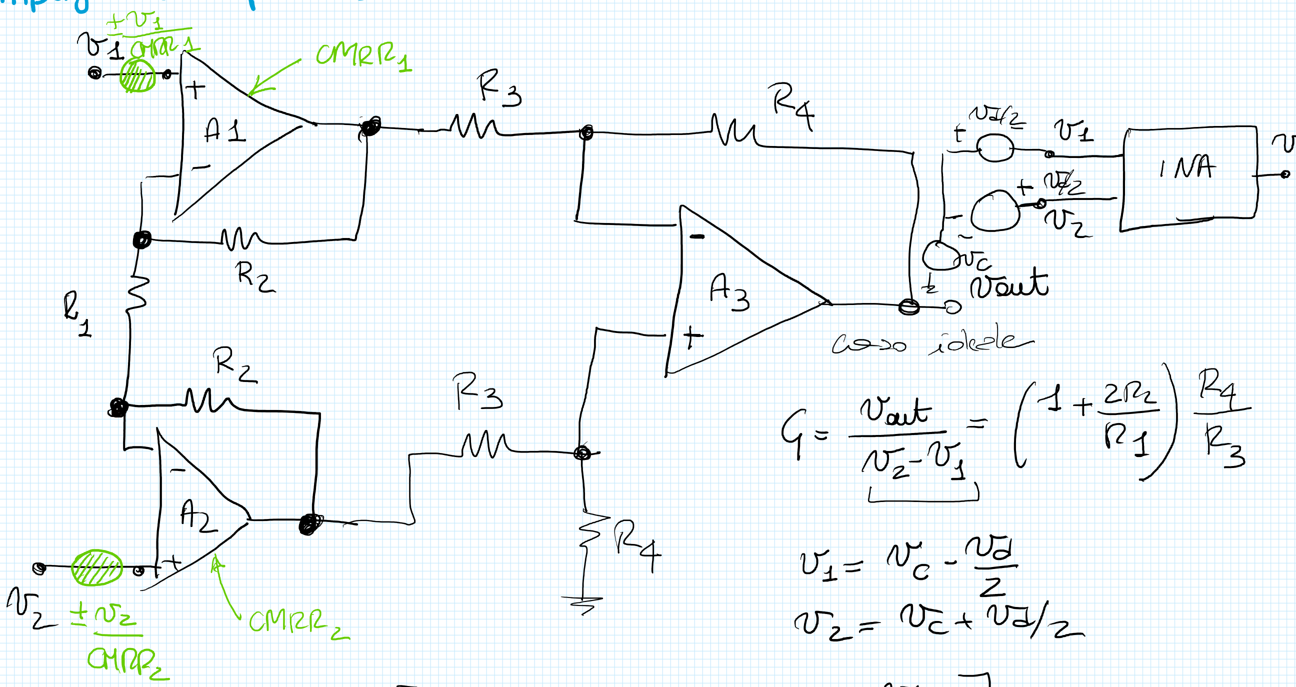
$\left(1+\frac{R_2}{R_1}\right) = \frac{R_1+R_2}{R_1}$

$$= G_{diff}\, v_d + G_c\, v_c$$

$$CMRR_{TOT} = \left|\frac{G_{diff}}{G_c}\right| = \left| CMRR \pm 1/2 \right| \simeq CMRR_{opamp}$$

(CMRR dell'opamp)

*** amplificatore per strumentazione**



$$G = \frac{v_{out}}{v_2 - v_1} = \left(1 + \frac{2R_2}{R_1}\right)\frac{R_4}{R_3}$$

$$v_1 = v_c - \frac{v_d}{2}$$

$$v_2 = v_c + v_d/2$$

$$v_{out} = \left(1 + \frac{2R_2}{R_1}\right)\frac{R_4}{R_3} \cdot \left[v_2 \pm \frac{v_2}{CMRR_2} - v_1 \mp \frac{v_1}{CMRR_1}\right] =$$

$CMRR_2 = CMRR_1 = CMRR$

$$= \left(1 + \frac{2R_2}{R_1}\right)\frac{R_4}{R_3}\left[\left(v_c + \frac{v_d}{2}\right)\left(1 \pm \frac{1}{CMRR}\right) - \left(v_c - \frac{v_d}{2}\right)\left(1 \pm \frac{1}{CMRR}\right)\right]$$

$$G_{dTOT} = \left(1 + \frac{2R_2}{R_1}\right)\left(1 \pm \frac{1}{CMRR}\right) G_{d_3}$$

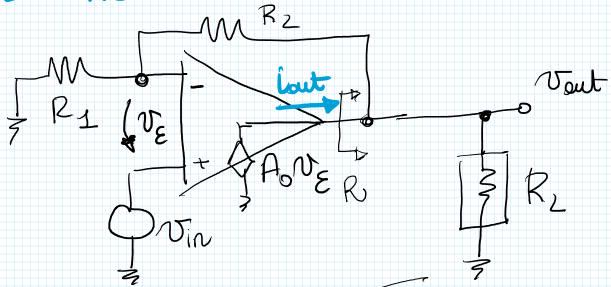
$$G_{c_{TOT}} = 1 \cdot G_{c_3}$$

$$CMRR_{TOT} = \left|\frac{G_{dTOT}}{G_{c\ldots}}\right| \simeq \left(1 + \frac{2R_2}{R_1}\right)\left|\frac{G_{d3}}{G_{c_3}}\right| =$$

($CMRR_3$)

$$CMRR_{TOT} = \left| \frac{G_{dTOT}}{G_{CTOT}} \right| \simeq \left(1 + \frac{2R_2}{R_1}\right) \left| \frac{G_{d3}}{G_{c3}} \right| = \left(1 + \frac{2R_2}{R_1}\right) CMRR_3$$

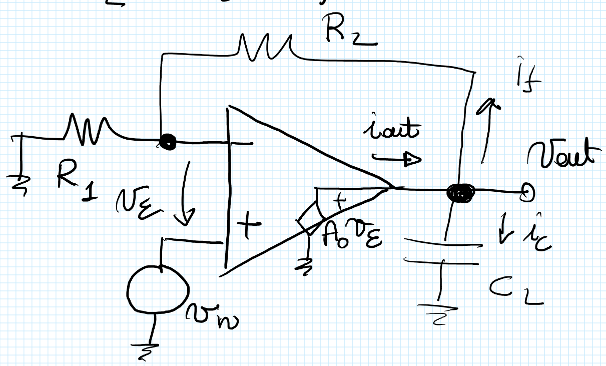
★ LIMITAZIONE DELLA CORRENTE DI USCITA



$i_{out_{MAX}}$ è fornito dal datasheet

$$|i_{out}|_{max} = \frac{\Delta V_{max}}{R_{min}}$$

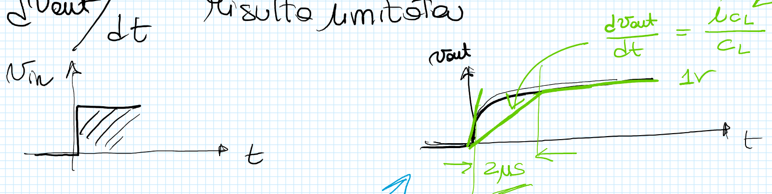
$$R = R_L // (R_1 + R_2) \geq R_{min}$$



$$i_{out} = i_{C_L} + i_f \qquad i_{C_L} = C_L \frac{dv_{out}}{dt}$$

$$i_{C_L max} = i_{out_{max}} - i_f = i_{out_{max}} - \frac{v_{out}}{R_1 + R_2}$$

→ dv_{out}/dt risulta limitata



"slew-rate" esterno

$C_L = 100\ nF$

$i_{out_{max}} = 50\ mA$ $\left[\frac{Q}{T}\right]$

$$\left.\frac{dv_{out}}{dt}\right|_{MAX} = \frac{50\ mA}{100\ nF} = \frac{5\ 10^{-2}}{10^{-7}} \frac{V}{s} = \qquad \left[\frac{Q}{V}\right]$$

$$= 5\ 10^5 \frac{V}{s} = 0.5\ V/\mu s$$

★ SLEW-RATE (INTERNO)

$= 5\ 10\ \frac{V}{s} = 0.5\ V/\mu s$

★ SLEW-RATE (INTERNO)

$$SR = \left.\frac{dv_{out}}{dt}\right|_{max}$$

la limitaz. deriva dalla corrente disponibile nei nodi interni dell'opamp per caricare le capacità interne e in particolare la capacità di compensazione

$$0.1\ V/\mu s \le SR \le 100\ V/\mu s$$

$$v_{out} = A_{out} \sin(\omega t)$$

$$\left.\frac{dv_{out}}{dt}\right|_{MAX} = \left.A_{out}\omega \cos \omega t\right|_{MAX} = A_{out}\,\omega = A_{out}\,2\pi f$$

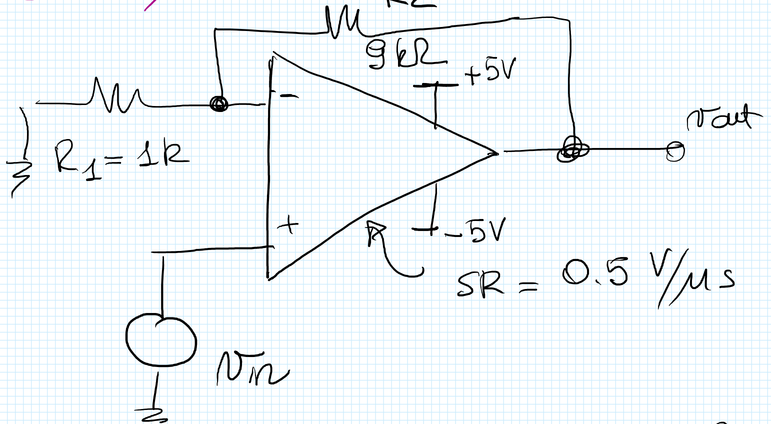
se $\left.\frac{dv_{out}}{dt}\right|_{MAX} = SR \Rightarrow SR = A_{out}\,2\pi f$

$$\left.A_{out}\right|_{MAX} = \frac{2\pi f}{SR} \Rightarrow f_{max} \le \frac{SR\ \ A_{out}|_{MAX}}{2\pi}$$

(MAX DINAMICA)

f_{max}: LARGHEZZA DI BANDA A PIENA POTENZA

ESEMPIO / ESERCIZIO



SR = 0.5 V/μs

$f_{in} = 10\ kHz$

↳ A_{in} max?

$\omega_{in} = 2\pi f_{in}$

$$v_{out} = \left(1 + \frac{R_2}{R_1}\right) v_{in} = \left(1 + \frac{R_2}{R_1}\right) A_{in} \sin \omega_{in} t =$$

$$\left(1 + \frac{R_2}{R_1}\right) = 10$$

$$\frac{dv_{out}}{dt} = \frac{d}{dt}\left[10 * A_{in} * \sin \omega_{in} t\right] =$$

$$= 10 * A_{in}\ \omega_{in} \cos \omega_{in} t$$

$$SR = \frac{dv_{out}}{dt} = 0.5\ V/\mu s \Rightarrow A_{in}\big|_{MAX} = \frac{SR}{10 * 2\pi f_{in}} = 795\ mV\ \ \text{NO}$$

(SR ← 0.5 V/μs)

$$SR = \frac{dV_{out}}{dt}\Big|_{max} = 0.5\,V/\mu s \Rightarrow A_{in}\Big|_{MAX} = \frac{SR}{10 \cdot 2\pi f_{in}} = 795\,mV$$

(f_{in} = 10kHz)

$V_{out}\big|_{MAX} = \pm 5V$ limitata dalla tens. di alimentazione

$A_{in}\big|_{MAX} \leq 500\,mV$

Se $f_{in} = 20\,kHz \Rightarrow$ limitaz. da SR $A_{in\,max} = 398\,mV$