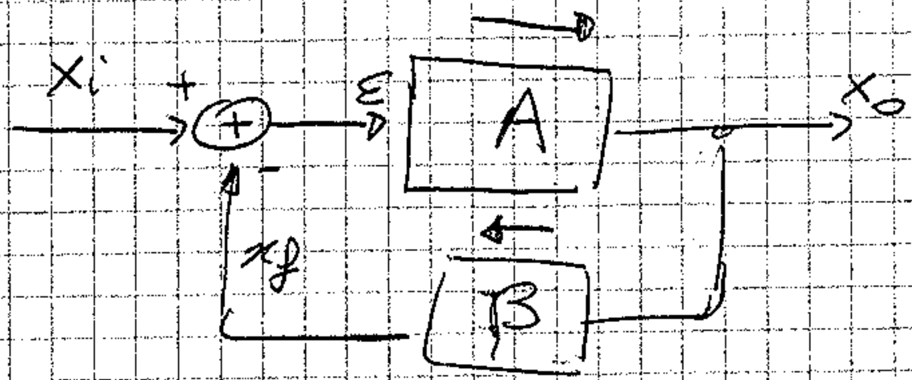
$$g_m = \left.\frac{\partial i_d}{\partial V_{GS}}\right|_{V_{DS}=cost} = 2K_n(V_{GSQ} - V_{TH})$$

fino ad ora ci siamo occupati di amplificatori ad anello.

AMPLIFICATORI RETROAZIONATI



A amplificatore come quelli già visti a cui non viene applicato tutto x_i ($\varepsilon = x_i - x_f$)

$$x_f = \beta x_o$$

Dobbiamo trovare $A_f = \frac{x_o}{x_i}$

$$x_o = A\varepsilon = A(x_i - x_f) = A(x_i - \beta x_o)$$

$$x_o(1 + \beta A) = A\, x_{in}$$

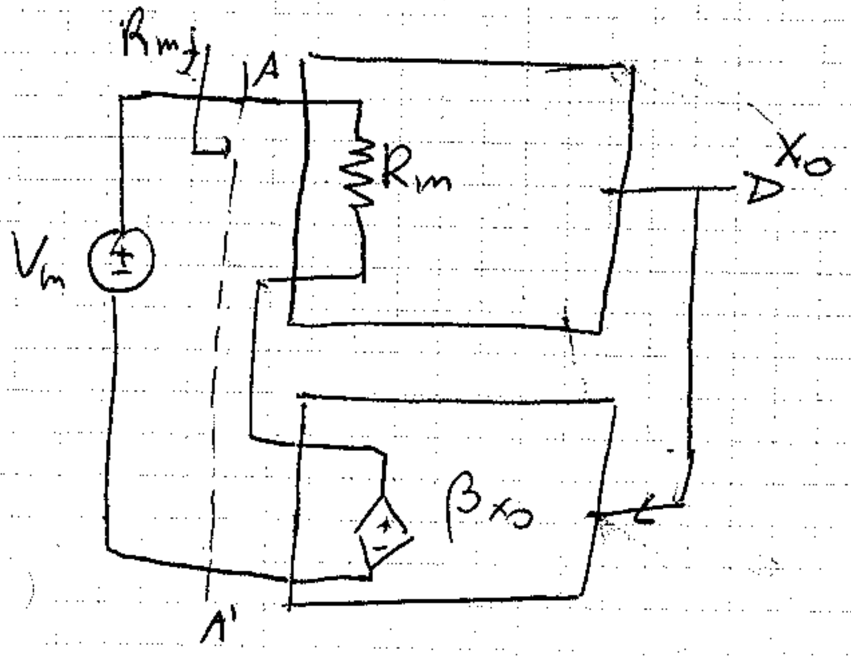
$$A_f = \frac{\cancel{1+\beta A}\ A}{1+\beta A}$$

Definiamo $T = \beta A$ il guadagno d'anello (33)

$$A_f = \frac{1}{\beta} \frac{T}{1+T} \quad \text{se } |T| \gg 1 \text{ allora}$$

$$A_f \simeq \frac{1}{\beta}$$

All'ingresso si fa un confronto, mentre all'uscita si fa una misura



$$V_\varepsilon = V_{in} - V_f \qquad R_{inf} = \frac{V_{in}}{i_{in}}$$

$$V_\varepsilon = R_{in} i_{in}$$

$$i_{in} = \frac{V_{in} - \beta x_o}{R_{in}} =$$

$$V_\varepsilon = V_{in} - x_o \beta = V_{in} - \beta A v_\varepsilon$$

$$V_\varepsilon (1 + \beta A) = V_{in} \qquad R_{in} I_{in} (1+\beta A) = V_{in}$$

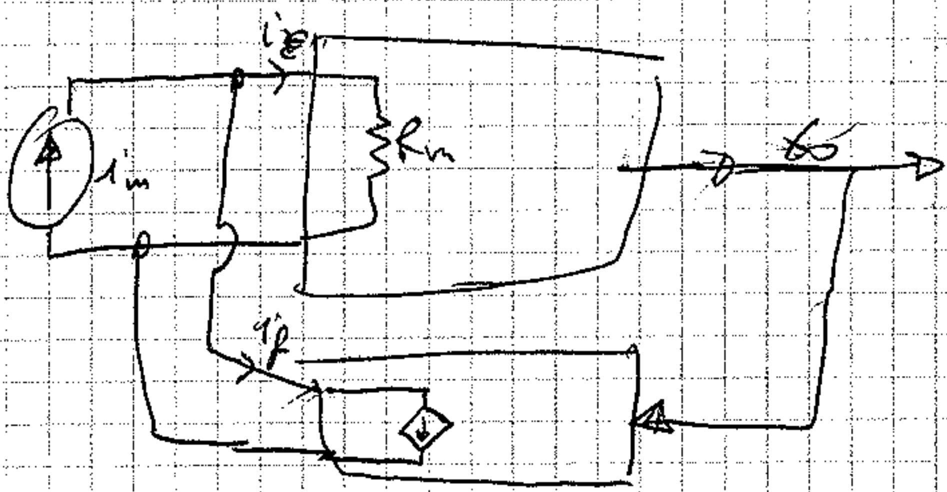
$$R_{mf} = R_m(1+\beta A) = R_m(1+T)$$

<u>Esempio</u>

$R_{in} = 10\ k\Omega \qquad T = 10^3$

$R_{mf} = 10^7\ \Omega = 10\ M\Omega$

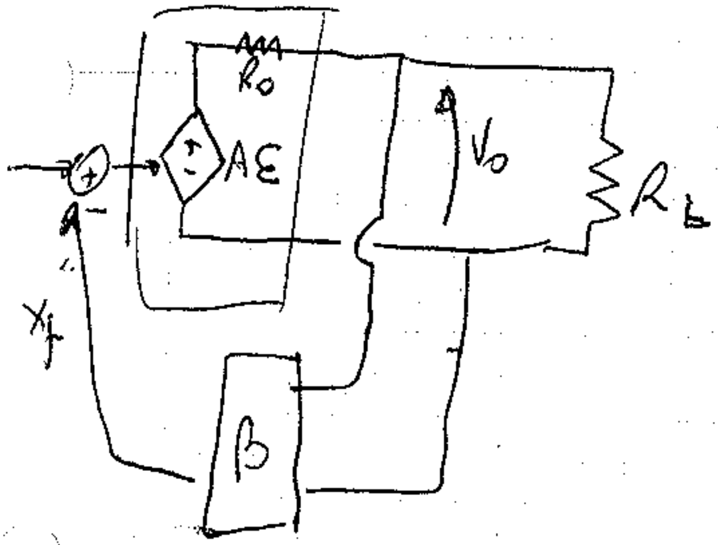
Si può anche ~~cercare~~ di creare un amplificatore pilotato in corrente



$i_f = \beta x_o \qquad i_\varepsilon = i_{in} - i_f$

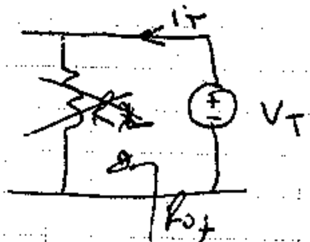
$$R_{mf} = \frac{R_m}{1+\beta A} = \frac{R_m}{1+T}$$

MISURA di TENSIONE di Uscita



Per misurare spengo x_i e inserisco un generatore di test alla parte di uscita di A

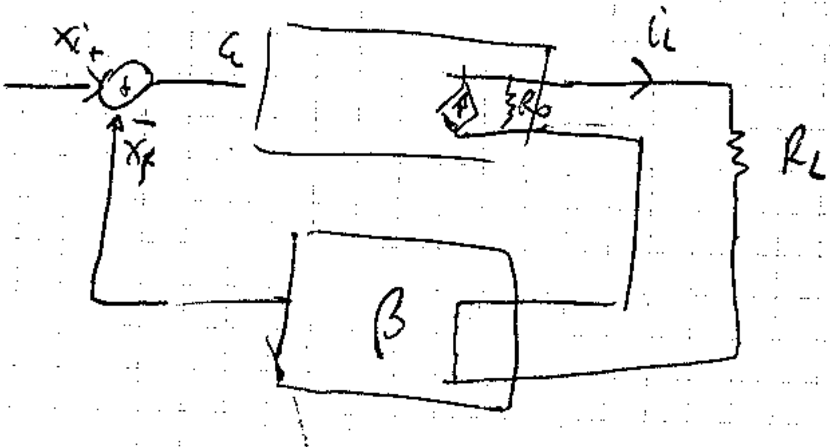
$$i_T = \frac{V_T - A\varepsilon}{R_o} =$$



$$= \frac{V_T + A x_f}{R_o} = \frac{V_T + \beta A V_o}{R_o} = V_T \left(\frac{1+\beta A}{R_o} \right)$$

$$R_{of} = \frac{V_T}{i_T} = \frac{R_o}{1+\beta A} = \frac{R_o}{1+T}$$

MISURA di CORRENTE di uscita

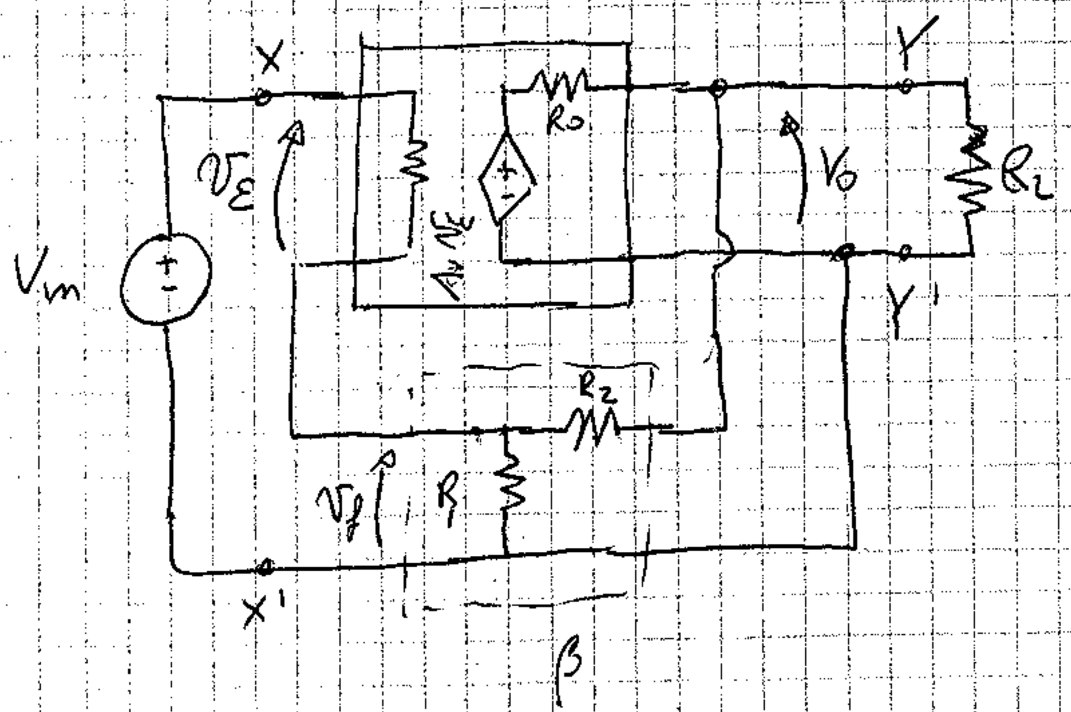


Ricapitoliamo

Amplif.	Confronto	Misura
A_V	V	V
A_I	I	I
G	V	I
R_M	I	V

Poiché $A_f \simeq \frac{1}{\beta}$ se $|T| \gg 1$ si ha che

$\beta < 1$ affinché si abbia un amplificatore



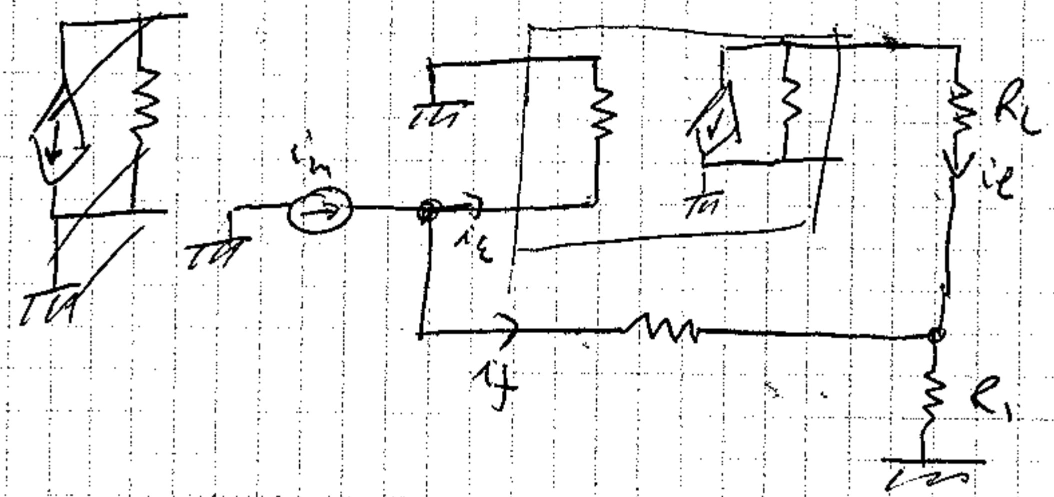
$$\beta = \frac{V_f}{V_o} = \frac{R_1}{R_1 + R_2} \qquad \beta = \frac{1}{1 + \frac{R_2}{R_1}}$$

Se $|\beta A_v| \gg 1 \Rightarrow A_f \simeq \frac{1}{\beta} = \left(\frac{1}{1+\frac{R_2}{R_1}}\right)^{-1} =$

35

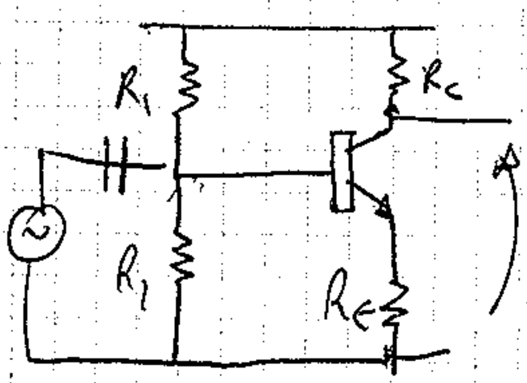
$= 1 + \frac{R_2}{R_1}$

AMPLIFICATORE di CORRENTE



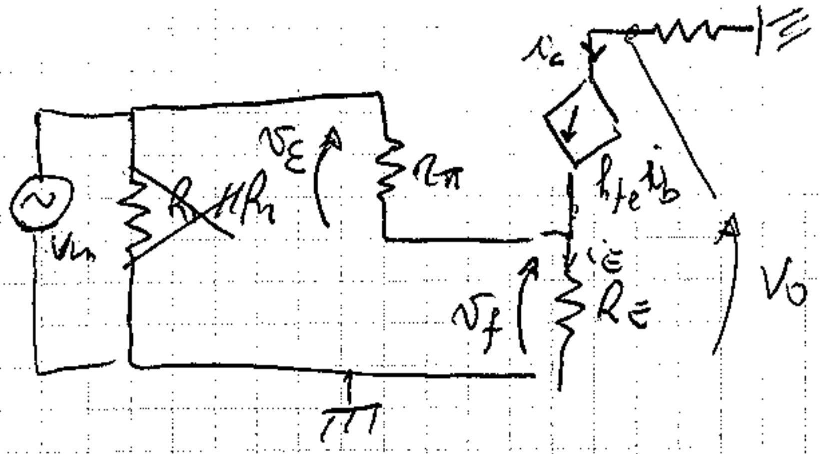
$i_\varepsilon = i_{in} - i_f$

Esempio di circuito



già visto in precedenza.

Troviamone il circuito equivalente di piccolo segnale



$R_1 // R_2$ possiamo toglierlo

$V_o = -R_C\, i_c$ $\qquad$ $i_E = i_B + i_c \simeq i_c$

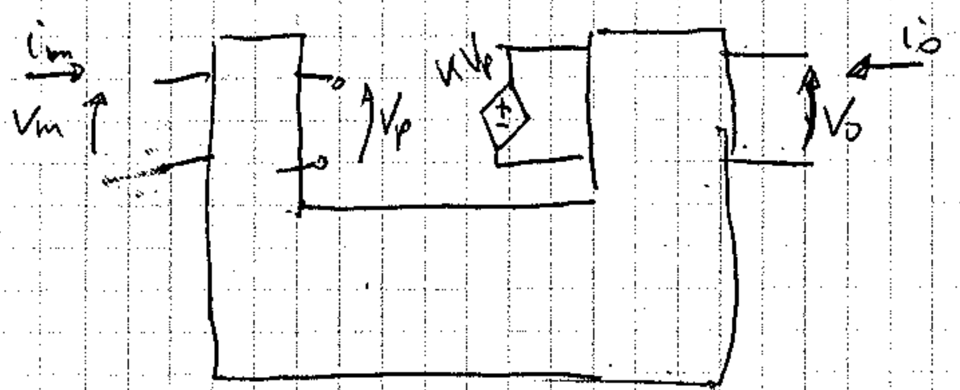
$V_f = R_E\, i_c$

Possiamo dire che R_E è la rete β in quanto $V_f \propto i_c$ come V_c.

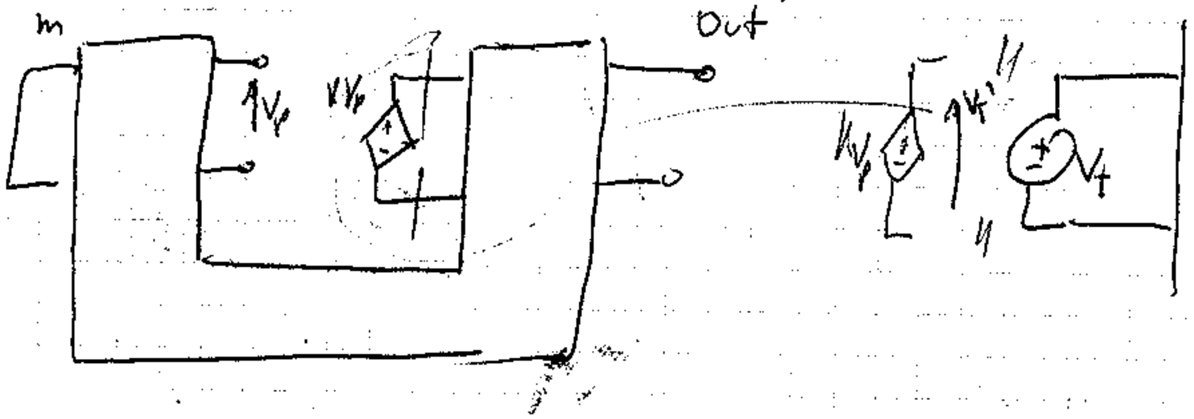
$v_E = v_{in} - v_f$

Metodi alternativi per risolvere e studiare un amplif. retroazionato senza conoscere A e β

METODO del GUADAGNO d'ANELLO



- dobbiamo identificare un generatore pilotato - (36)
- Spegnere tutti i generatori di tensione e corrente indipendenti



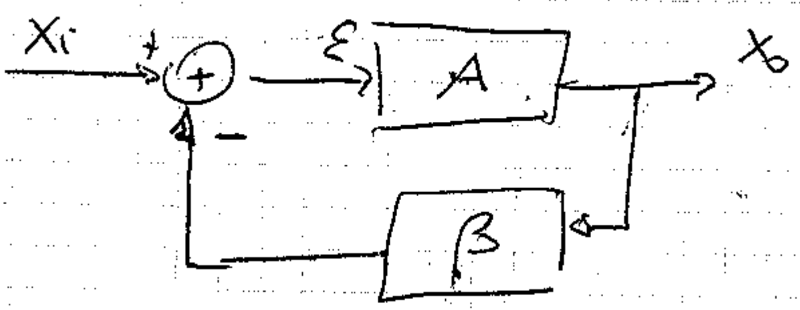
- stacco il generatore di tensione dipendente (KV_p) e lo sostituisco con un generatore dello stesso tipo, ma indipendente (V_t)

$$T = -\frac{V_T'}{V_T} \qquad A_f = A_\infty \frac{T}{1+T} + \frac{d}{1+T}$$

$$A_\infty = A_f \,(K \to \infty)$$

$$d = A_f \,(K = 0)$$

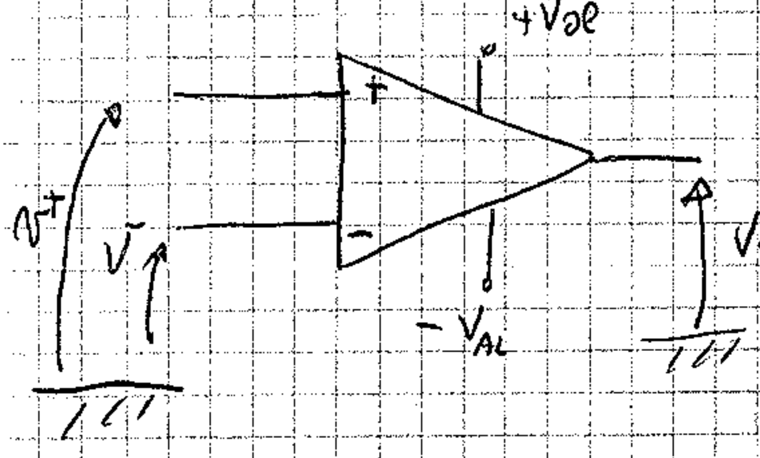
Nella maggior parte dei casi,



A_∞ tiene conto delle prop. del segnale

d tiene conto delle prop. del segnale attraverso la rete β

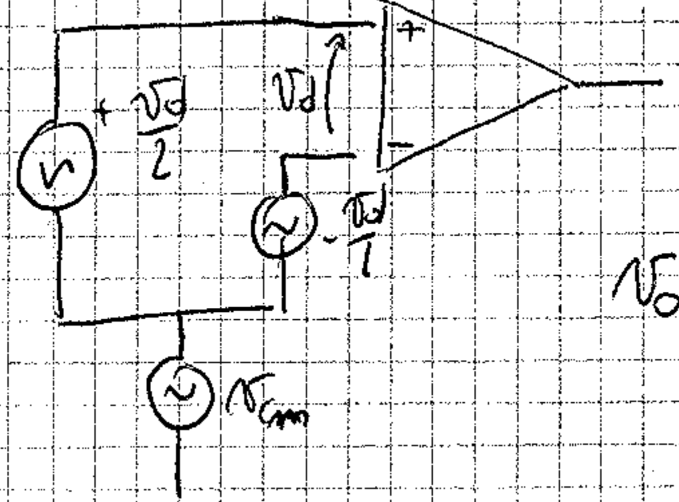
AMPLIFICATORE OPERAZIONALE



$$V_o = A^+ v^+ + A^- v^-$$

$$v_d = v^+ - v^-$$

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



$$\begin{cases} v^+ = V_{cm} + \dfrac{v_d}{2} \\ v^- = v_{cm} - \dfrac{v_d}{2} \end{cases}$$

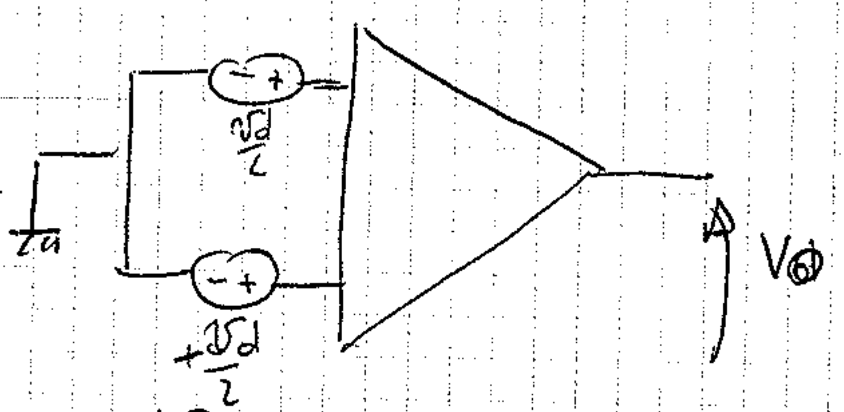
$$v_o = A_d v_d + A_{cm} v_{cm}$$

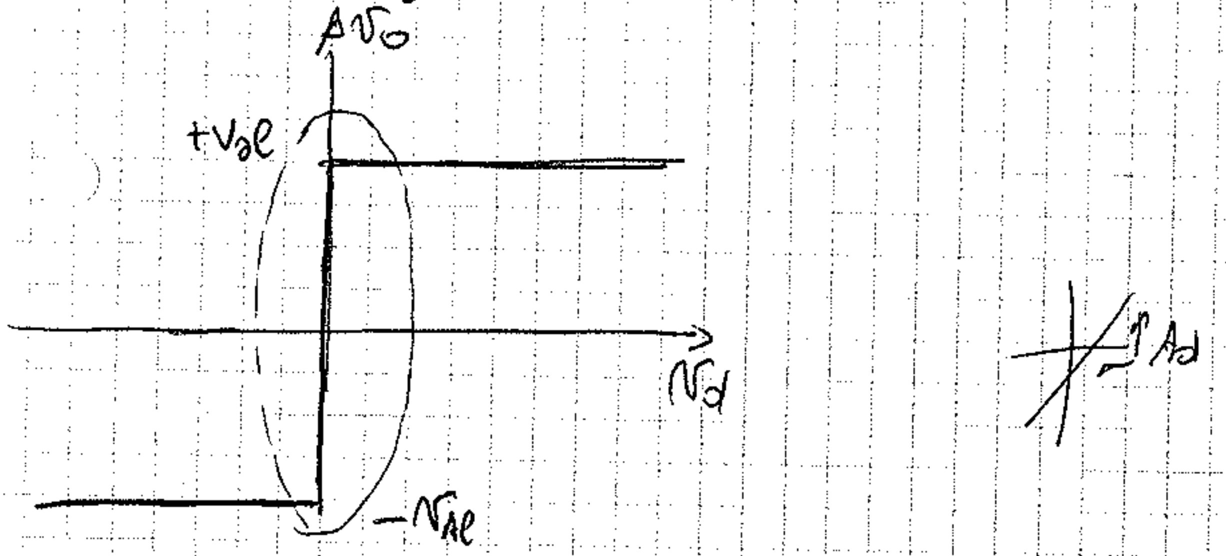
$$A_{cm} << A_d \qquad 10^4 < A_d < 10^7$$

$$1 < A_{cm} < 10$$

$$CMRR = 20 \log_{10} \frac{A_d}{A_{cm}}$$

Modo differenziali



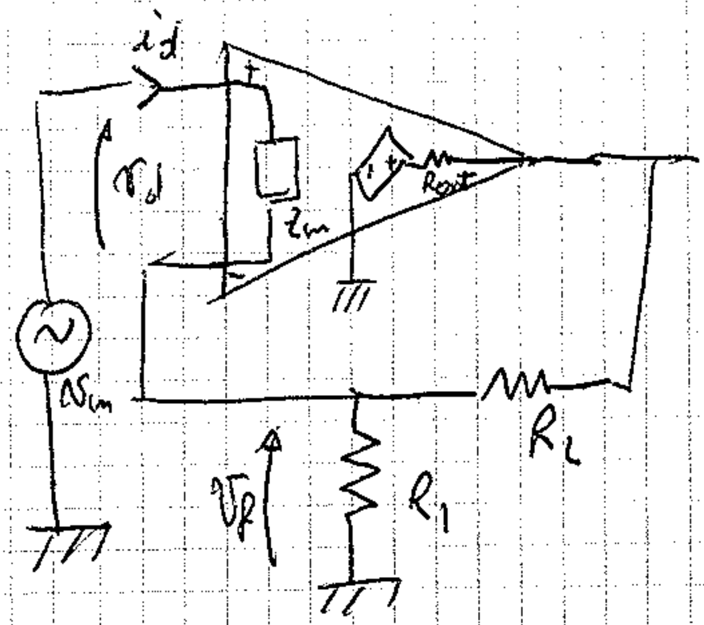


Esempio $\quad A_d = 10^6 \quad v_o = 1\,V \rightarrow v_d = \frac{v_o}{A_d} = 1\,\mu V$

$v_d = 1\,mV \Rightarrow v_o \neq 10^3\,V$ perché tensione di uscita compresa tra le t. di alim.

Anche v_{com} deve essere compresa nella tensione di alimentazione.

Se Amp. Op. è in linearità



$10^4 < A_d < 10^7$

$10\Omega < R_{out} < 1K\Omega$

Z_{in} BJT $\Rightarrow R_{in} \in [1, 100] K\Omega$

Z_{in} MOS $\Rightarrow 100\ fF < C_{in} < 1\ pF$

Spegno gen indipendenti, identifico g. pilotato e cambio il circuito con un g. di test e valuto l'effetto dell'amplificazione.

$$V'_T = A_d V_d = -A_d \cdot \frac{(\cancel{R_{out}+R_2})(R_1 // Z_{in})}{R_1 // Z_{in} + R_2 + R_{out}} V_T$$

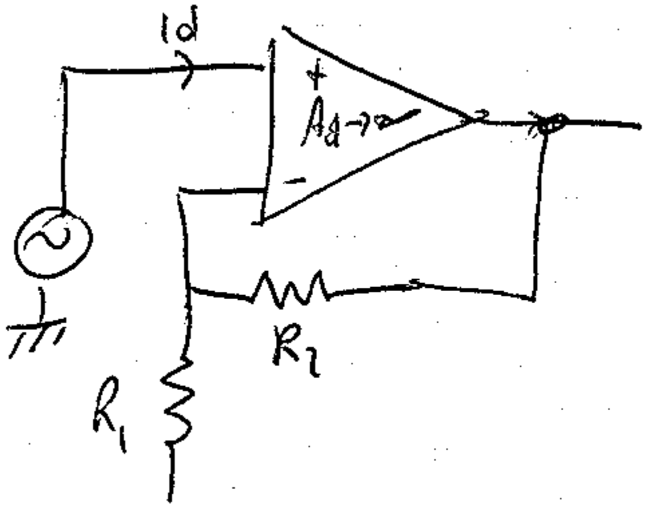
$$T = -\frac{V'_T}{V_T} = A_d \frac{\cancel{R_{out}+R_2}\ R_1 // Z_{in}}{R_1 // Z_{in} + R_2 + R_{out}}$$

Se $|Z_{in}| \gg R_1$ e $R_{out} \ll R_2$ allora

$$T = A_d \frac{R_1}{R_2 + R_1}$$

$A_\infty = A_f \ (A_d \to \infty)$

$d = A_f \ (A_d = 0)$

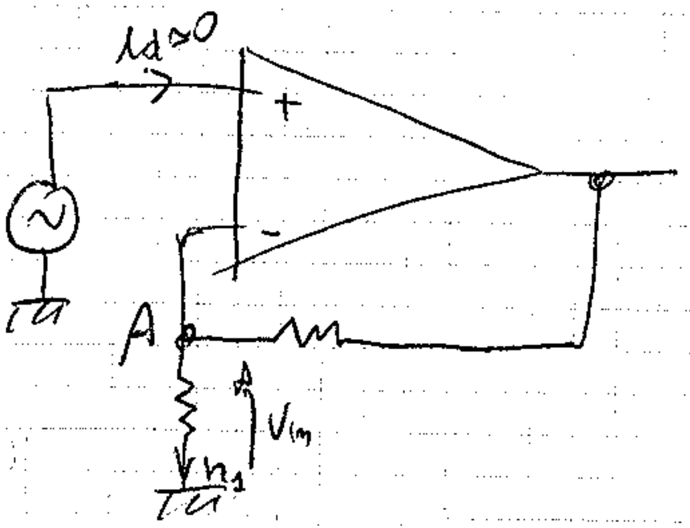


$T \gg 1$

$A_f \simeq A_\infty$

$V_d \to 0 \Rightarrow i_d \to 0$

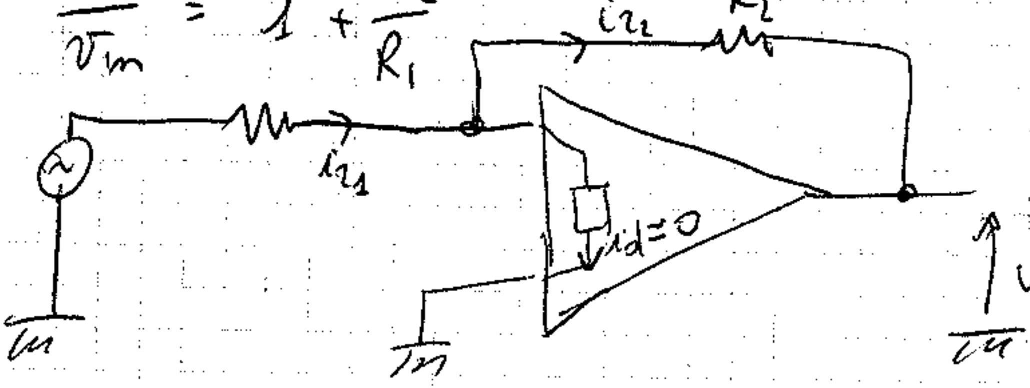
Se amp op. è retroazionato e se $|T| \gg 1$ allora $v_d \simeq 0 \Rightarrow i_d \simeq 0$



$$i_{r_1} = \frac{V_{in}}{R_1}$$

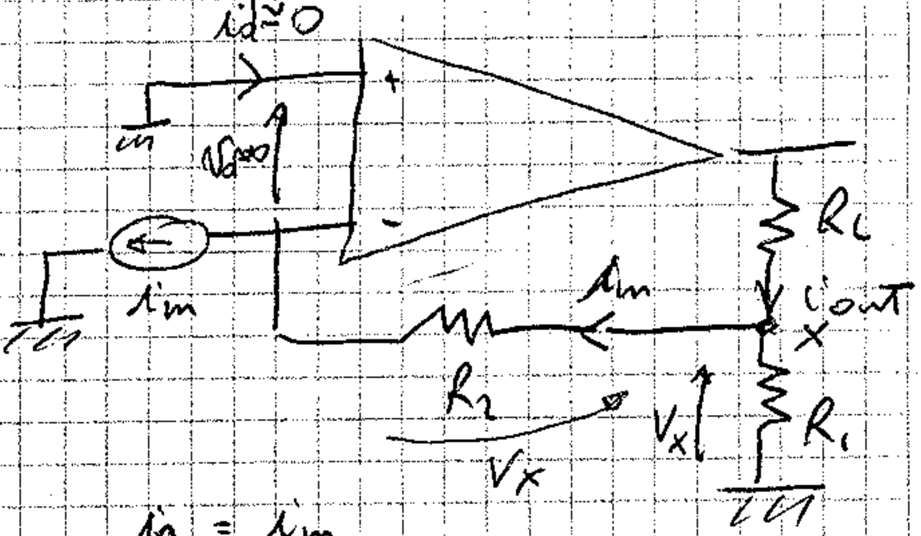
$$i_{r_1} = i_{r_2} = \frac{v_o - v_{in}}{R_2} = \frac{v_{in}}{R_1}$$

$$\frac{v_o}{v_{in}} = 1 + \frac{R_2}{R_1}$$



$i_{r_2} = -\frac{V_o}{R_2}$ $\quad i_{r_1} = \frac{V_{in}}{R_1}$

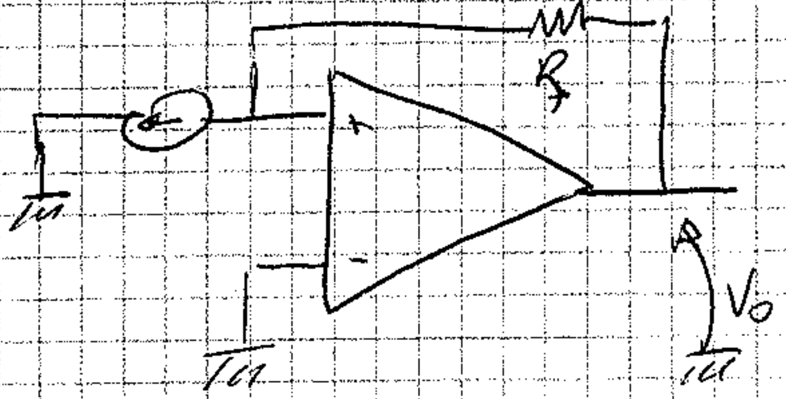
Amplificatori di corrente



$i_{R_2} = i_{in}$

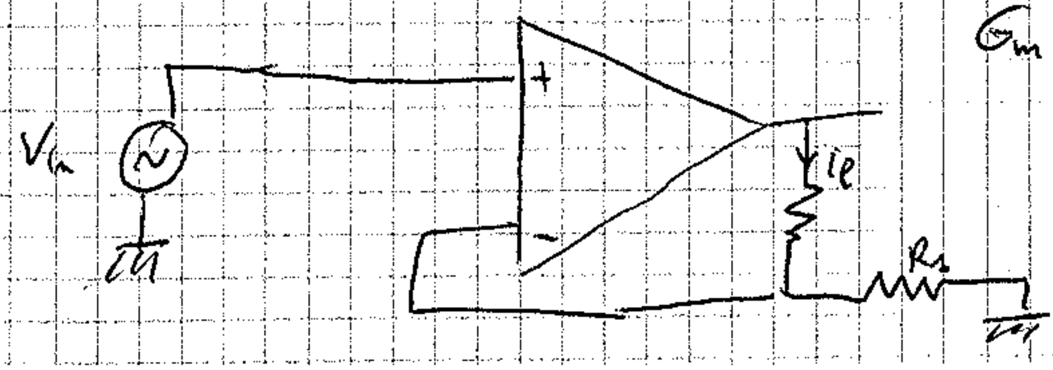
$i_{in} = \frac{R_1}{R_1 + R_2} i_{out}$ $\quad A_i = \frac{i_{out}}{i_{in}} = \left(\frac{R_1}{R_1 + R_2} \right)^{-1} = \frac{R_1 + R_2}{R_1}$

Amplificatore di trans-resistenza



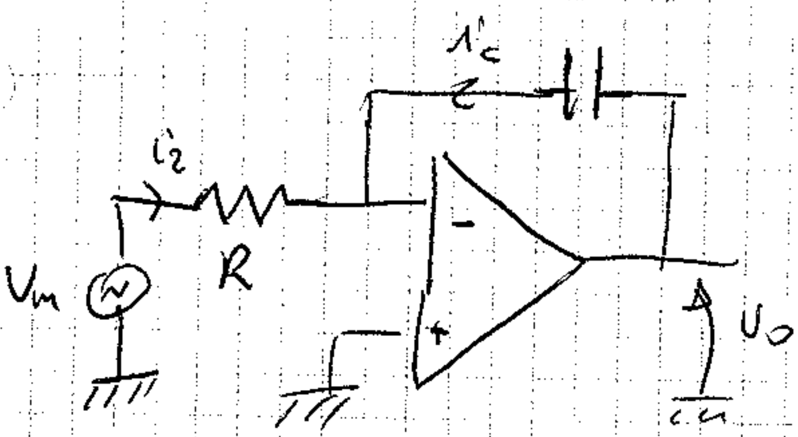
$R_{out} = R_f$

Amplificatore di trans conduttanza



$G_m = \frac{i_L}{v_{in}} = \frac{1}{R_1}$

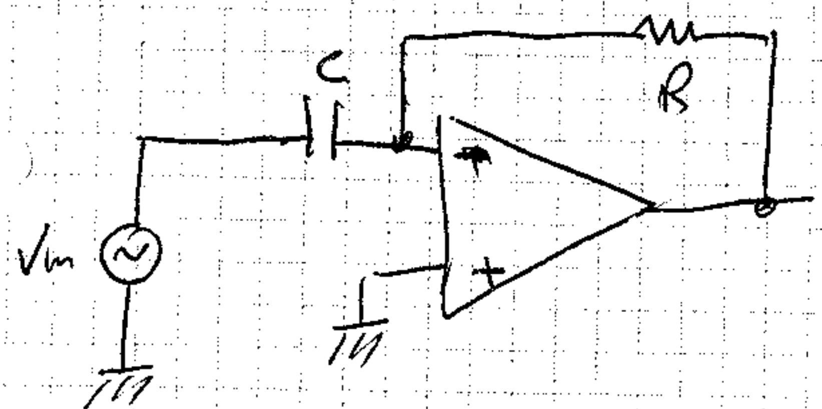
CIRCUITO INTEGRATORE



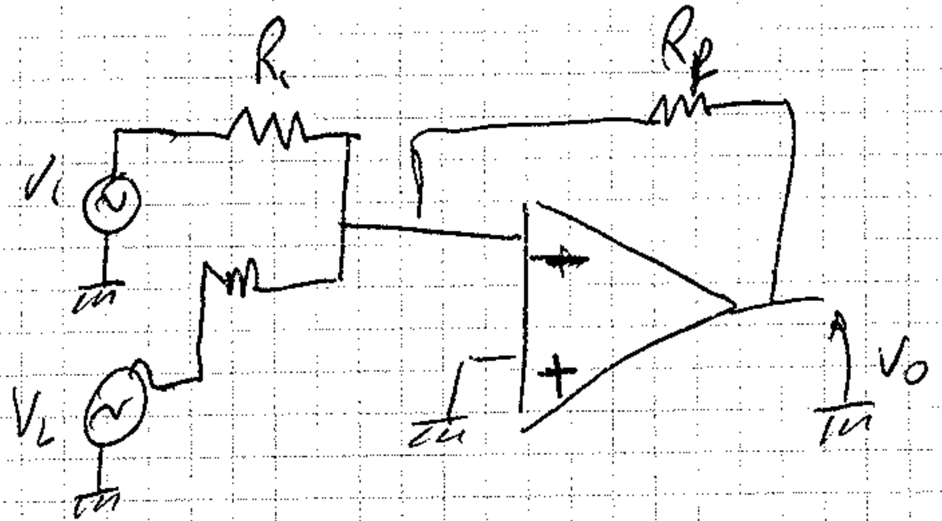
$$i_2 = \frac{V_{in}}{R} \qquad i_c = C\frac{dv_o}{dt} \qquad v_o = \frac{1}{C}\int i_c \, d\tau$$

$$v_o = -\frac{1}{C}\int \frac{V_{in}}{R}\, d\tau = -\frac{1}{RC}\int v_{in}\, d\tau$$

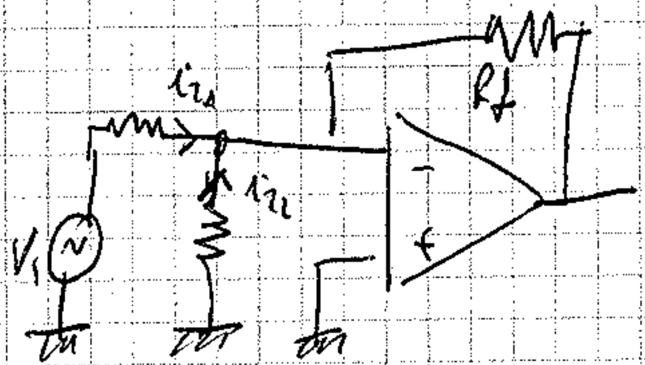
CIRCUITO DERIVATORE



Circuiti sommatori



$$V_0 = V_0' + V_0''$$



$$i_{R_2} \simeq 0$$

$$i_{R_1} = \frac{V_1}{R_1}$$

$$\frac{V_0'}{V_1} = -\frac{R_f}{R_1}$$

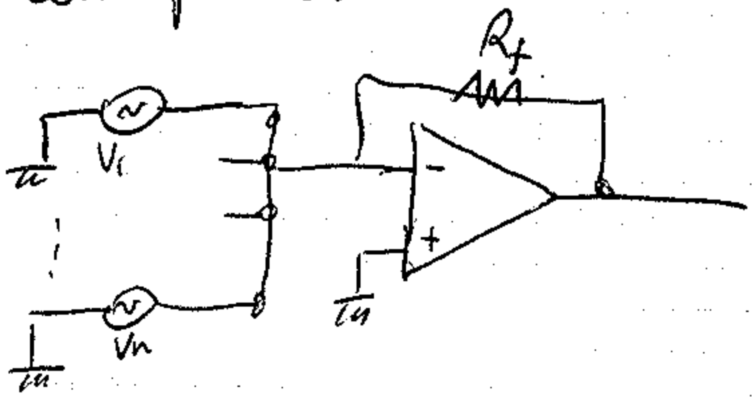
Spengo V_1 e accendo V_2 ottengo

$$\frac{V_0''}{V_2} = -R_f/R_2$$

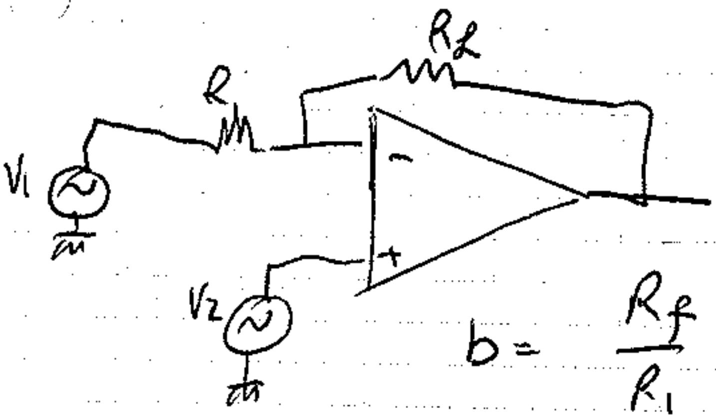
$$V_0 = V_0' + V_0'' = -\frac{R_f}{R_1} V_1 - R_f/R_2 \, V_2$$

$$V_0 = -R_f \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} \right)$$

Con più correnti



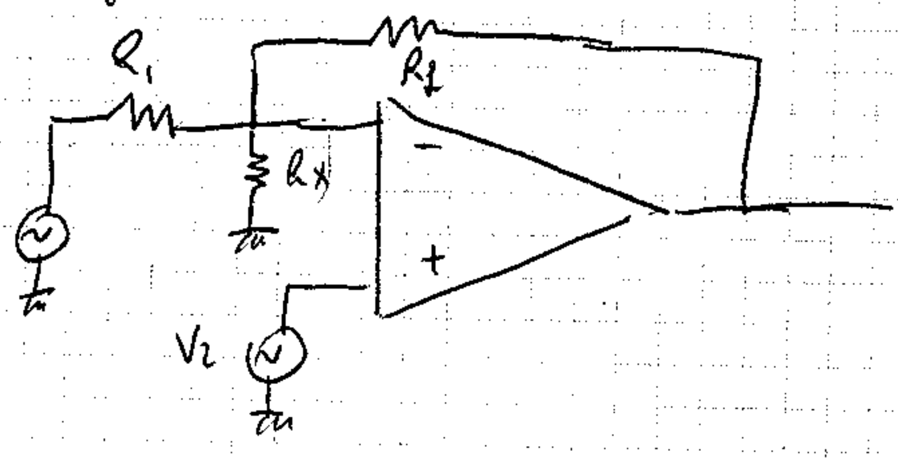
Voglio trovare un circuito con segno (es: $V_0 = a V_1 - b V_2$)



$$V_0 = \left(\cancel{1} + \frac{R_f}{R_1}\right) V_1 - \frac{R_f}{R_1} V_2$$

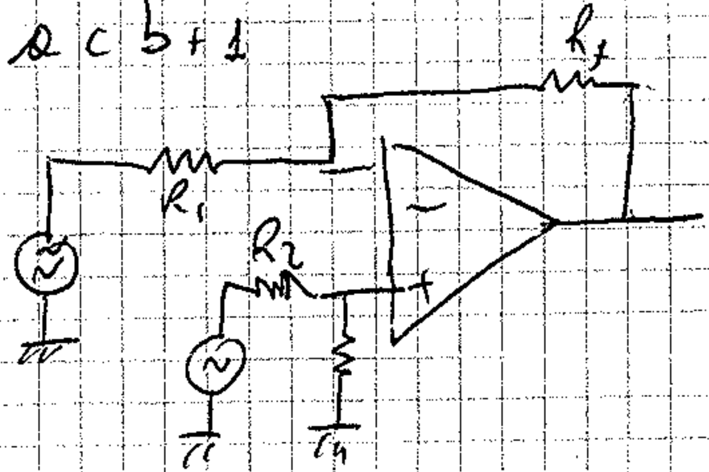
$$b = \frac{R_f}{R_1} \qquad a = b + 1$$

se voglio $a > b+1$



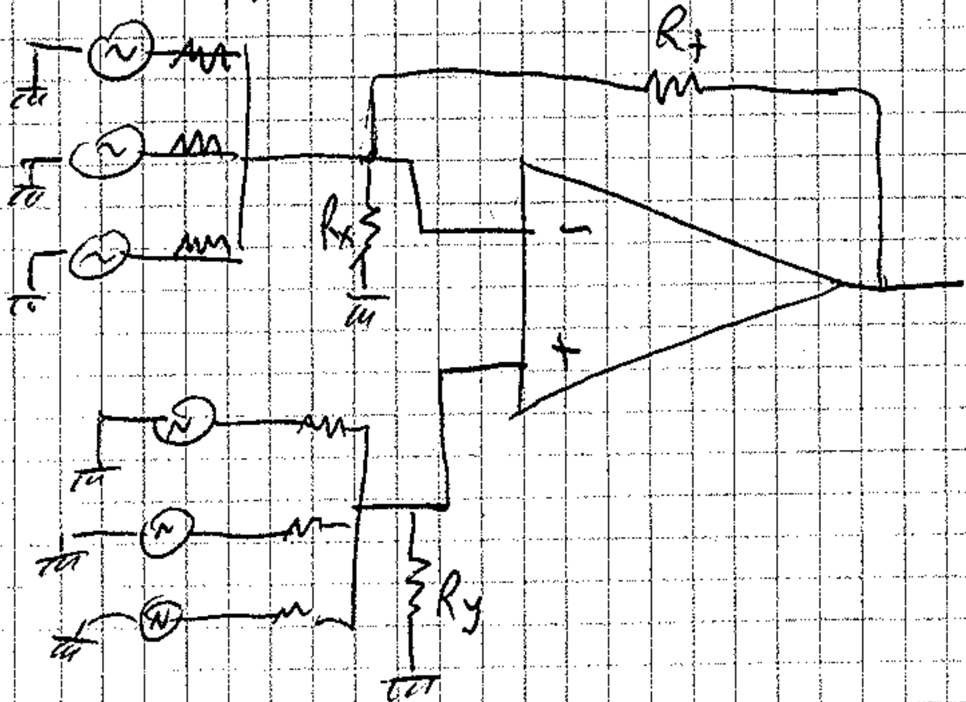
$$V_0 = \left(1 + \frac{R_f}{R_x \| R_1}\right) V_1 - \left(\frac{R_f}{R_1}\right) V_2$$

$a < b + 1$



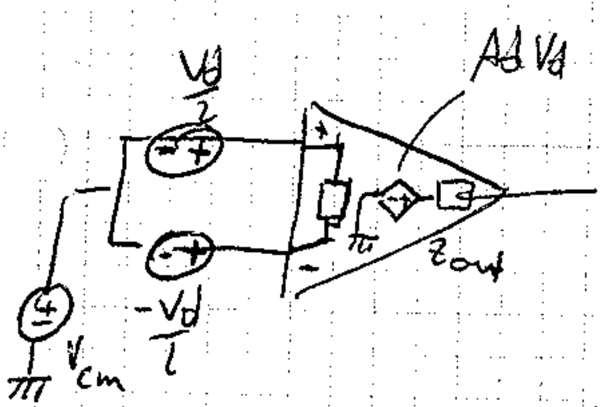
$$V_0 = \frac{R_3}{R_2+R_3}\left(1+\frac{R_f}{R_1}\right)V_1 - \frac{R_f}{R_1}\,V_2$$

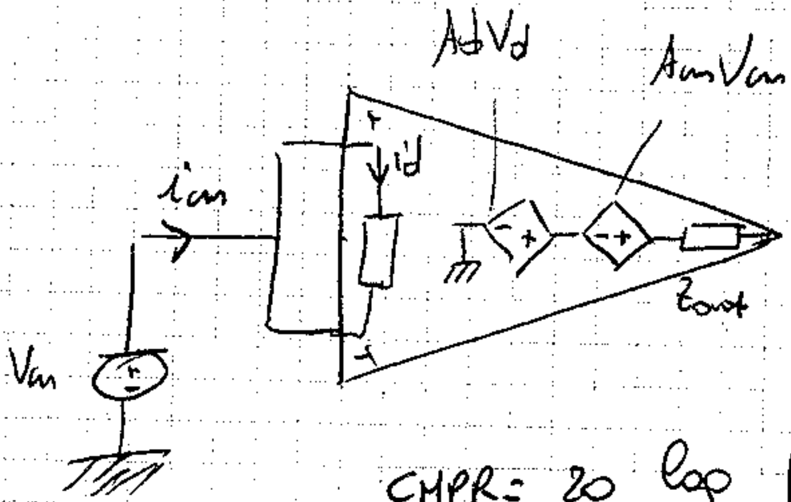
In generale



$$V_0 = \sum_i a_i v_i - \sum_j b_j v_j$$

LIMITI di FUNZIONAMENTO OP. AMP.

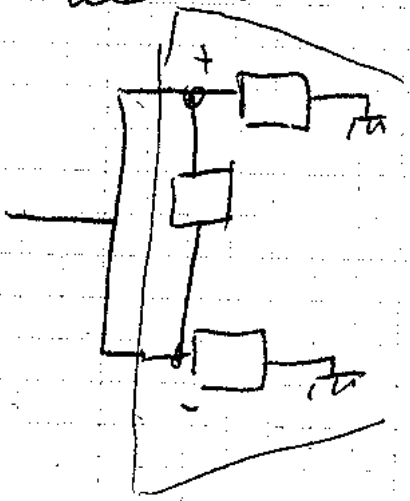


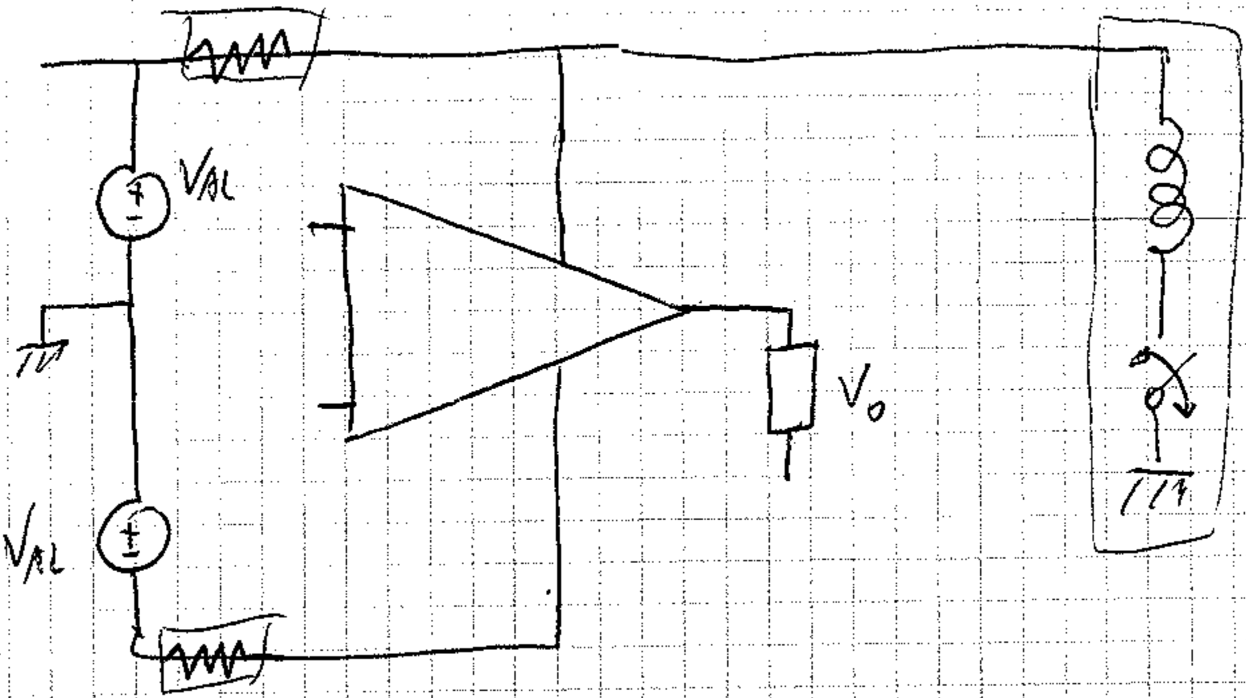


$$CMPR = 20 \log_{10}\left(\left|\frac{A_v}{A_{cm}}\right|\right)$$

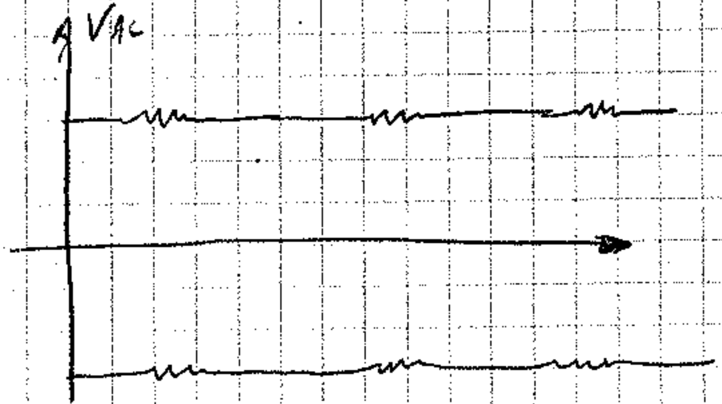
$i_{cm} \neq 0$, $i_d = 0$

In realtà





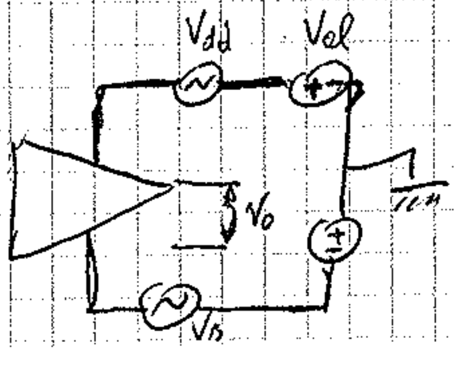
Alimentazione può variare nel tempo.



Dovute alla impedenza delle reti di interconnessione.

Vengono riportati dei dati che quantificano le capacità degli amplif. op. di rigettare i disturbi

Test:



si misura quanto del disturbo viene perso al carico. (42)

$$\frac{V_o}{V_{dd}} \doteq A_{dd}^{+} \qquad PSRR^{+} = 20 \log_{10} \left| \frac{A_d}{A_{dd}^{+}} \right|$$

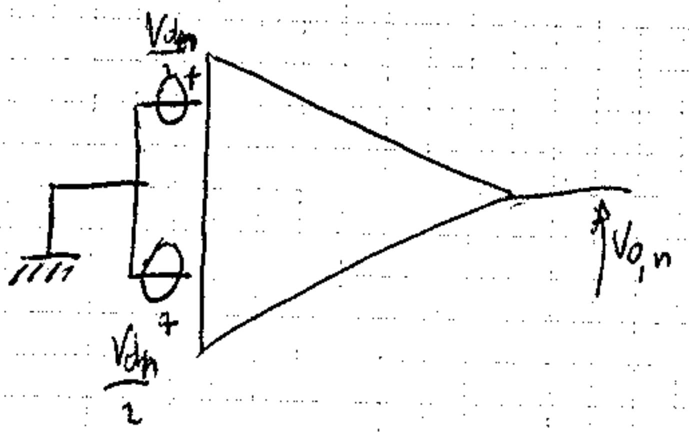
si spegne $\cancel{V_{ss}}$

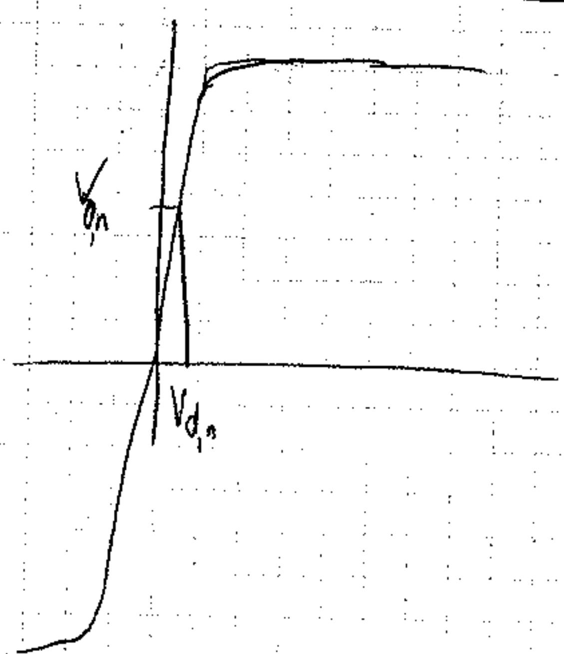
$$\frac{V_o}{V_{ss}} \doteq A_{dd}^{-} \qquad PSRR^{-} = 20 \log_{10} \left| \frac{A_{ds}}{A_{dd}^{-}} \right|$$

si spegne V_{dd}

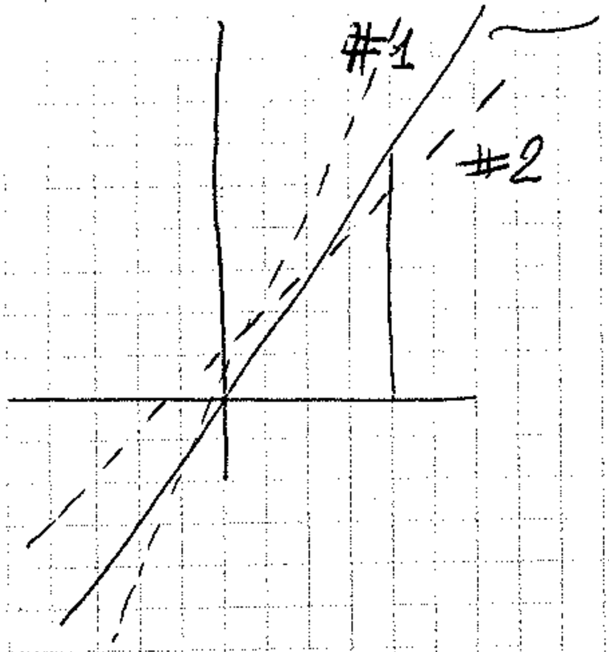
Si aggiungono all'interno dell'amplificatore due generatori pilotati ($A_{dd}^{+} V_{dd}$ e $A_{dd}^{-} V_{ss}$)

TOLLERANZE di FABBRICAZIONE OP AMP



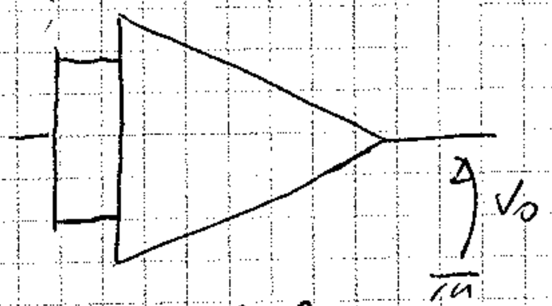


In realtà $V_o \neq V_{o,n}$ in virtù delle tolleranze di fabbricazione

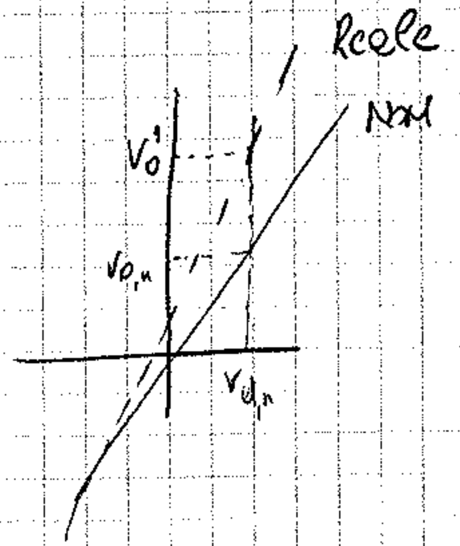


caratteristica nominale

in generale



$V_o \neq 0$

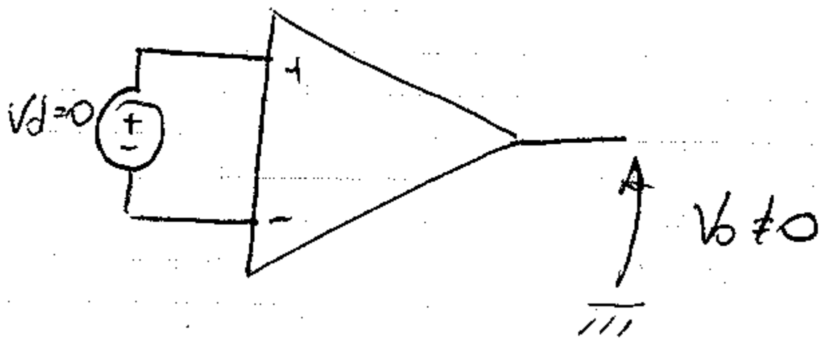


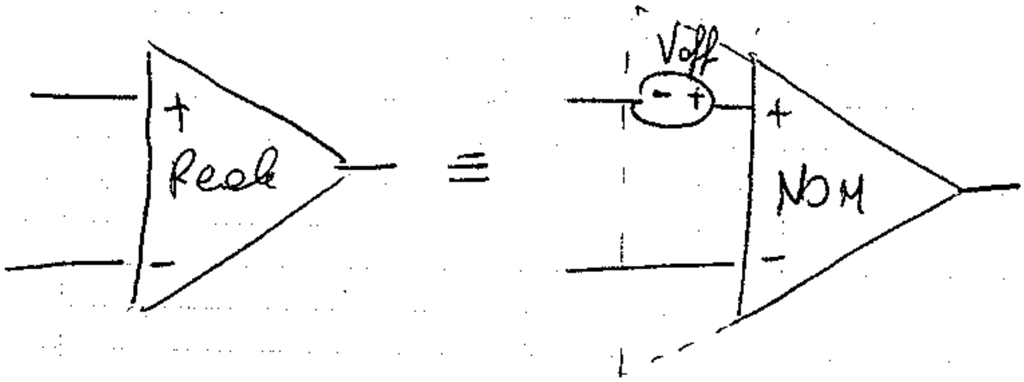
OFFSET di USCITA dell'Amplificatore

$$V_{o,off} \doteq |V_o' - V_{o,n}|$$

DEF: offset di un amplif.: $V_{of} = \dfrac{V_{o,off}}{A'_d}$

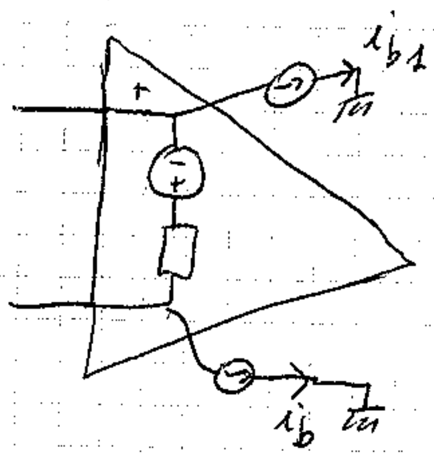
A'_d pendenza della caratteristica reale.





Voff varia con la temperatura e con l'invecchiamento

In genere $10\mu V < V_{off} < 10\ mV$



$10pA < i_b < 100nA$

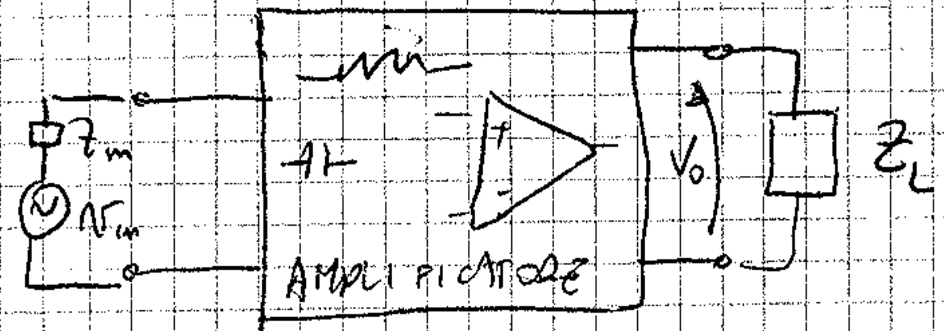
$$I_b \doteq \left|\frac{I_{b1}+I_{b2}}{2}\right|$$

$$I_{off} = |I_{b1} - I_{b2}|$$

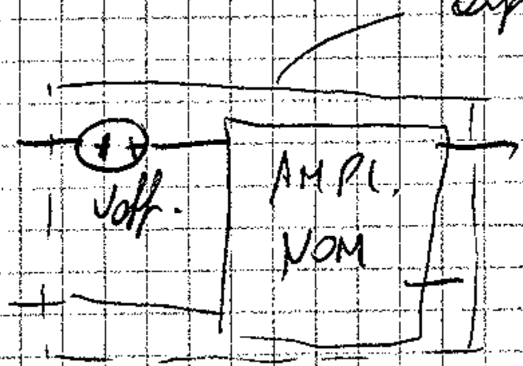
$$I_{b1} = I_b + \frac{I_{off}}{2}$$

$$I_{b2} = I_b - \frac{I_{off}}{2}$$

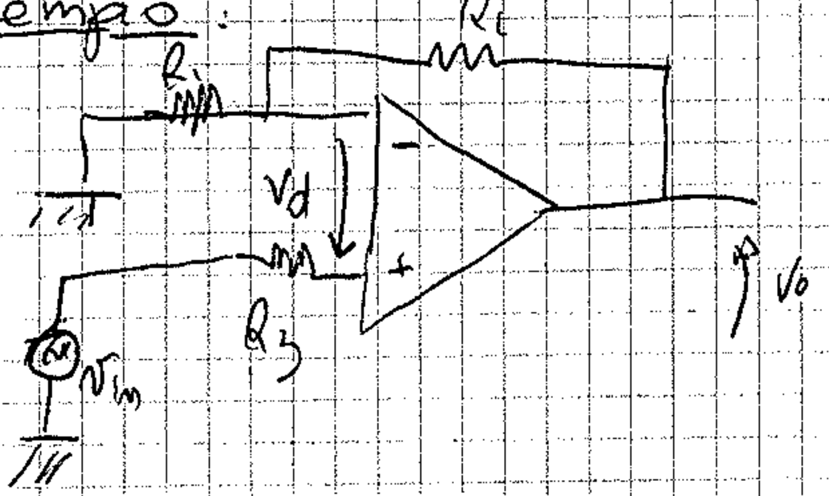
ANALISI OFFSET



- Spegniamo tutti i generatori indipendenti.
- calcolo tensione di uscita causata da V_{off}, I_{off}.
- calcolo il generatore di ingresso equival.

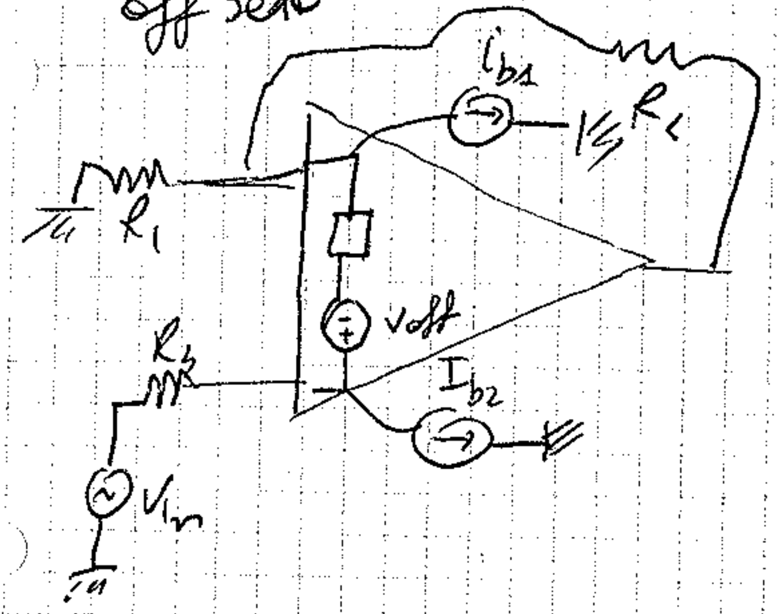


Esempio:



analizziamo il circuito con generatori di offset

(44)



Spegniamo V_{in} e troviamo $V_{o,off}$

Spegnamo I_{b1} e I_{b2}, lasciamo acceso Voff

$$V_o{}'_{off} = \left(1 + \frac{R_2}{R_1}\right) V_{off}$$

adesso $I_{b1} = 0$ $V_{off} = 0$ $i'_{b2} \neq 0$

si ha che I_{b2} passa in R_3

$$V_{R3} = R_3 I_{B_2}$$

$$V''_{o,off} = -R_3 I_{b2}\left(1 + \frac{R_2}{R_1}\right)$$

Spengo I_{b2} e Voff lascio acceso I_{b1}

$$V'''_{o,off} = -R_2 I_{b1}$$

$$V_{o,off} = V_o'{}_{off} + V_o''{}_{,off} + V_o'''{}_{,off}$$

$$V_{off}^{t} = \frac{V_{o,off}}{A_V} = V_{off} - R_3 I_{b_2} + \frac{R_2}{\left(1 + \frac{R_2}{R_1}\right)} I_{b_1}$$

$$I_{b_1} = \frac{I_b}{1} + \frac{I_{off}}{2}$$

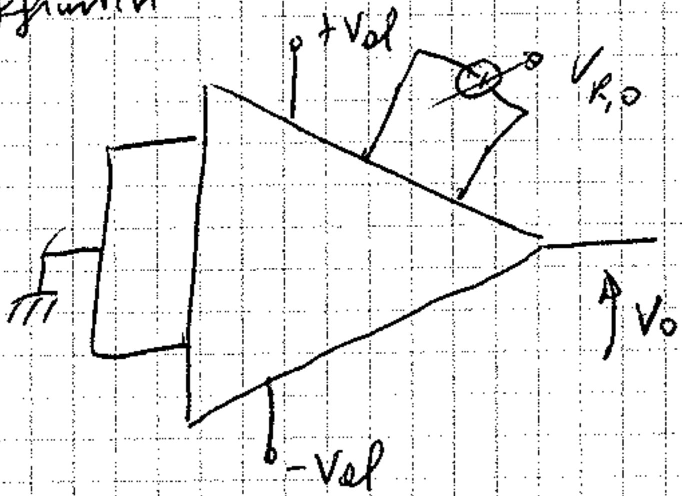
$$I_{b_2} = I_b - \frac{I_{off}}{2}$$

$$V_{off}^{t} = V_{off} - R_3 \left(I_b - \frac{I_{off}}{2}\right) + \frac{R_1}{\left(1 + \frac{R_2}{R_1}\right)} \left(I_b + \frac{I_{off}}{2}\right)$$

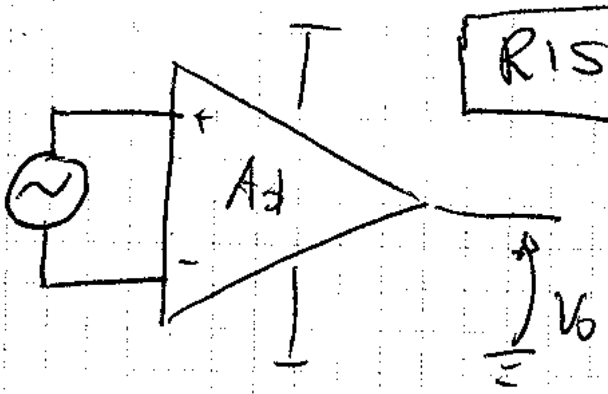
$$= V_{off} + \left(R_1 // R_2 - R_3\right) I_b + \frac{I_{off}}{2} \left(R_1 // R_2 + R_3\right)$$

Se $R_3 = R_1 // R_2$ si annulla il contributo di I_b

Gli amplificatori hanno anche terminali aggiuntivi



RISPOSTA IN FREQUENZA

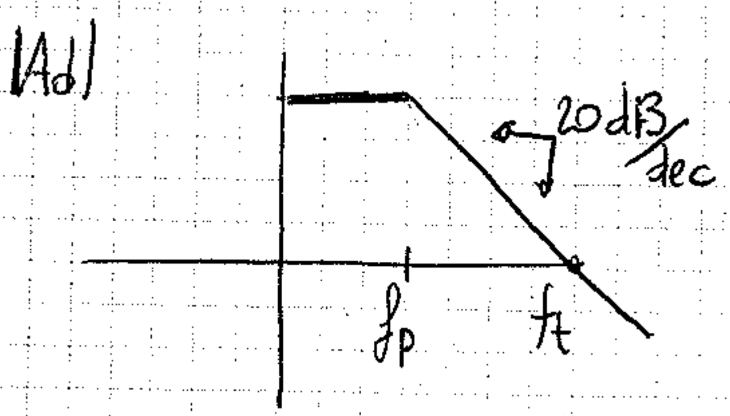


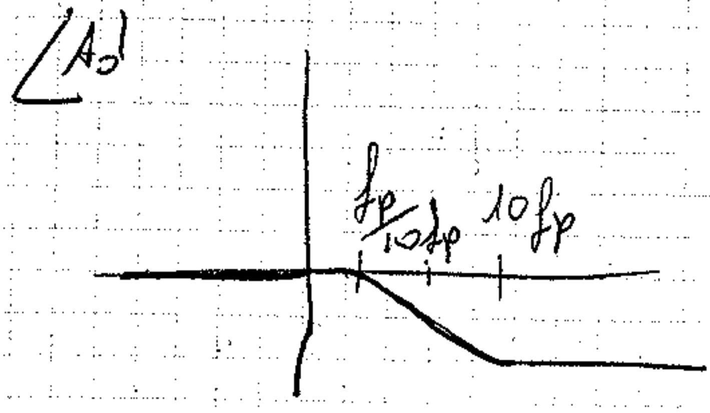
15

$A_{d0} \approx 10^5 \div 10^6$

$f_p \simeq 1 \div 10\ Hz$

$f_t \simeq 1 \div 10\ MHz$





$$A_d = \frac{A_{d0}}{\frac{s}{s_p} + 1} \qquad s_p = -j 2\pi f_p$$

$$A_d(s = j\omega) = \frac{A_{d0}}{\frac{j\omega}{s_p} + 1}$$

$$|A_d|_{s = j\omega} = \frac{A_{d0}}{\sqrt{1 + \left(\frac{\omega}{s_p}\right)^2}}$$

Se $\omega \gg |s_p|$ allora si ha che

$$|A_d| = \frac{A_{d0}}{\frac{f}{f_p}}$$

Di conseguenza

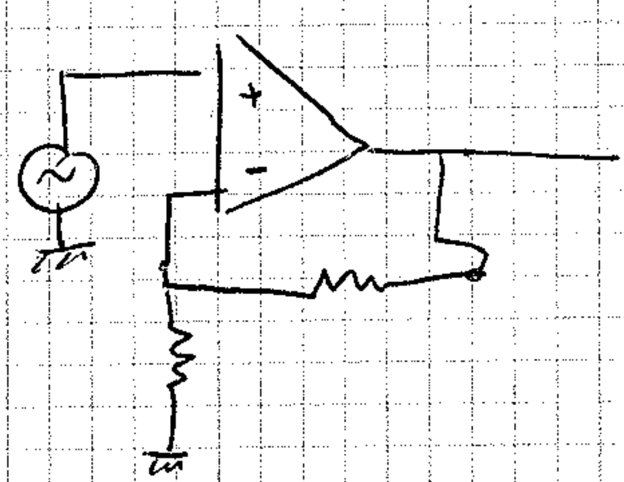
$$f_t \underset{\uparrow}{=} A_{d0} \cdot f_p$$

guadagno in f_t

Esempio: se $A_{d0} = 10^6$ $f_p = 10\ Hz$

$$f_T = 10^7\ Hz = 10\ MHz$$

In generale l'amplificazione presenterà delle limitazioni superiori



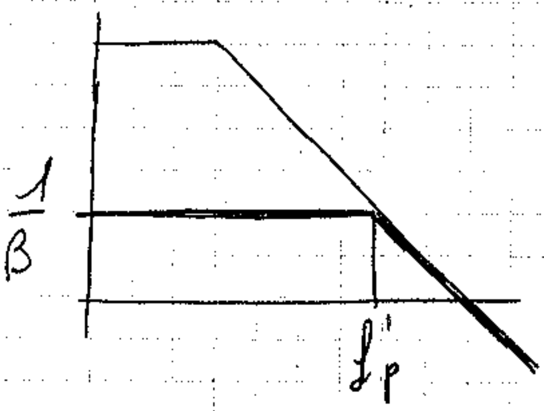
$$A_f(f) = \frac{A_d(f)}{1+\beta A_d(f)}$$

$$A_f = \frac{\dfrac{A_{do}}{1+\dfrac{s}{s_p}}}{1+\beta\,\dfrac{A_{do}}{1+\dfrac{s}{s_p}}} = \frac{A_{do}}{1+\dfrac{s}{s_p}+\beta A_{do}}$$

$$A_f(s) = \frac{A_{do}}{\underbrace{1+\beta A_{do}}_{\simeq \frac{1}{\beta}}} \cdot \frac{1}{1+\dfrac{s}{s_p\,(1+\beta A_{do})}}$$

$$A_f(\omega) = A_{fo}\,\frac{1}{1+j\dfrac{\omega}{\omega_p'}}$$

con $\omega_p' = 2\pi f_p\,(1+\beta A_{do})$

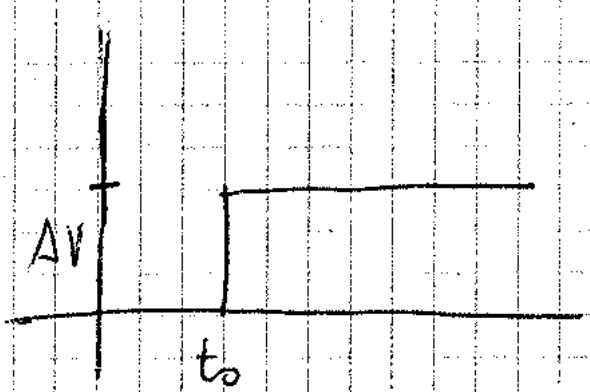


Amplificatore retroazionato ha banda utile maggiore!!

Esempio: $A_{do} = 10^6$ $\quad f_p = 10\ \text{Hz} \rightarrow f_T = 10\ \text{MHz}$

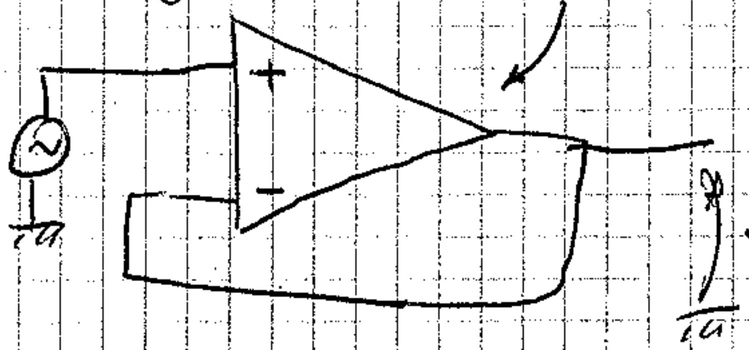
$$A_{fo} = \frac{1}{\beta} = 10 \longrightarrow T_o = \beta A_{do} = 10^5$$

$$\cancel{f_p' = \frac{1}{\beta} f_T} \qquad f_p' = f_p\,(\beta A_{do}+1) = 10^6\ \text{Hz}$$



$$v_{in} = \Delta V \, u(t-t_0)$$

Come si comporta un inseguitore di tensione quando riceve un gradino?

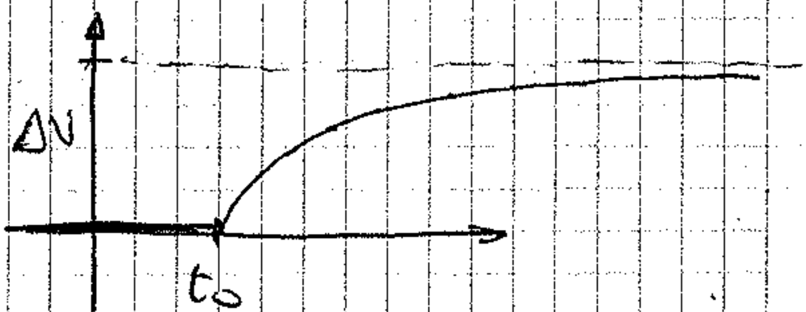


$$A_{f0} = 1$$

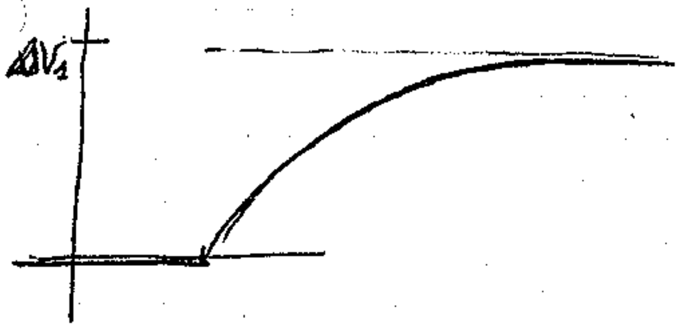
$$A_f = \frac{A_{f0}}{1 + \frac{s}{s_{p1}}}$$

$$v_0(t) = \Delta V \left(1 - e^{-\frac{t-t_0}{\tau}}\right) u(t-t_0)$$

$$\tau = \frac{1}{f_p'}$$



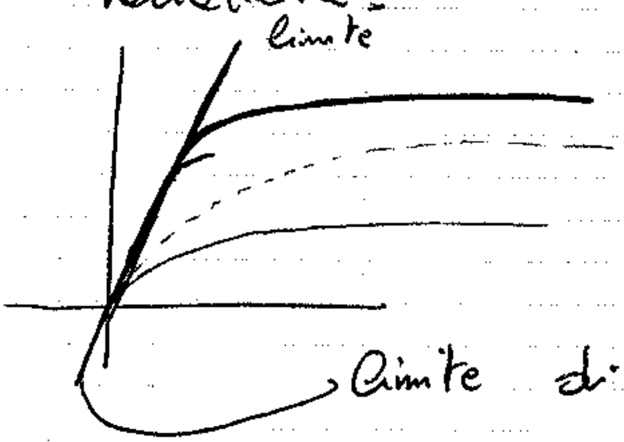
Aumentando l'ampiezza del gradino si ha che



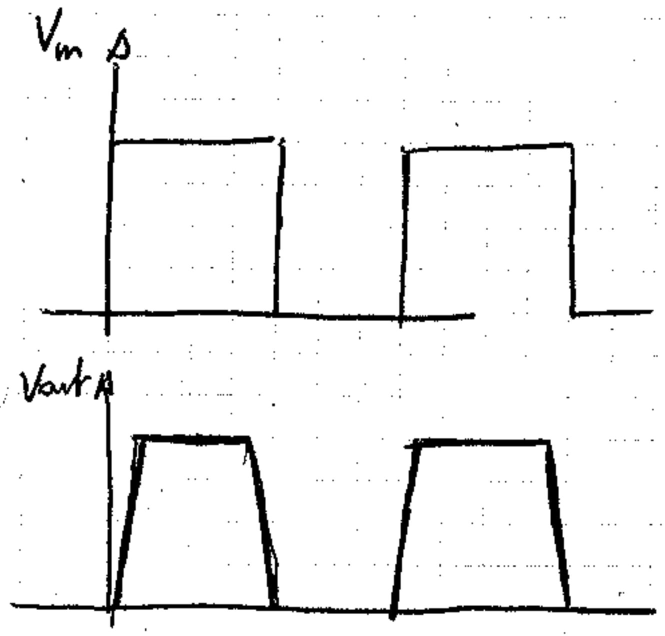
$$\left.\frac{dV_0}{dt}\right|_{t=t_0} = \frac{\Delta V}{\tau}$$

maggiore è ΔV maggiore è la derivata

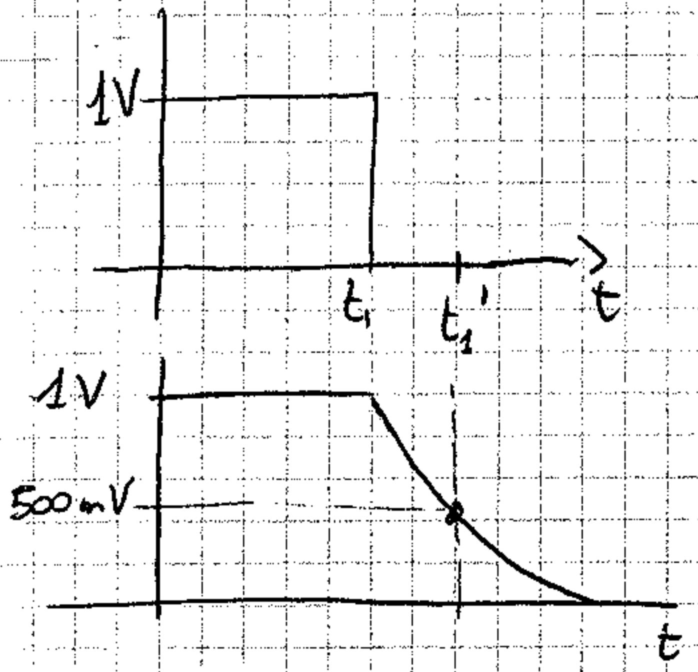
Gli AMP. OP. hanno un limite alla variazione.



limite di SLEW RATE (S.R.)

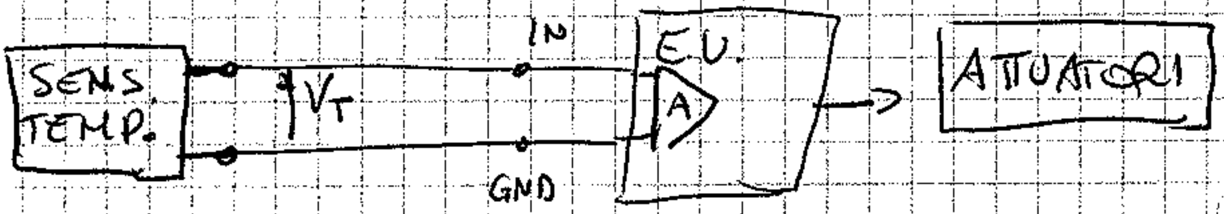


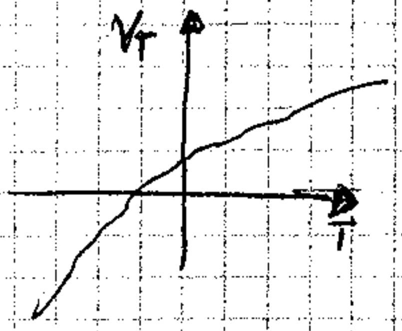
Consideriamo la fase di transizione:

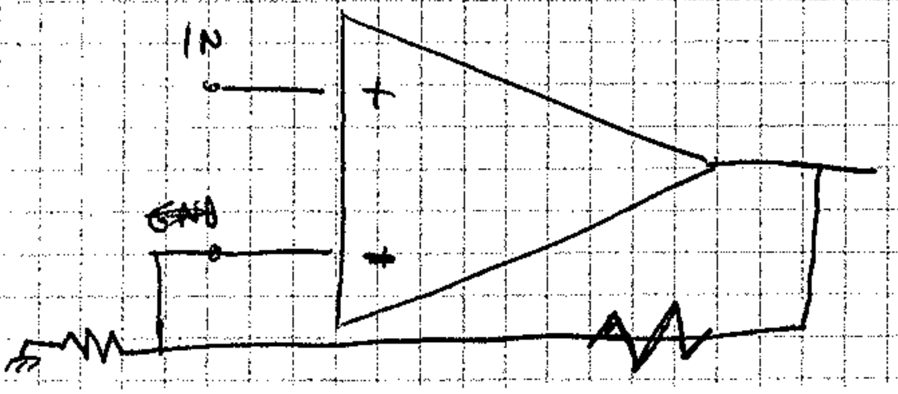


$t = t_1'$: $V_{in} = 0V$ $V_{out} = 500\ mV$

Esempio



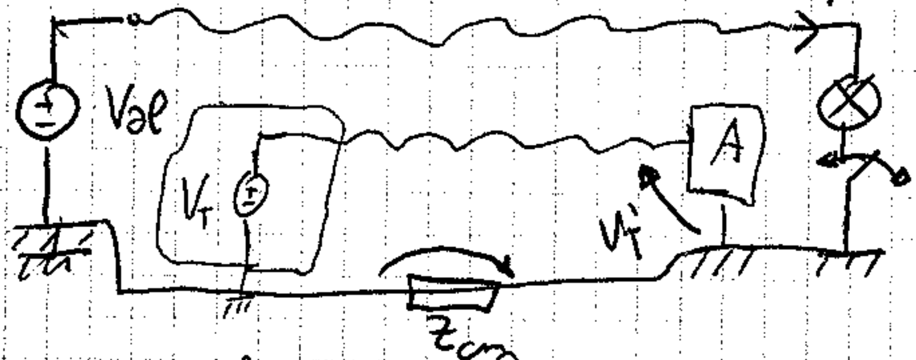




Questa soluzione non viene quasi mai utilizzata

Viene utilizzata se il sensore si trova in prossimità dell'amplificatore stesso. (48)
Non viene utilizzato se il segnale viene trasportato dai cavi

Esempio

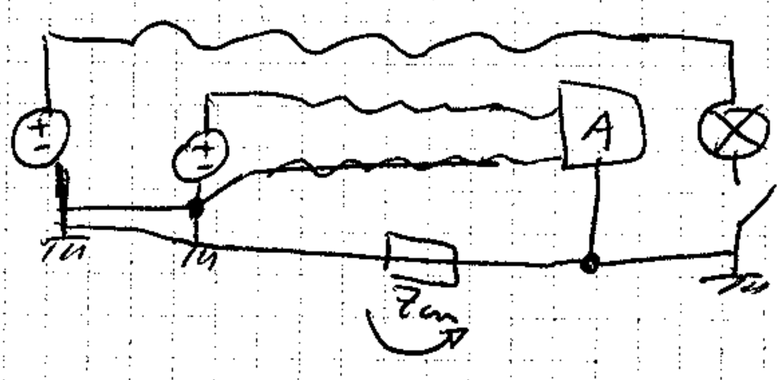


Supponiamo che i cavi facciano parte dello stesso fascio. (Inoltre la massa delle due parti non è proprio la stessa)

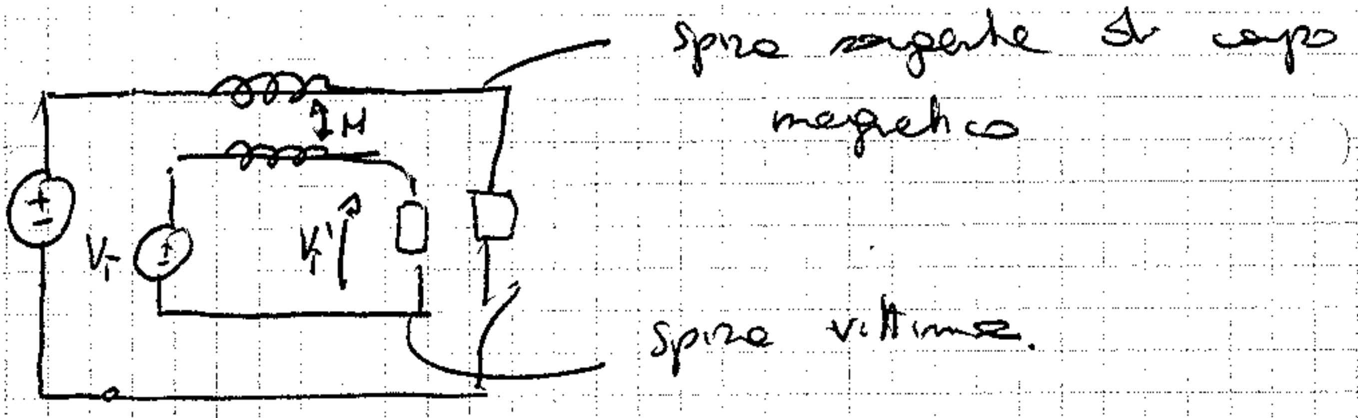
Si ha ~~ampia~~ caduta di tensione ai capi di Z_{cm}

$$V_T' = V_T - Z_{cm} I_p$$

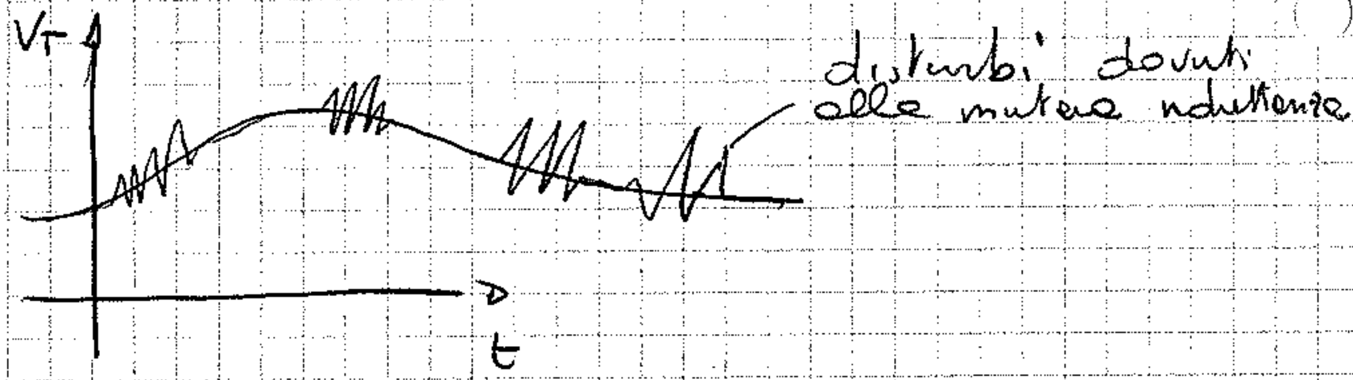
Quindi si può ricorrere a questa soluzione



Equivalente circuitale della situazione

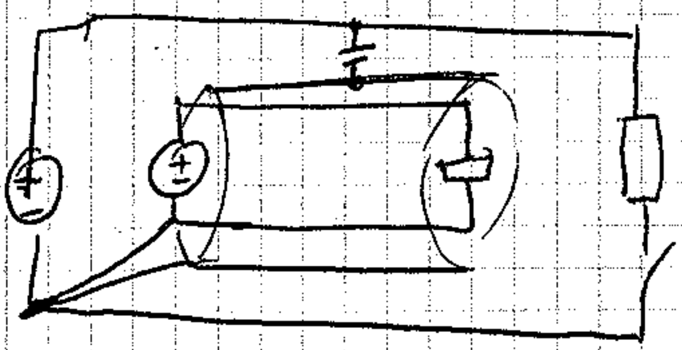


$V_T' \neq V_T$

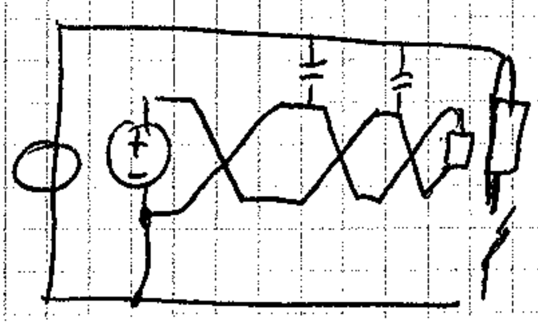


Si ha anche accoppiamento capacitivo (dovuto anche all'isolante dei cavi)

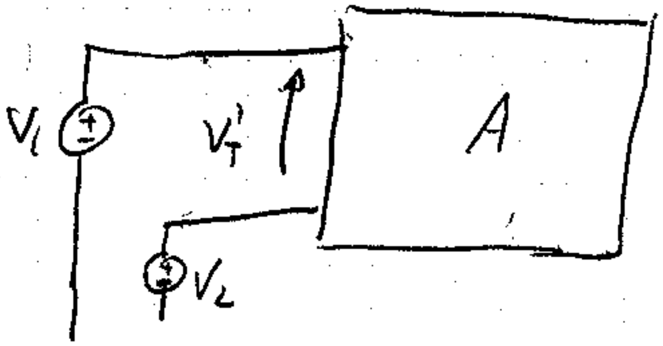
Di solito si usano soluzioni schermate



Oppure twistate

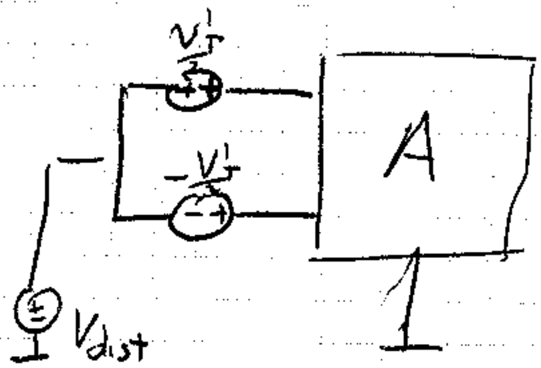


In ogni caso si ha che:



e se V_1 che V_2 sono corrotti!!!

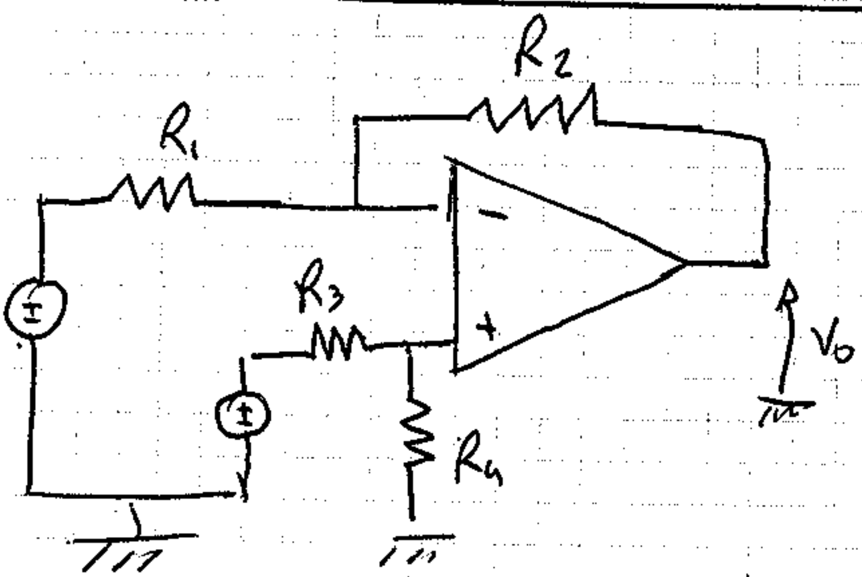
Chi capla fa il possibile per minimizzare i disturbi.



Tuttavia l'amplificatore deve rigettare i disturbi

Di solito si utilizza come soluzione l'

<u>AMPLIFICATORE DIFFERENZIALE</u>



$$V_0 = \frac{R_4}{R_3+R_4}\left(1+\frac{R_2}{R_1}\right)V_1 - \frac{R_2}{R_1}V_2$$

Se $\frac{R_2}{R_1} = \frac{R_4}{R_3+R_4}\left(1+\frac{R_2}{R_1}\right)$ si ha che

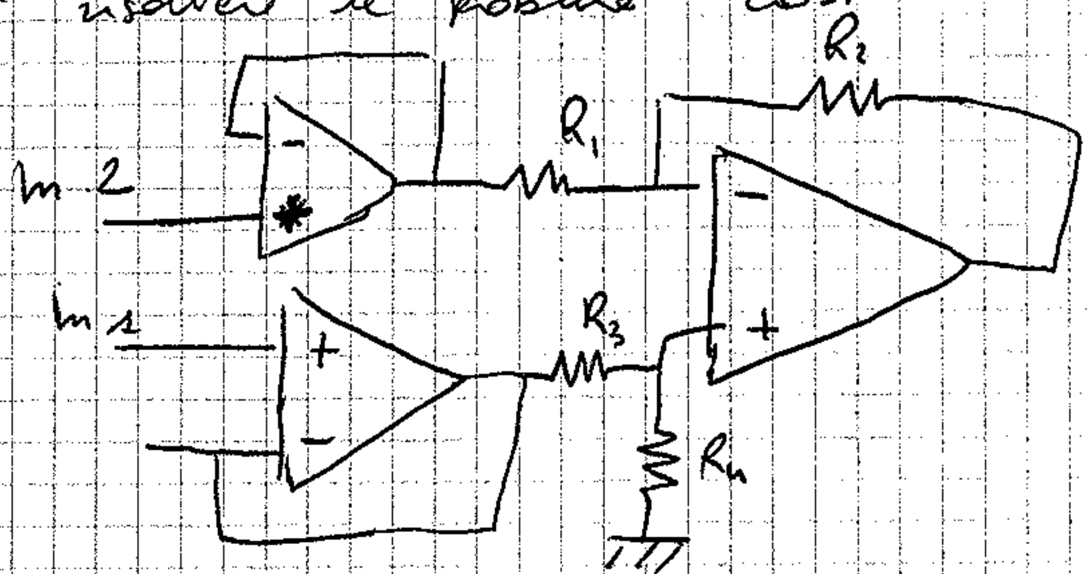
$$V_0 = \frac{R_2}{R_1}(V_1 - V_2)$$

A_{diff}

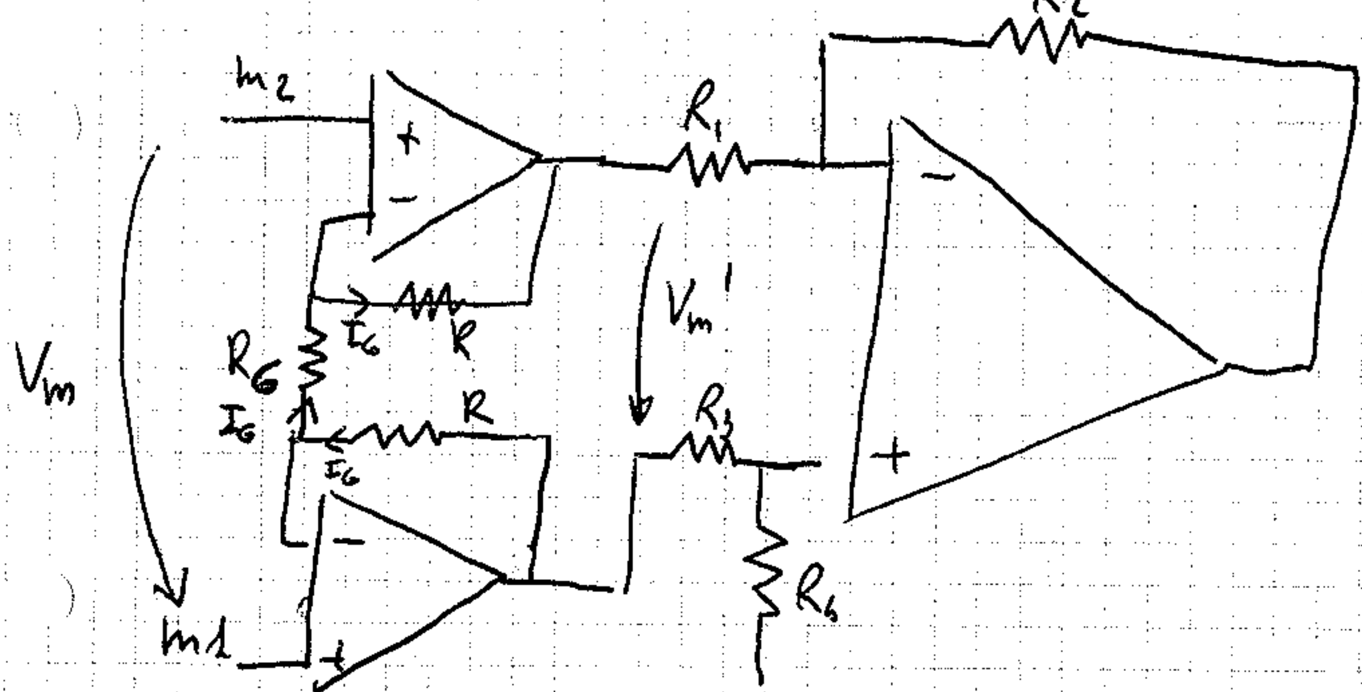
$$\frac{R_1}{R_2}\left(1+\frac{R_2}{R_1}\right) = 1 + \frac{R_4}{R_3}$$

$$\frac{R_1}{R_2} = \frac{R_4}{R_3}$$

Se si hanno altre resistenze in serie si può risolvere il problema così



Altra soluzione:



Per modificare il guadagno di questo amplificatore basta modificare R_G

Questo amplificatore è detto:
<u>AMPLIFICATORE da STRUMENTAZIONE</u>

$V_{R_G} = V_{in}$ $\qquad$ $I_G = \frac{V_{in}}{R_G}$

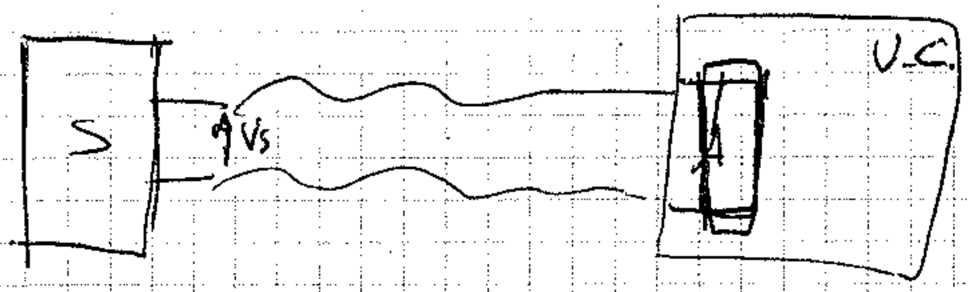
$V_{in}' = V_{in} + 2 R I_G = V_{in}\left(1 + 2\frac{R}{R_G}\right)$

$V_o = \frac{R_2}{R_1} V_{in}' =$

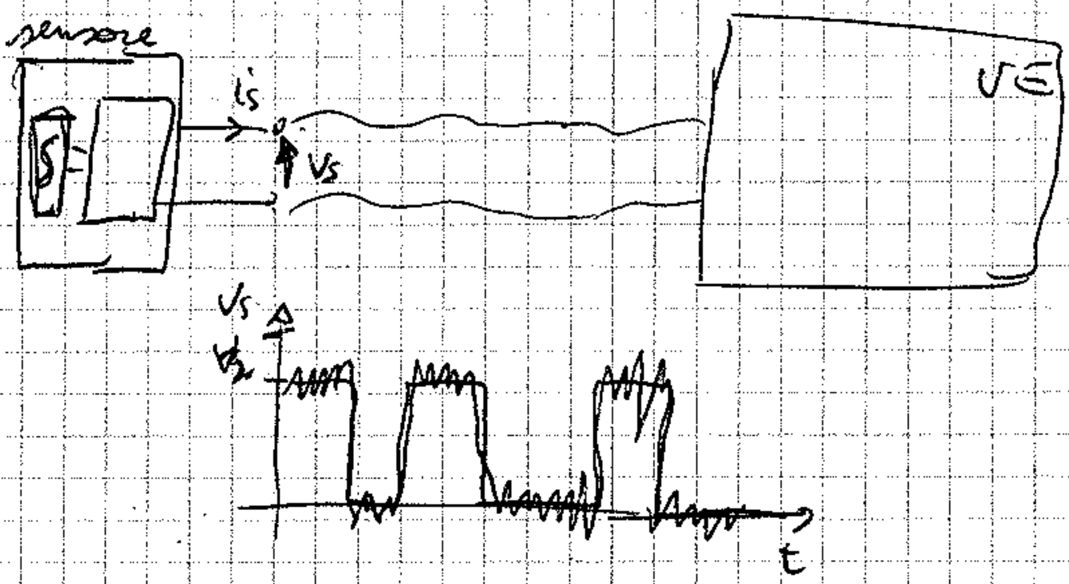
$\frac{V_o}{V_{in}} = \frac{R_2}{R_1}\left(1 + 2\frac{R}{R_G}\right)$ $\qquad$ unica resistenza variabile è R_G

hanno un elevato CMRR

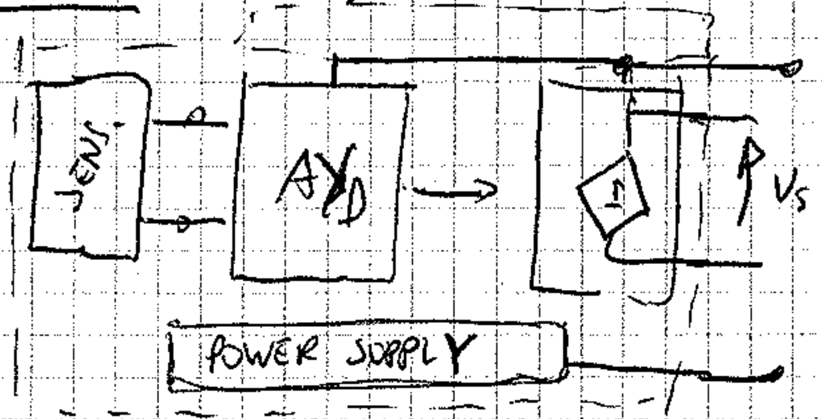
TRASMISSIONE ANALOGICA



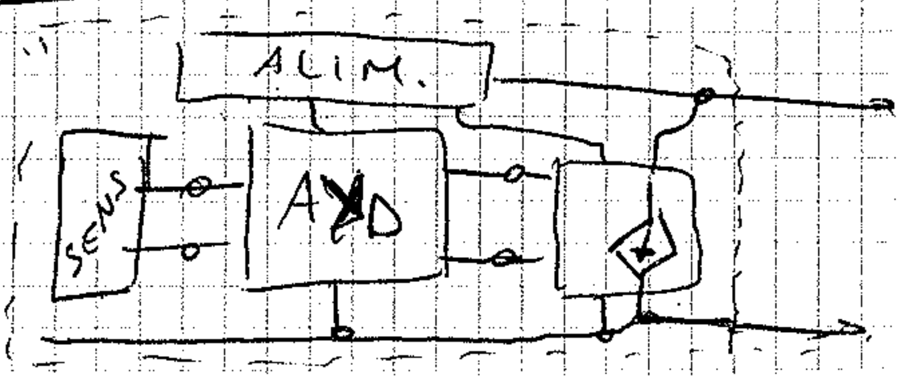
TRASMISSIONE DIGITALE

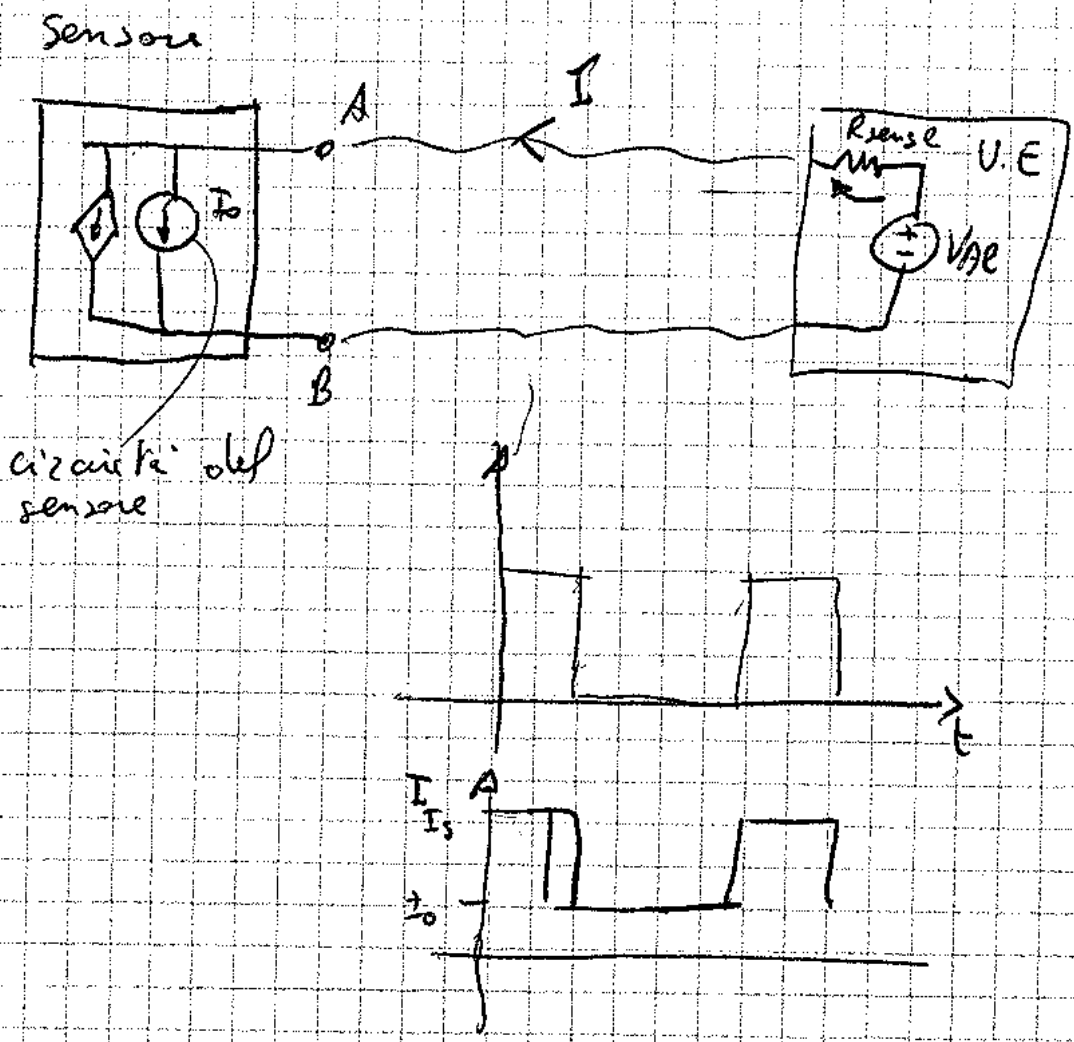


Sensore: a 3/4 terminal.



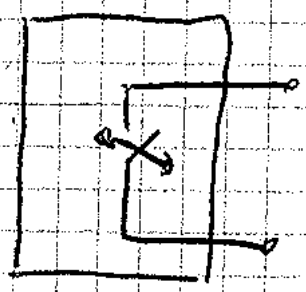
Sensore a 2 terminali.

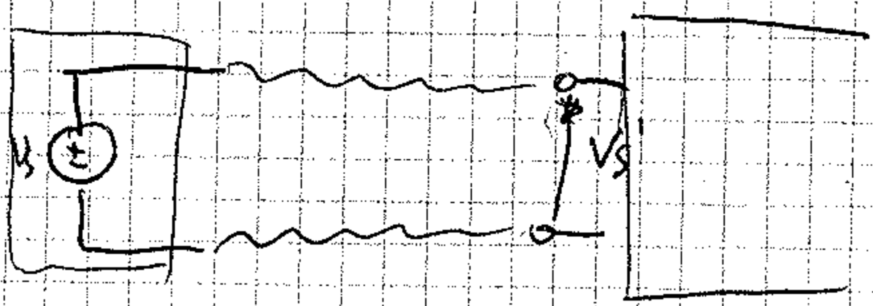


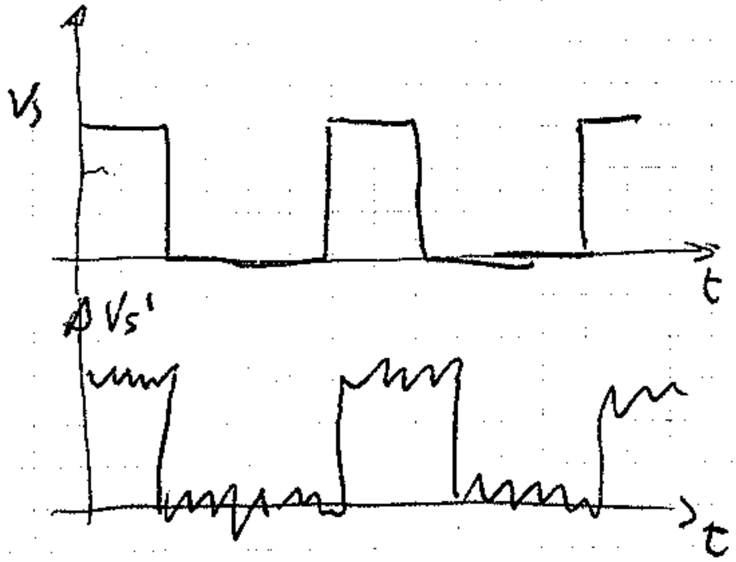


In mercato $I_o = 7\,mA$ $I_s = 14\,mA$

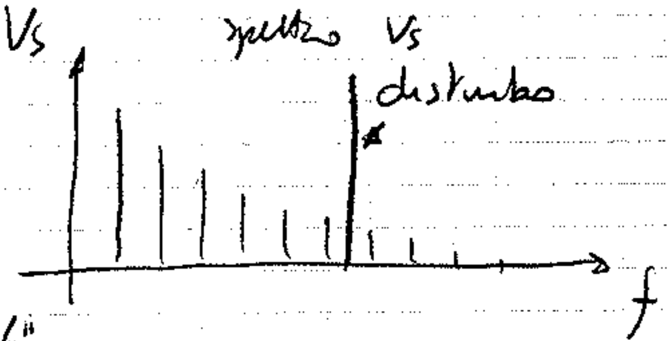
Sensore a soglia



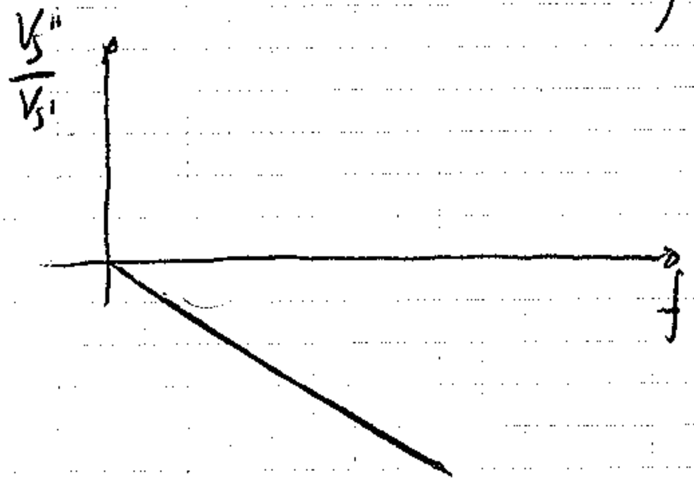




Per recuperare il segnale potrei usare un filtro passabasso (RC), ma corromperei il segnale.

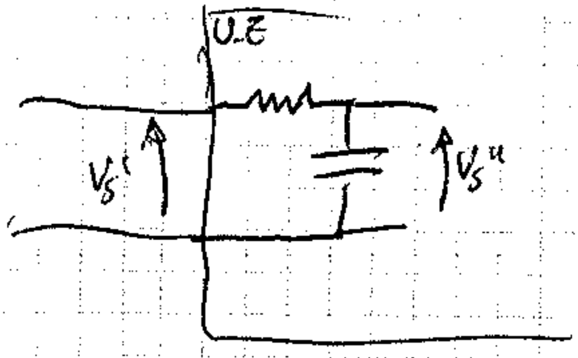


Supponiamo V_s'' ~~hai~~ ai capi del filtro passabasso

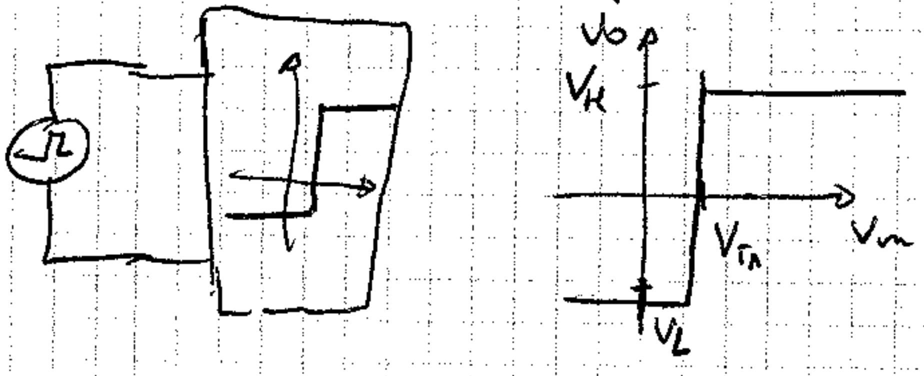


trasferimento. Per ottenere il segnale completo devo spostare il polo della f. di trasferimento e così ricompare il disturbo

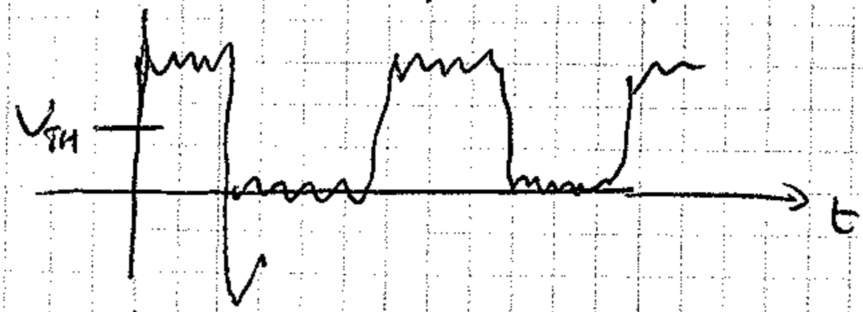
Si utilizza il passa basso per eliminare i disturbi a frequenze elevate, ma quelli a frequenze basse rimangono

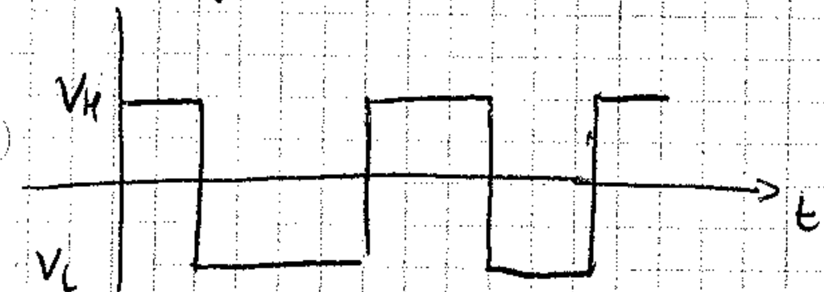


Possiamo usare dei comparatori di tensione

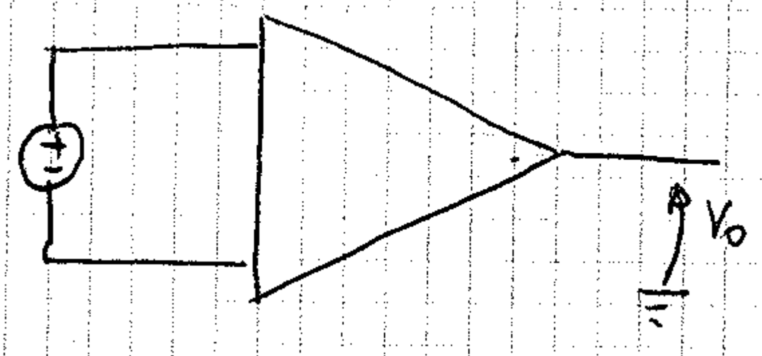


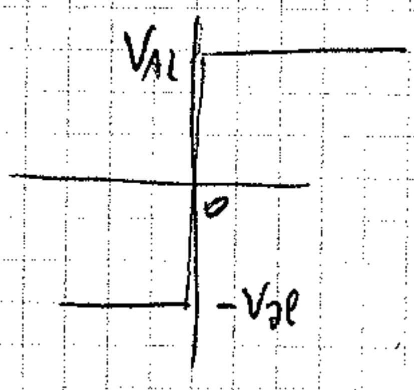
~~Questo dispositivo p~~



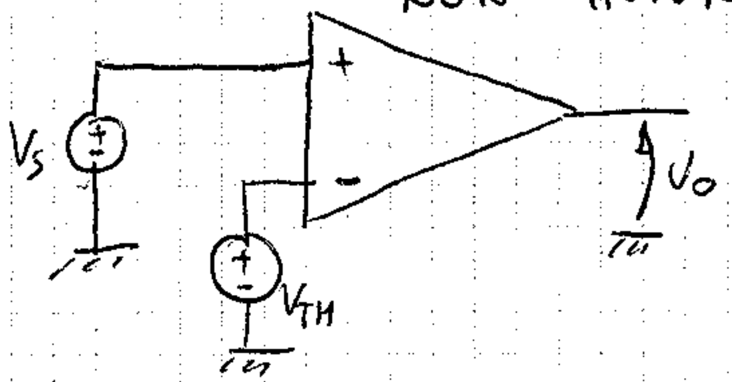


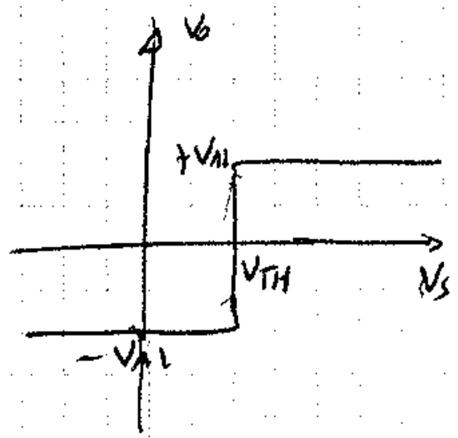
Questo dispositivo può essere schematizzato



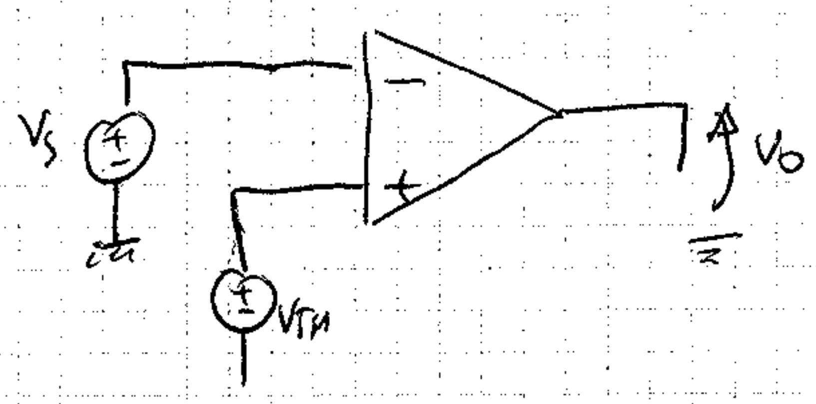


NON INVERTENTE

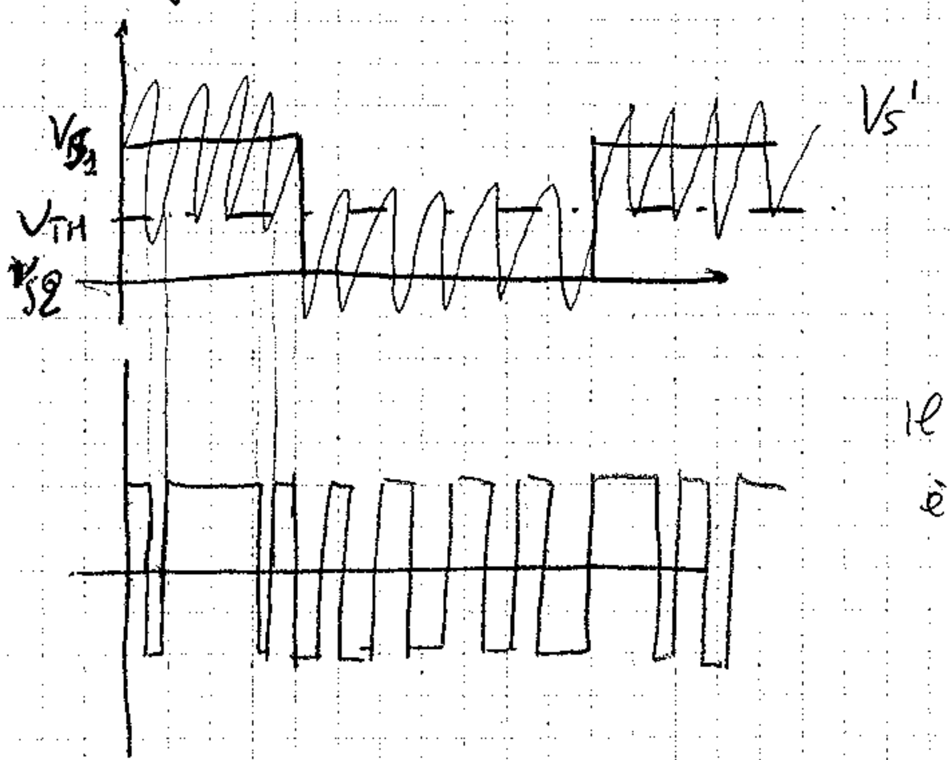




Per ottenere l'invertente si scambiano V_s e V_{TH}



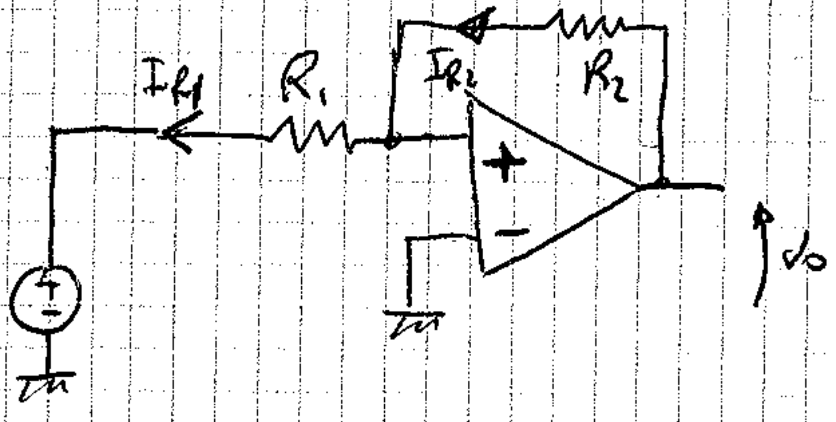
Esempio:

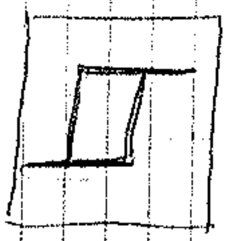


Il segnale legittimo è perso per sempre

Dobbiamo modificare il comparatore per renderlo maggiormente immune

Comparatori con isteresi





In generale $V_d \neq 0$

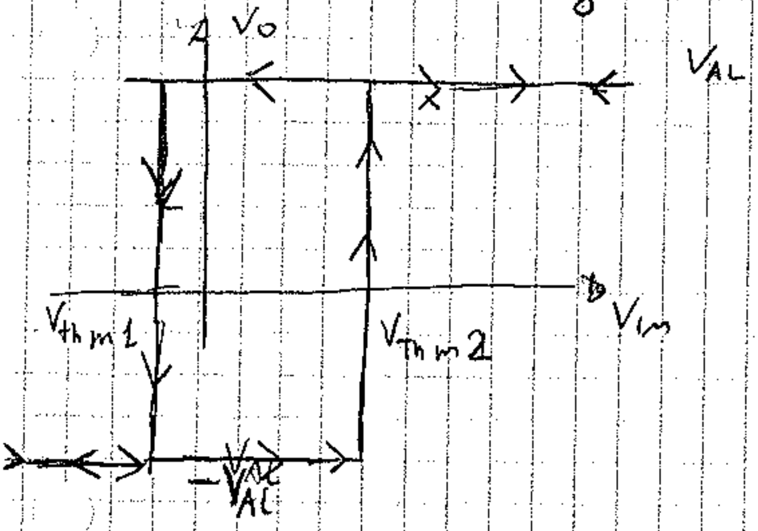
$I_{R_1} \simeq I_{R_2}$ $\qquad V_d = \frac{R_1}{R_1+R_2} V_o + \frac{R_2}{R_1+R_2} V_i$

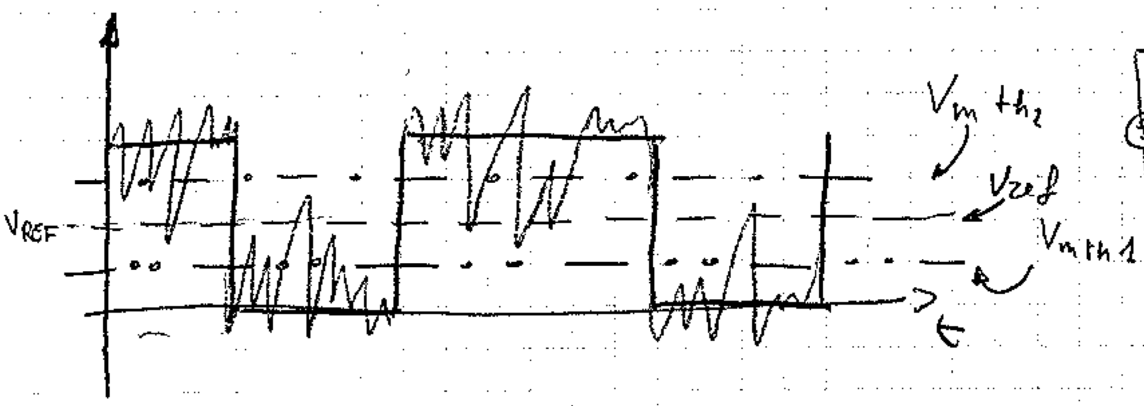
$$V_{in,th} = -\frac{R_1}{R_2} V_o$$

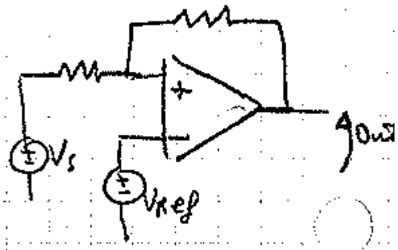
$V_{in\,th_1} = -\frac{R_1}{R_2} V_{AL}$ $\qquad V_T = +\frac{R_1}{R_2} V_{AL}$

se $V_o > 0$ $\qquad$ se $V_o < 0$

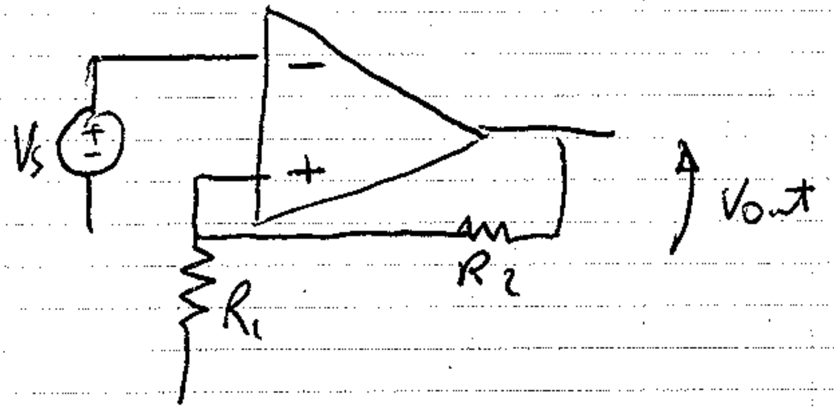
Coesistono 2 soglie di commutazione





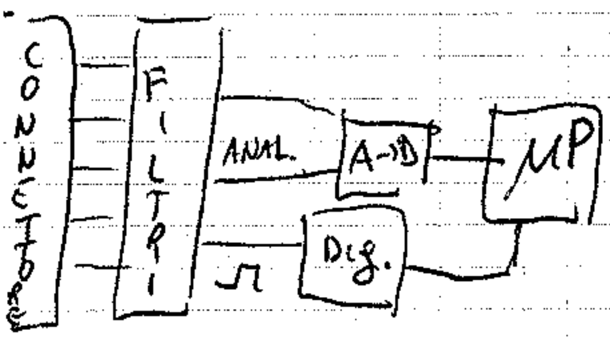


Comparatori con isteresi (invertenti)



Ampiezza isteresi dipende dal rapporto $R_2 \div R_1$

UNITÀ ELETTRONICA



Protezione da sovratensioni: