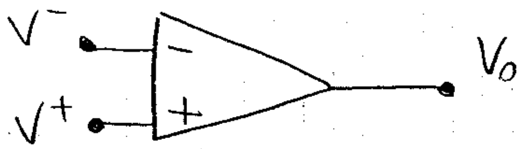
LEZ. 2 : - A.O.

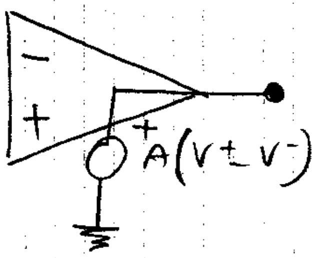
AMPLIFICATORE OPERAZIONALE : INTRODUZIONE

■ A.O. IDEALE



$$V_0 = A(V^+ - V^-)$$

- $A \to \infty$
- $R_{IN} \to \infty$
- $R_{OUT} = 0$



USCITA di A.O. ID. : È GEN. DI TENS. ID.

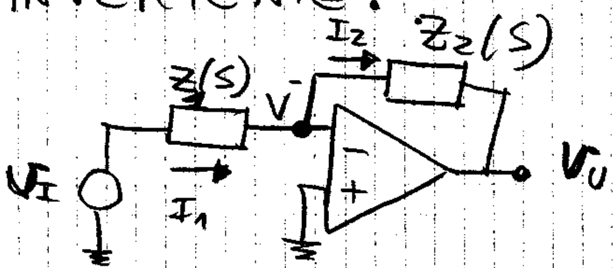
- Tempo di risposta nullo

■ CONFIGURAZ. A REAZIONE NEGATIVA

V_0 FINITO ; $(V^+ - V^-) = \frac{V_0}{A} \longrightarrow 0$

$V^+ = V^-$ C.TO CIRC. VIRTUALE
(Se $V^+ = 0V \to$ MASSA VIRT.)

- INVERTENTE :



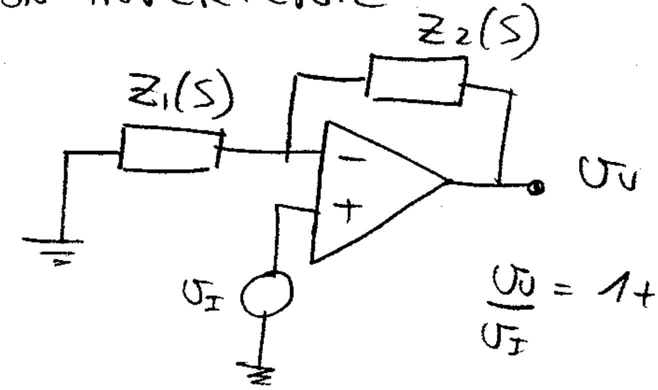
$$\frac{V_U}{V_I} = -\frac{Z_2(S)}{Z_1(S)}$$

Risoluz: $V^- = V^+ = 0V$

$I_1 = I_2$

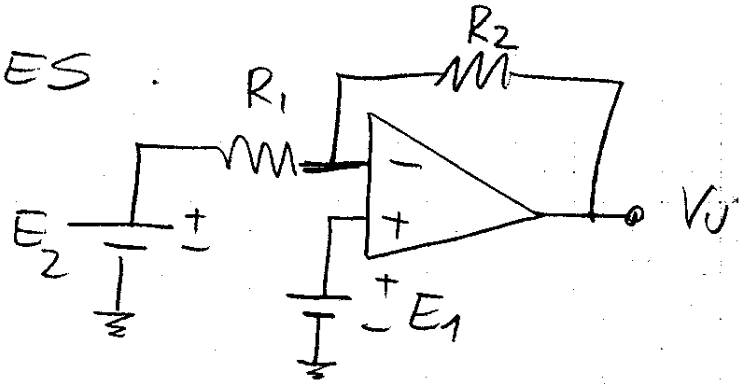
$I_1 = \frac{V_I}{Z_1(S)}$

- NON-INVERTENTE



$$\frac{V_U}{V_I} = 1 + \frac{Z_2(S)}{Z_1(S)}$$

- ES.



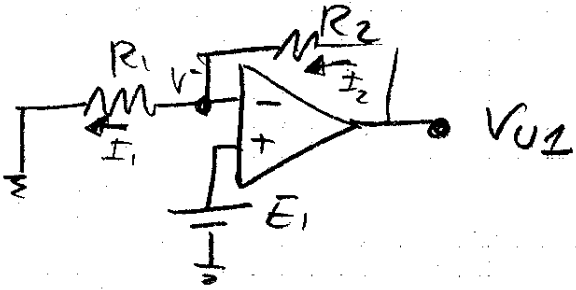
$R_1 = 1\,k\Omega$ $\qquad E_1 = -2\,V$ $\qquad A \to \infty$

$R_2 = 2\,k\Omega$ $\qquad E_2 = +1\,V$

? V_U ?

- Reaz. neg. $\longrightarrow$ Rete lin. $\longrightarrow$ Sovrapp. eff.

(1) Spengo E_2 :



$V^+ = E_1$

$V^- = V^+ = E_1$

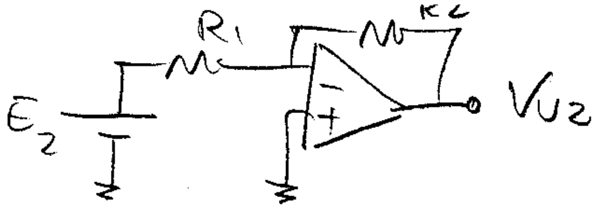
$I_1 = \frac{V^-}{R_1} = \frac{E_1}{R_1}$ $\qquad I_1 = I_2$

$$V_{U1} = V^- + I_2 R_2 = E_1 + \frac{E_1}{R_1} R_2 = E_1\left(1 + \frac{R_2}{R_1}\right) =$$

$$= -2 \cdot (1+2) = -6\,V$$

Anche: da config. non-inv.

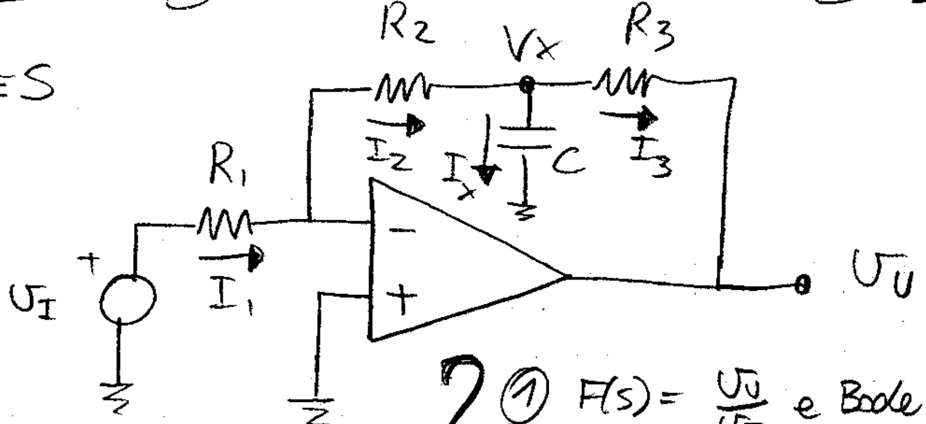
(2) Spengo E_1



$$V_{U2} = -E_2 \cdot \frac{R_2}{R_1} = -1 \cdot 2 = -2\ V$$

$$V_U = V_{U1} + V_{U2} = -6 - 2 = -8\ V$$

ES



$A \to \infty$
$R_1 = 2\,k\Omega$
$R_2 = R_3 = 10\,k\Omega$
$C = 100\,mF$

? (1) $F(s) = \frac{V_U}{V_I}$ e Bode
(2) $v_U(t)$ per $v_I(t)$ a rampa $\to v_I(t) = 100,$

- Reaz. Neg.; $A \to \infty \Rightarrow V^- = V^+ = 0\ V$

(1) $$I_1 = \frac{V_I - V^-}{R_1} = \frac{V_I}{R_1}$$

$$I_2 = I_1$$

$$V_x = 0 - I_2 R_2 = -I_1 R_2 = -V_I \cdot \frac{R_2}{R_1}$$

(OSS: è come amp. inv.)

$$I_x = \frac{V_x}{1/sC} = -\frac{sCR_2}{R_1} \cdot V_I$$

$$I_3 = I_2 - I_x = I_1 - I_x$$

$$V_U = V_x - I_3 R_3 = V_x - I_1 R_3 + I_x R_3 =$$

$$= -V_I \frac{R_2}{R_1} - V_I \cdot \frac{R_3}{R_1} - V_I \frac{sCR_2R_3}{R_1} =$$

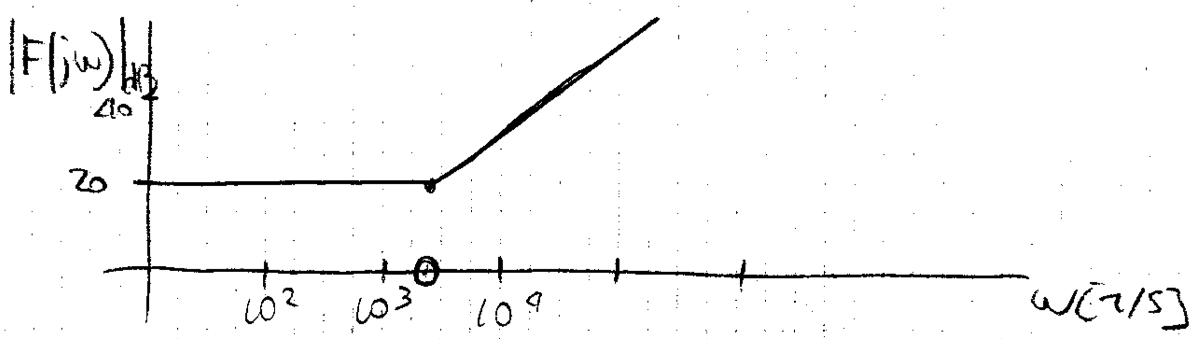
$$= -V_I \left[\frac{1}{R_1}\left(R_2 + R_3 + sCR_2R_3\right)\right]$$

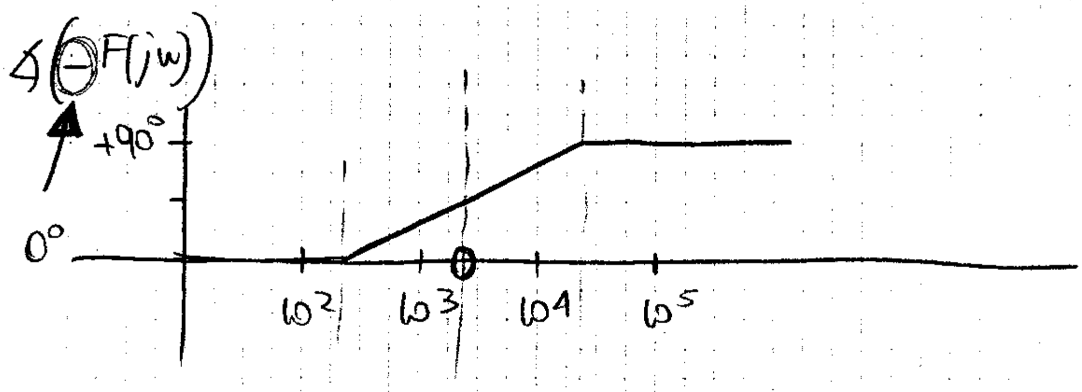
$$F(s) = \frac{v_U}{v_I} = -\frac{R_2+R_3}{R_1}\left(1 + sC\frac{R_2R_3}{R_2+R_3}\right)$$

$$F(s) = -10\,(1+\tau s) \qquad \tau = 5\cdot10^{-4}\,s$$

zero: $z = -\frac{1}{5\cdot10^{-4}} = -0.2\cdot10^{4} = -2\cdot10^{3}$ r/s

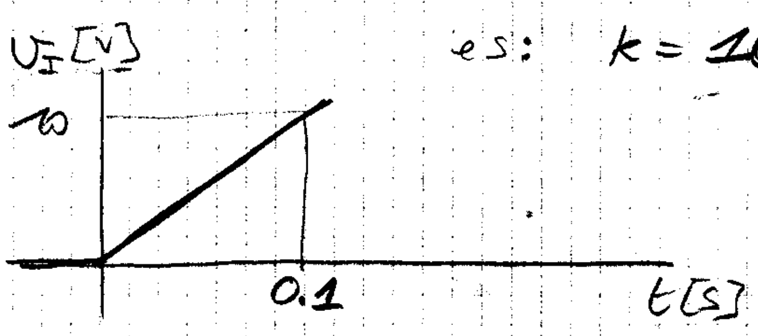
$$\omega_z = 2\cdot10^{3}\ r/s$$





② $v_I(t) = \begin{cases} 0 & t<0 \\ Kt\ [V] & t \geq 0 \end{cases}$

es: $k = 100\ V/s$



$$F(s) = \frac{v_U(s)}{v_I(s)} \longrightarrow v_U(s) = F(s)\cdot v_I(s)$$

$$v_U(s) = -10(1+\tau s)\cdot v_I(s)$$

$$v_U(s) = -10\,v_I(s) - 10\tau\cdot s\cdot v_I(s)$$

"s" è l'operatore <u>DERIVATA</u>

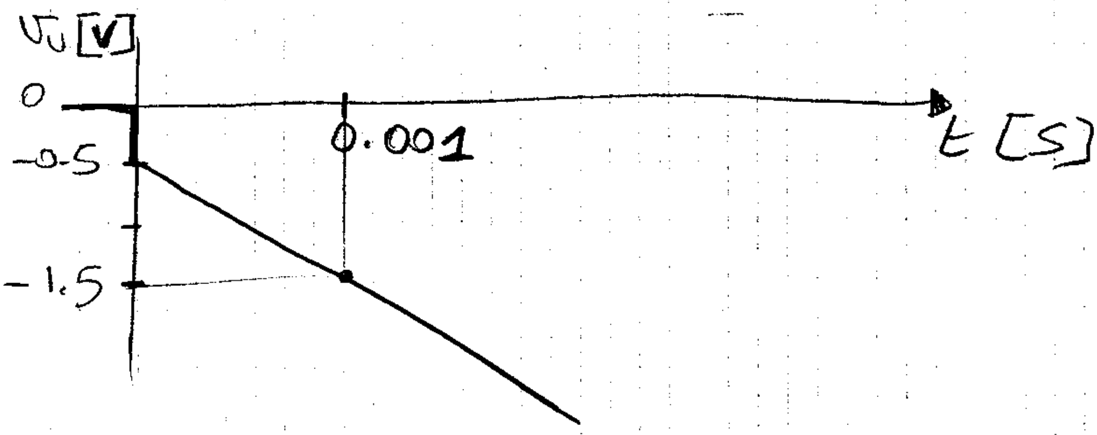
Dominio del tempo: (Questo è un caso FORTUNATO)

$$v_U(t) = -10\, v_I(t) - 10\tau \frac{d}{dt} v_I(t)$$

Dimensioni!!

$$v_U(t) = -10 \cdot \underbrace{K \cdot t}_{\text{rampa}} - 10\,\underbrace{\tau \cdot K}_{\text{costante}}$$

$$v_U(t) = \begin{cases} 0 & t < 0 \\ -1000\,t - 0.5 \ \text{V} & t \geq 0 \end{cases}$$



- Verifica con TEOR. VAL. FINALE e INIZ.

$$V_I(s) = \frac{K}{s^2}$$

$$V_U(s) = F(s) \cdot V_I(s) = -10(1+s\tau) \cdot \frac{K}{s^2}$$

$$v_U(0^+) = \lim_{s\to+\infty} s \cdot V_U(s) = \lim_{s\to+\infty} -\cancel{s} \cdot 10(1+s\tau)\frac{K}{s^{\cancel{2}}} =$$

$$= \lim_{s\to+\infty}\left(-\frac{10K}{s}\right) + \lim_{s\to+\infty}\left(-10\tau K \frac{\cancel{s}}{\cancel{s}}\right) =$$

$$= 0 - 10\,\underbrace{\tau}_{[s]}\underbrace{K}_{[V/s]} = -10 \cdot 5 \cdot 10^{-4} \cdot 10^{2} = -0.5 \ \text{V}$$

$$v_U(\infty) = \lim_{s\to 0^+} s \cdot V_U(s) = \lim_{s\to 0^+} -10K\,\frac{1+s\tau}{s} = -\infty$$

• ES : $\boxed{\text{SINTESI di RETE (1)}}$

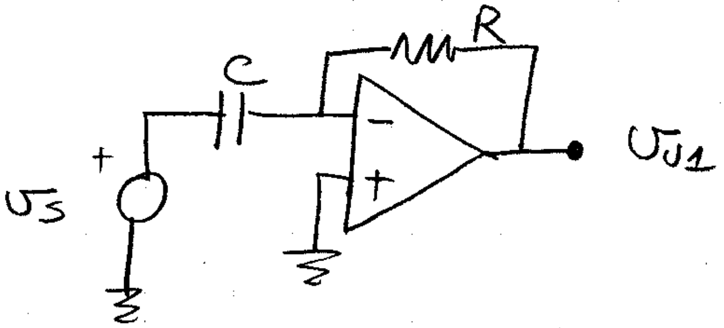
ho:

Voglio realizzare $\quad V_U(t) = -0.3 \frac{d}{dt} V_S(t) + 5 \quad [V]$

(Tempo in [S]) $\qquad [S] \qquad \left[\frac{V}{S}\right]$

A disposizione: A.O., R, C, L, Batteria
└ con alimentaz.

(1) Realizzo $\quad v_{U1}(t) = -0.3 \frac{d}{dt} v_S(t)$ → Derivatore (invertente)



$$\frac{v_{U1}}{v_S} = -\frac{R}{1/sC} = -sCR = -s\tau \qquad \tau = CR$$

$$v_{U1}(s) = -s\tau\, v_S(s)$$

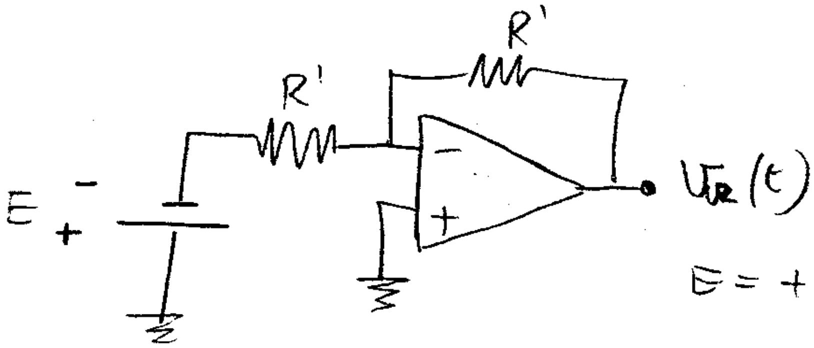
$$\Updownarrow$$

$$v_{U1}(t) = -\tau \frac{d}{dt} v_S(t)$$

Dimensionamento: $\tau = 0.3\ s \longrightarrow$ Es: $\begin{cases} C = 1\mu F \\ R = 300k\Omega \end{cases}$

(2) Realizzo $v_{U2}(t) = +5\ V$

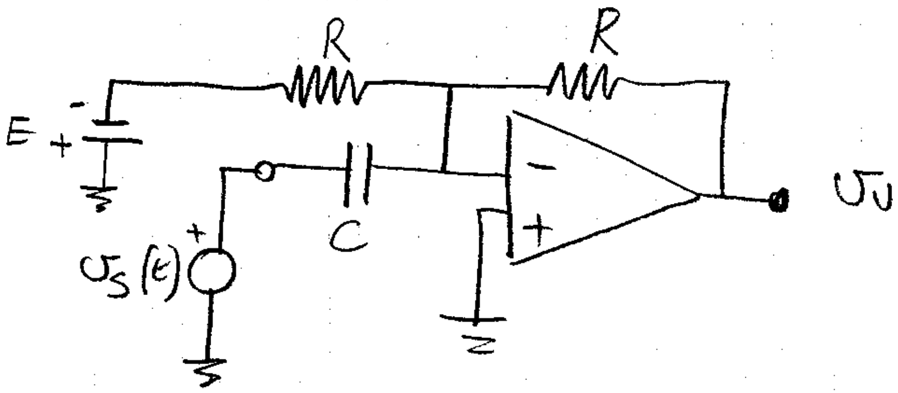
Varie possibilità. Scelgo questa: (batteria a scelta)



$E = +5\ V$

$$v_{U2} = -\frac{R'}{R'} \cdot (-E) = -(-E) = E = +5\ V$$

(TOT) Posso usare 1 SOLO A.O (SOVRAPP. EFFETTI)



$R = 300\ k\Omega$
$C = 1\ \mu F$
$E = +5\ V$

- ES: $\boxed{\text{SINTESI di RETE (2)}}$

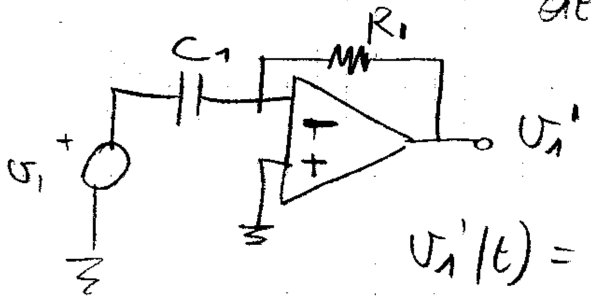
Ho $v_1(t)$; $v_2(t)$ - Voglio:

$$v_U(t) = \frac{d}{dt} v_1(t) + 100 \int_0^t v_2(t')\, dt' + 10 \quad [V]$$

c'è 1 [s] $\quad [s^{-1}] \quad [V \cdot s]$

Alla fine uso Sommatore Invertente
(+ comodo!!)

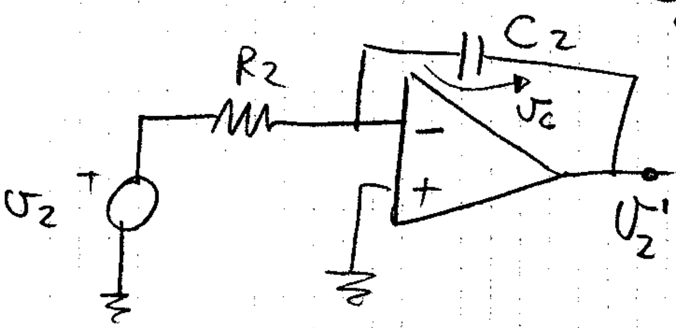
① Creo $v_1'(t) = -0.1 \frac{d}{dt} v_1(t)$



$$v_1'(t) = -\tau_1 \frac{d}{dt} v_1(t) \quad ; \quad \tau_1 = R_1 C_1$$

$$\tau_1 = 0.1 \text{ s} \rightarrow \begin{matrix} C = 1\,\mu F \\ R = 100\,k\Omega \end{matrix}$$

② Creo $v_2'(t) = -100 \int_0^t v_2(t')\,dt'$



$$\frac{v_2'}{v_2} = -\frac{1/sC_2}{R_2} = -\frac{1}{sC_2R_2} = -\frac{1}{s}\cdot\frac{1}{\tau_2} \quad ; \quad \tau_2 = C_2 R$$

$$\Updownarrow$$

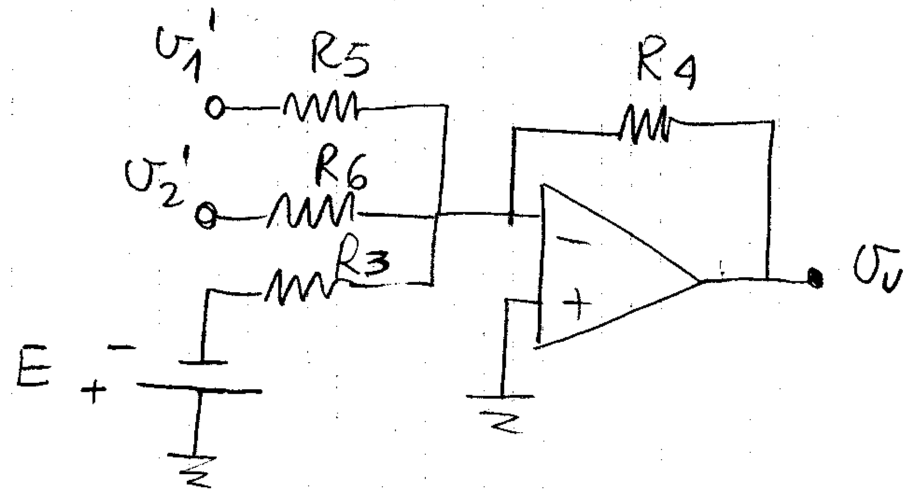
$$v_2'(t) = -\frac{1}{\tau_2}\int_0^t v_2(t')\,dt' + \underbrace{v_C(0)}_{= 0\,V}$$

(C scarico a $t = 0$)

voglio: $100 = \frac{1}{\tau_2} \rightarrow \tau_2 = 10^{-2}$ s

$$\begin{cases} C_2 = 100\,mF \\ R_2 = 100\,k\Omega \end{cases}$$

TOT USO SOMMATORE INVERTENTE
(E' + COMODO)!



Scelgo $R_4 = 1\ k\Omega$

$$R_5 = \frac{R_4}{10} = 100\ \Omega$$

$$R_6 = R_4 = 1\ k\Omega$$

$$E = +5 \Rightarrow R_3 = \frac{R_4}{2} = 500\ \Omega$$

NON-IDEALITÀ DELL'A.O.

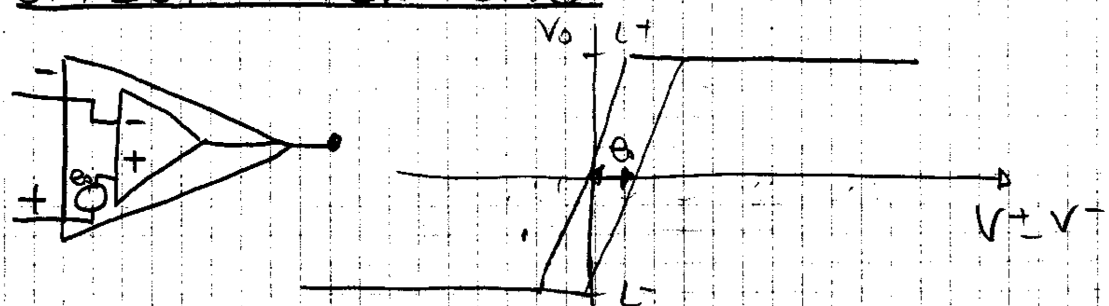
GUADAGNO FINITO

$A \neq \infty$ (TIP: $A = 10^3 \div 10^6$)

$\Rightarrow V^+ \neq V^-$

- Tecnica risolutiva: $V_0 = A(V^+ - V^-)$
  si scrivono 2 eq. e si elimina V^-

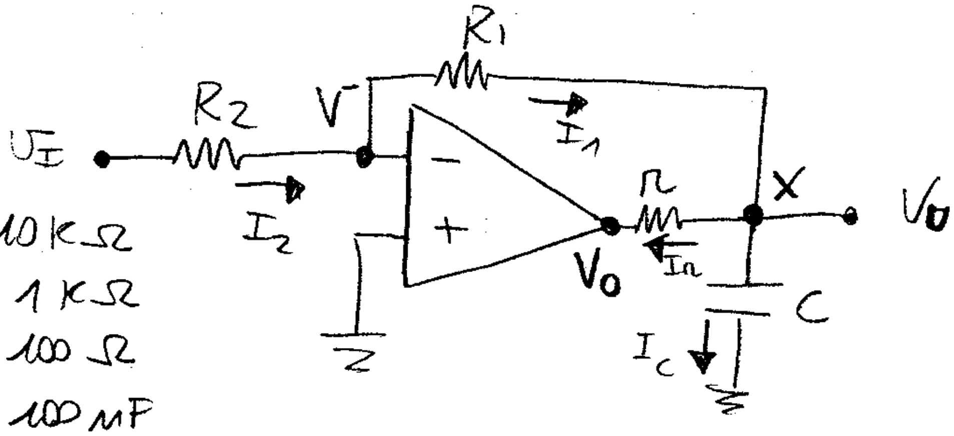
OFFSET DI TENSIONE



Gen. id. di Tens. in serie a mors. "+"

$|e_0|$ = qualche mV

• ES (TEMA D'ESAME 24/6/97)



$R_1 = 10\,k\Omega$
$R_2 = 1\,k\Omega$
$r = 100\,\Omega$
$C = 100\,nF$

? ① $A \to \infty$; det F.d.T. $\frac{V_U}{V_I}$
② Effetto di offset $e_0 = +5\,mV$ $(A \to \infty)$
③ $A = 100$ det $F(s) = \frac{V_U}{V_I}$, Bode, Risp. al gradino.

① $A \to \infty \Rightarrow V^+ = V^-$

$V^- = 0\,V$

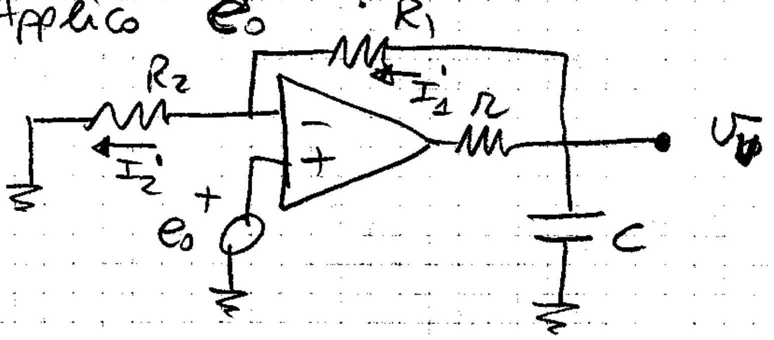
$I_1 = I_2$

$I_2 = \frac{V_I}{R_2}$

$V_U = -I_1 R_1 = -I_2 R_1 = -V_I \frac{R_1}{R_2}$

$F(s) = \frac{V_U}{V_I} = -\frac{R_1}{R_2} = -10$ (non dip. da r e C)

② Spengo gen. indip. V_I
Applico e_0



NON INV!

$A \to \infty \Rightarrow V^- = V^+ = e_0$

$V_U = e_0 + I_1' R_1 = e_0 + I_2' R_1 = e_0 + \frac{e_0}{R_2} R_1 = e_0 \left(1 + \frac{R_1}{R_2}\right)$

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(3) $v_o = A(V^+ - V^-)$

$V^+ = 0 \longrightarrow v_o = -A V^-$ } 2 eq. da propr. dell' A.O.
$I_1 = I_2$

+

$I_1 = I_R + I_C$ ← 1 eq. da legge Kirchoff nodo X

= 3 eq. in 3 incognite (V^-, V_o, v_U)

$$I_2 = \frac{v_I - V^-}{R_2}$$

$$I_1 = \frac{V^- - v_U}{R_1}$$

$$I_R = \frac{v_U - V_o}{R}$$

$$I_C = \frac{v_U}{1/sC} = sC\,v_U$$

$$\begin{cases} V_o = -AV^- & (1) \\ \dfrac{v_I - V^-}{R_2} = \dfrac{V^- - v_U}{R_1} & (2) \\ \dfrac{V^- - v_U}{R_1} = \dfrac{v_U - V_o}{R} + sC\,v_U & (3) \end{cases}$$

da (3) ricavo V^-:

$$V^- = v_U \frac{R_1}{R} - V_o \frac{R_1}{R} + sCR_1 v_U + v_U$$

$$V^- = \left(1 + \frac{R_1}{R} + sCR_1\right) v_U - \frac{R_1}{R} V_o$$

sost. nella (1) e ricavo V_o

$$V_o = -A\left(1 + \frac{R_1}{R} + sCR_1\right) v_U + A\frac{R_1}{R} V_o$$

$$V_0 = \frac{-A\left(1+\frac{R_1}{r}+sCR_1\right)}{1-A\frac{R_1}{r}}\, v_U$$

Dalla (1) calcolo V^-

$$V^- = -\frac{V_0}{A} = \frac{1+\frac{R_1}{r}+sCR_1}{1-A\frac{R_1}{r}}\, v_U$$

SOST. V^- nella (2)

$$(2):\quad R_1 v_I - R_1 V^- = R_2 V^- - R_2 v_U$$

$$R_1 v_I = (R_1+R_2)\, V^- - R_2 v_U$$

SOST: $$R_1 v_I = (R_1+R_2)\,\frac{1+\frac{R_1}{r}+sCR_1}{1-A\frac{R_1}{r}}\, v_U - R_2 v_U$$

$$F(s) = \frac{v_U}{v_I} = \frac{R_1}{(R_1+R_2)\,\frac{1+\frac{R_1}{r}+sCR_1}{1-A\frac{R_1}{r}} - R_2}$$

<u>Verifico</u>: $A \to \infty \Rightarrow F(s) \to -\frac{R_1}{R_2}$ OK.

$$F(s) = \frac{R_1\left(1-A\frac{R_1}{r}\right)}{(R_1+R_2)\left(1+\frac{R_1}{r}+sCR_1\right) - R_2 + A\frac{R_1R_2}{r}} =$$

$$= \frac{R_1\left(1-A\frac{R_1}{r}\right)}{(R_1+R_2)\left(1+\frac{R_1}{r}\right) + R_2\left(A\frac{R_1}{r}-1\right) + sCR_1(R_1+R_2)}$$

$$= \frac{\cancel{R_1}\left(1-A\frac{R_1}{r}\right)}{\cancel{R_1}\left(1+\frac{R_1}{r}\right) + R_2\left(\cancel{1}+\frac{\cancel{R_1}}{r}+A\frac{\cancel{R_1}}{r}-\cancel{1}\right)} \cdot \frac{1}{1+sC\frac{\cancel{R_1}(R_1+R_2)}{\cancel{R_1}\left(1+\frac{R_1}{r}\right)+R_2\frac{\cancel{R_1}}{r}(A+1)}}$$

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$$F(s) = -\frac{A\frac{R_1}{r} - 1}{1+\frac{R_1}{r}+\frac{R_2}{r}(A+1)} \cdot \frac{1}{1+sC\dfrac{R_1+R_2}{1+\frac{R_1}{r}+\frac{R_2}{r}(A+1)}}$$

Numeri : $\frac{R_1}{r} = \frac{10^4}{10^2} = 100$

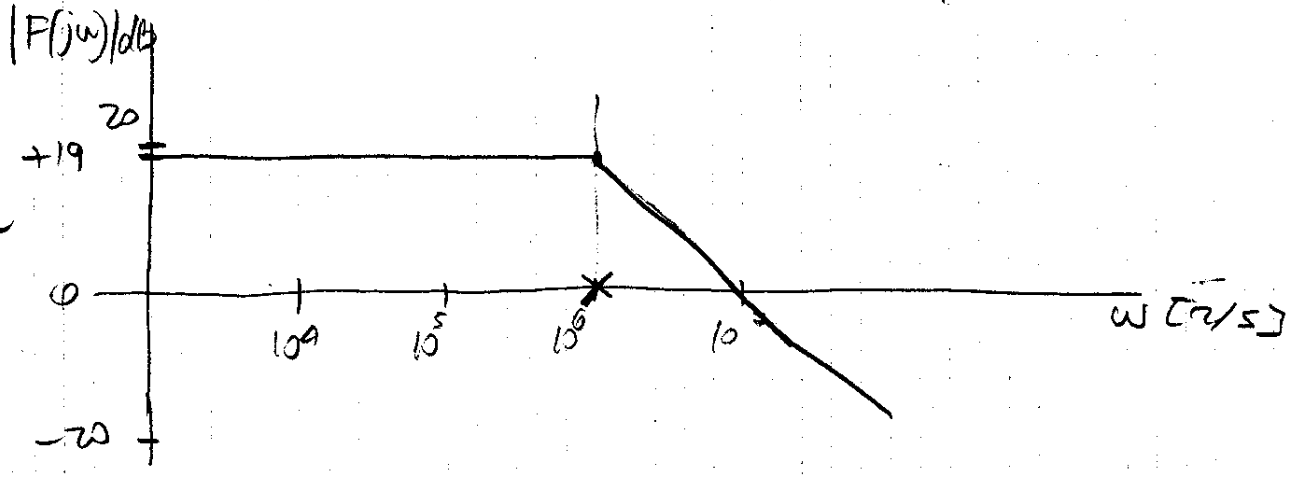
$\frac{R_2}{r} = \frac{10^3}{10^2} = 10$

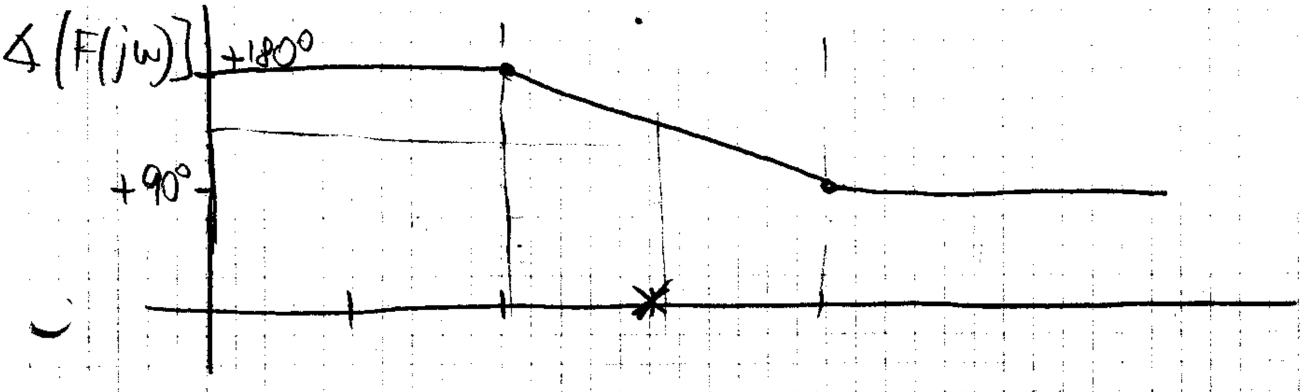
! DIRE CHE SE $A=A(s)$, CAMBIA LA F.d.T !

$$F(s) \simeq -\frac{10^4}{1+100+1010} \cdot \frac{1}{1+s\dfrac{C(R_1+R_2)}{1+100+1010}} =$$

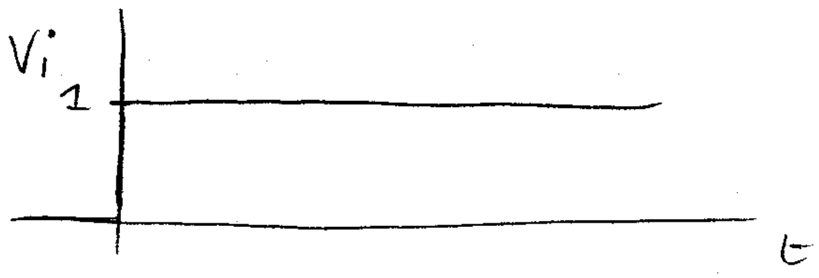
$$= -\frac{10^4}{1111} \cdot \frac{1}{1+s\cdot\dfrac{10^{-7}\cdot 11\cdot 10^3}{1111}} \simeq -9 \cdot \frac{1}{1+s\cdot 9{,}9\cdot 10^{-7}}$$

polo : $-1.01\cdot 10^6$ r/s $\rightarrow \omega_p = 1.01\cdot 10^6$ r/s



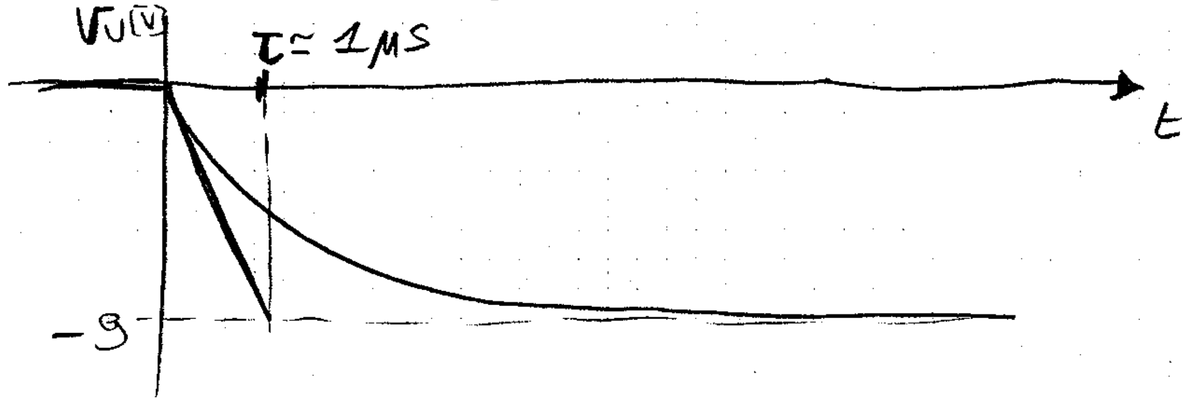


Risposta al gradino:



$$F(s) \simeq -9 \cdot \frac{1}{1+s\tau} \longrightarrow \text{PASSA-BASSO}$$

$$t \geq 0 : V_U(t) = -9 \cdot \left(1 - e^{-t/\tau}\right) \quad ; \quad \tau = 9.9 \cdot 10^{-7} \text{ sec.}$$



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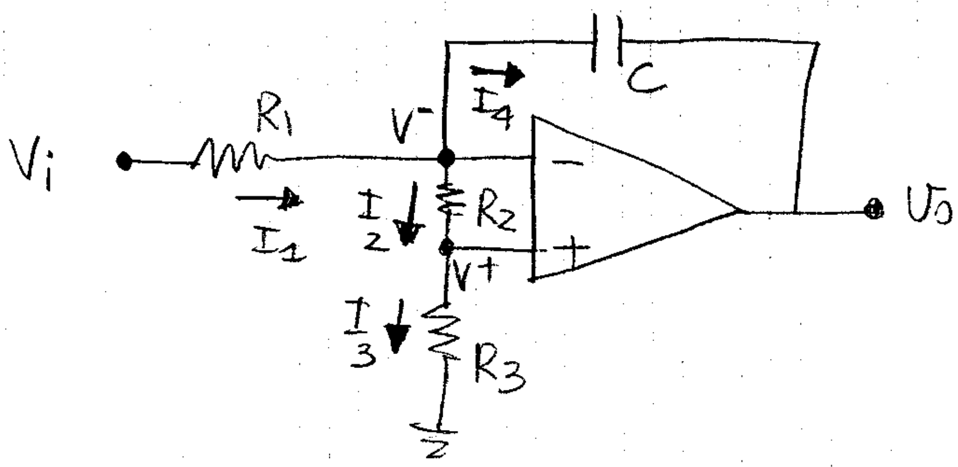
ES (TEMA D'ESAME 12/2/97)



$C = 100\ nF$
$R_1 = 100\ k\Omega$
$R_2 = 1\ k\Omega$
$R_3 = 1\ k\Omega$

① A.O. id : F.d.t. $\frac{V_o}{V_i}$; Diagr. Bode ; risp. gradino

② $A = 100$: Fdt $\frac{V_o}{V_i}$; Bode

③ $v_i(t) = 10 \sin 10^3 t$ [V] ? $v_o(t)$

① $A \to \infty$, Reaz. neg $\Rightarrow V^+ = V^-$

$$\Rightarrow I_2 = \frac{V^- - V^+}{R_2} = 0$$

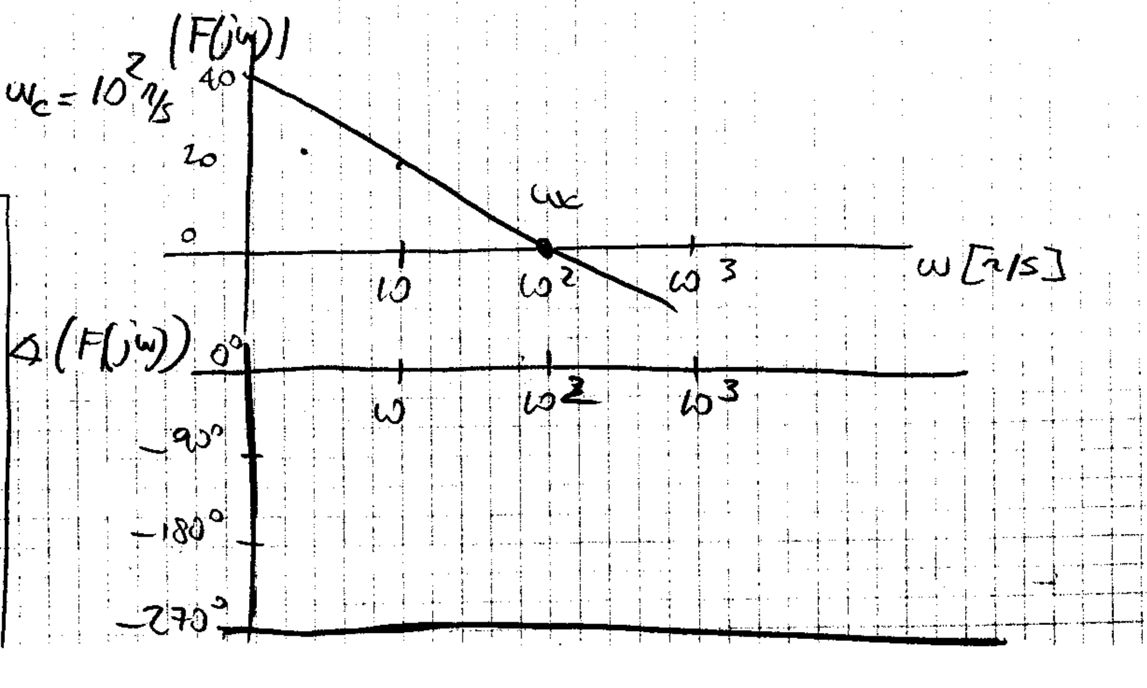
$$I_3 = 0 \Rightarrow V^- = V^+ = 0 \,!$$

$\Rightarrow I_1 = I_4 \Rightarrow$ è integratore

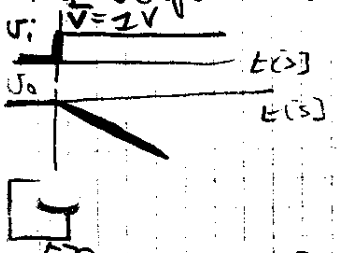
$$F(s) = \frac{V_o}{V_i} = -\frac{1}{sCR_1} = -\frac{1}{s\tau_1} \, ;$$

$$\tau_1 = CR_1 = 10^{-7} \cdot 10^5 = 10^{-2}\ s$$

$F(j\omega_c) = 1 \to \omega_c = 10^2\ r/s$



Risp. al gradino:



$t > 0$

$$v_o = -\frac{V}{\tau_1} \cdot t = -10^2 t$$

(2) $A \neq \infty \Rightarrow V^+ \neq V^- \Rightarrow I_2 \neq 0$

$I_3 = I_2$

$I_1 = I_2 + I_4$

$$\left.\begin{aligned} I_2 &= \frac{V^- - V^+}{R_2} \\ (V^+ - V^-) &= \frac{v_0}{A} \end{aligned}\right\} \Rightarrow I_2 = -\frac{v_0}{AR_2}$$

¿V^-? $\quad V^- = V^+ - \frac{v_0}{A} = I_2 R_3 - \frac{v_0}{A} = -\frac{v_0}{A}\frac{R_3}{R_2} - \frac{v_0}{A} =$

$$= -\frac{v_0}{A}\left(1 + \frac{R_3}{R_2}\right)$$

¿v_0? $\quad v_0 = V^- - \frac{I_4}{sC}$

¿I_4? $\quad I_4 = I_1 - I_2 = \frac{v_i - V^-}{R_1} - I_2 =$

$$= \frac{v_i}{R_1} + \frac{v_0}{AR_1}\left(1 + \frac{R_3}{R_2}\right) + \frac{v_0}{AR_2}$$

$$\Rightarrow v_0 = -\frac{v_0}{A}\left(1 + \frac{R_3}{R_2}\right) - \frac{1}{sC}\left[\frac{v_i}{R_1} + \frac{v_0}{A}\left(\frac{1}{R_1}\left(1 + \frac{R_3}{R_2}\right) + \frac{1}{R_2}\right)\right]$$

$$v_0\left[1 + \frac{1}{A}\,\frac{R_2+R_3}{R_2} + \frac{1}{A}\,\frac{1}{sC}\left(\frac{1}{R_1}\,\frac{R_2+R_3}{R_2} + \frac{1}{R_2}\right)\right] = -\frac{v_i}{sCR_1}$$

$$F(s) = -\frac{1}{sC_1R_1} \cdot \frac{1}{1 + \frac{R_2+R_3}{AR_2} + \frac{R_2+R_3}{AR_2}\frac{1}{sCR_1} + \frac{1}{A}\frac{1}{sCR_2}} =$$

$$= -\frac{1}{sC_1R_1} \cdot \frac{1}{\dfrac{AsCR_1R_2 + sCR_1(R_2+R_3) + R_2 + R_3 + R_1}{AsCR_1R_2}}$$

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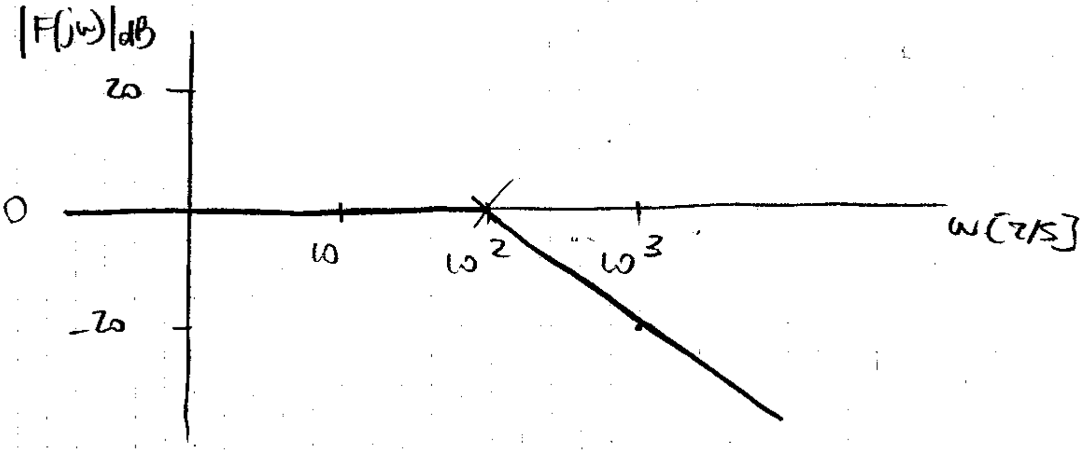
$$F(s) = -\frac{1}{\cancel{sCR_1}} \cdot \frac{A \cancel{sCR_1} R_2}{R_1 + R_2 + R_3 + sCR_1(AR_2 + R_2 + R_3)} =$$

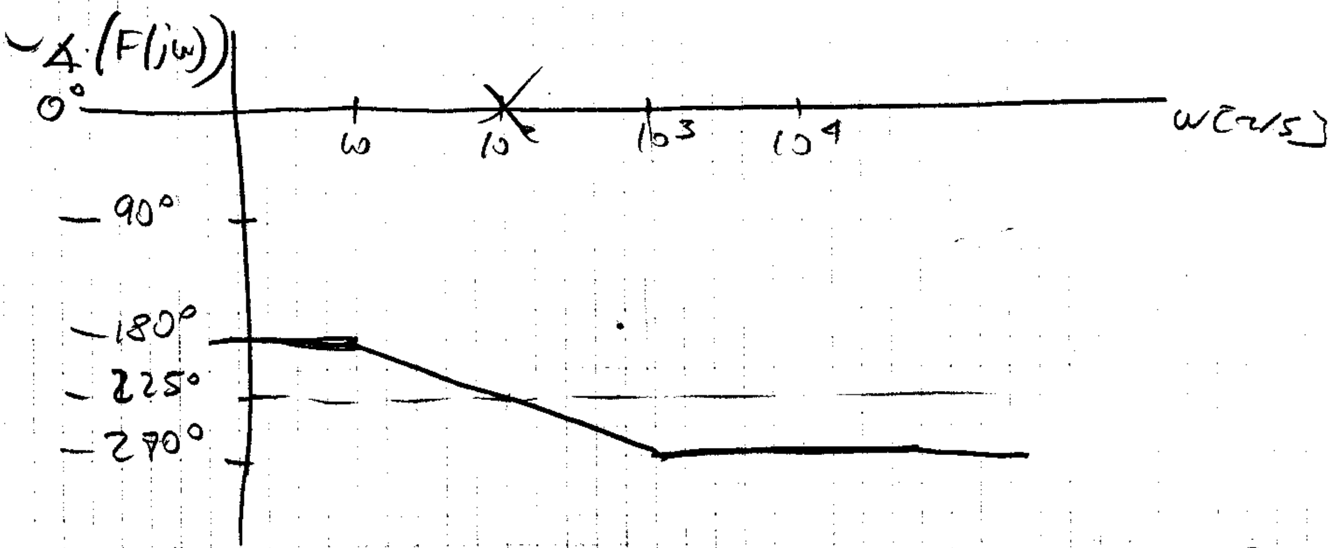
$$= -\frac{AR_2}{R_1 + R_2 + R_3} \cdot \frac{1}{1 + sC\dfrac{R_1 \cdot [(A+1)R_2 + R_3]}{R_1 + R_2 + R_3}} =$$

OK se $A \to \infty$

$$F(s) = -\frac{10^2 \cdot 10^3}{102'000} \cdot \frac{1}{1 + s\tau'} \simeq -\frac{1}{1 + s\tau'}$$

$$\tau' = C \cdot R_1 \frac{[(A+1)R_2 + R_3]}{R_1 + R_2 + R_3} \simeq 10^{-7} \cdot 10^5 \cdot \frac{10^5}{10^5} = 10^{-2}\,s$$



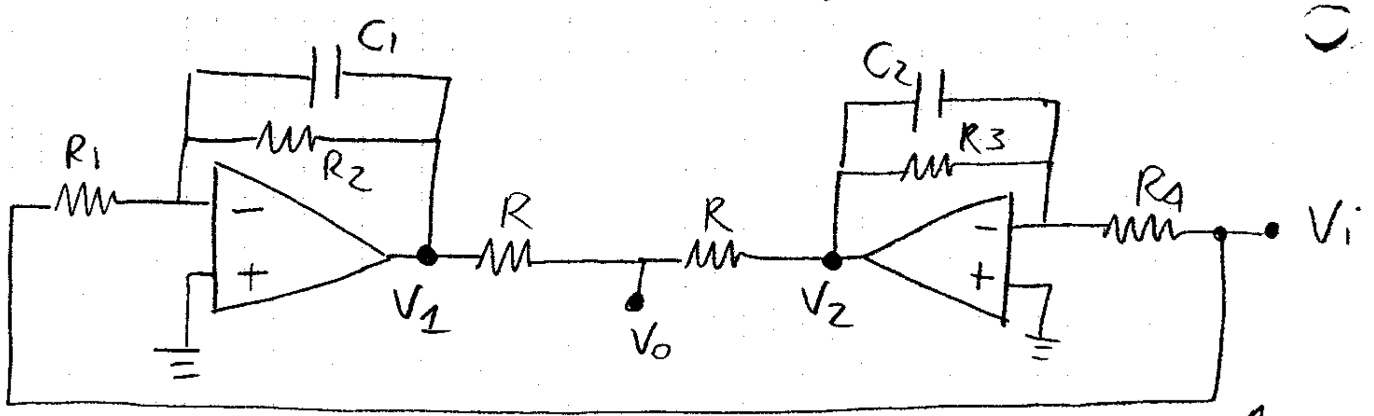


③ !! Aggiunta: $v_i(t) = 10 \sin 10^3 t$ [V] ? $v_o(t)$?

Dal diag.: $v_o(t) = 1 \sin(10^3 t + \varphi)$; $\varphi = -270°$

esatto: (OK amp.) $\varphi = -180° - \arctan\frac{10^3}{10^2} = -180° - 84° = -264°$

- ES (TEMA D'ESAME 19/11/96)



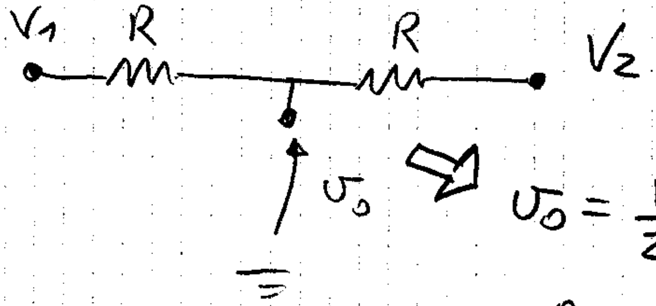
$A \to \infty$

$R = R_4 = 10\,k\Omega$; $R_1 = 1\,k\Omega$; $R_2 = 1\,M\Omega$;
$R_3 = 100\,k\Omega$; $C_1 = 100\,nF$; $C_2 = 1\,nF$

? (1) Det $F(s) = \frac{v_0}{v_i}$; Bode
(2) Risp. al grad.

(1) - Rete lineare
- Uscita di AO con $R_{out} = 0$ è gen. id. di Tens ⇨ x Trovare V_0 : sovrapp. effetti

Det. V_1 e V_2 poi:



⇨ $v_0 = \frac{1}{2}(V_1 + V_2)$

$$V_1 = -V_i \frac{R_2 // \frac{1}{sC_1}}{R_1} = -V_i \frac{\frac{R_2}{sC_1}}{R_2 + \frac{1}{sC_1}} \cdot \frac{1}{R_1} = -V_i \frac{R_2}{R_1} \cdot \frac{1}{1+sC_1 R_2}$$

$$V_2 = -V_i \frac{R_3}{R_4} \cdot \frac{1}{1+sC_2R_3}$$ x simmetria

$$F(s) = \frac{v_0}{v_i} = -\frac{1}{2}\left[\frac{R_2}{R_1} \cdot \frac{1}{1+sC_1R_2} + \frac{R_3}{R_4} \cdot \frac{1}{1+sC_2R_3}\right] =$$

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$$F(s) = -\frac{1}{2} \cdot \frac{\frac{R_2}{R_1} + sC_2 \frac{R_2R_3}{R_1} + \frac{R_3}{R_4} + sC_1 \frac{R_2R_3}{R_4}}{(1+sC_1R_2)(1+sC_2R_3)} =$$

$$= -\frac{1}{2} \cdot \frac{\frac{R_2R_4 + R_1R_3}{R_1R_4} + s\,\frac{C_2R_2R_3R_4 + C_1R_1R_2R_3}{R_1R_4}}{(\qquad)(\qquad)} =$$

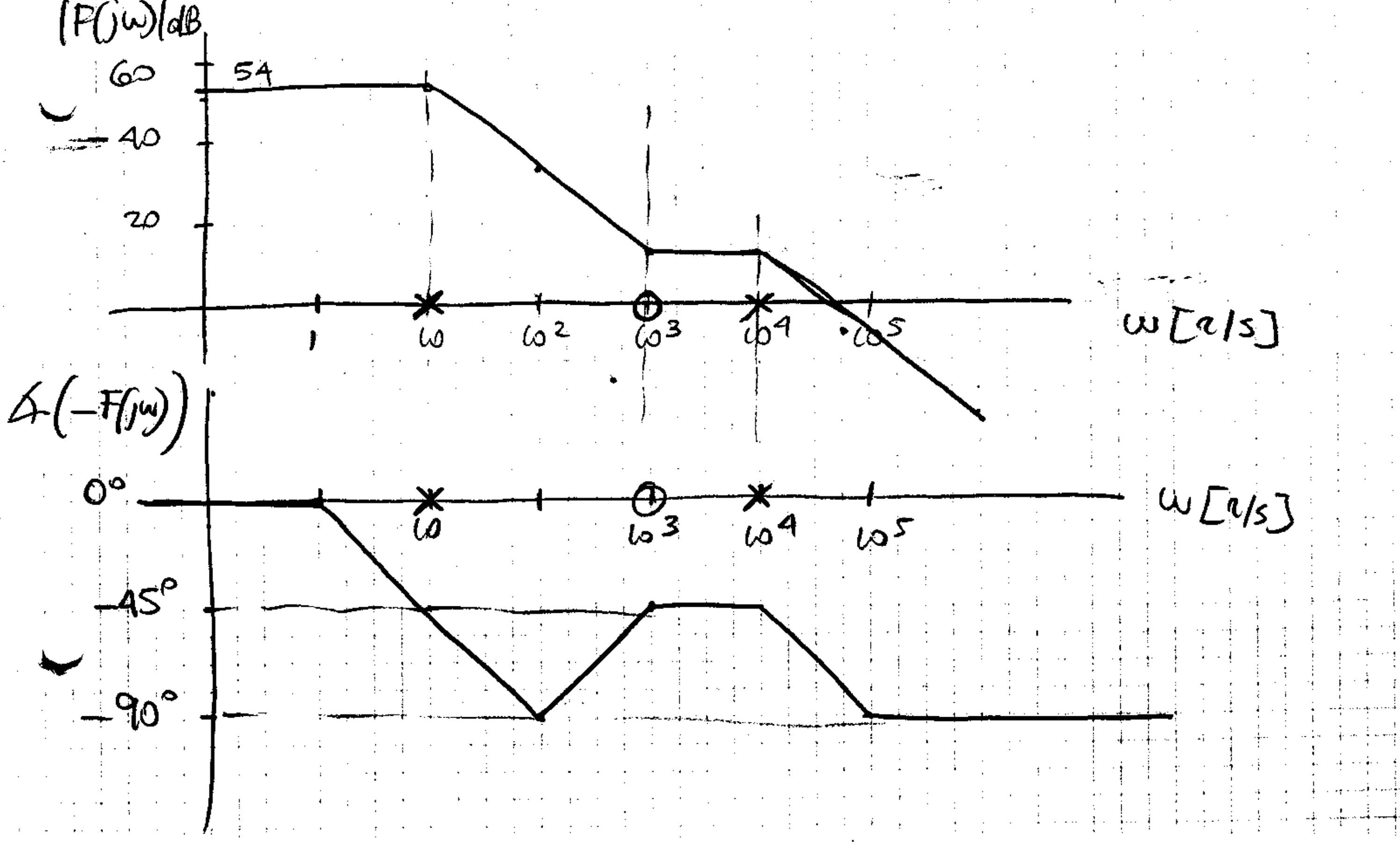
$$= -\frac{1}{2} \cdot \frac{R_2R_4+R_1R_3}{R_1R_4} \cdot \frac{1 + s\,\frac{C_2R_2R_3R_4 + C_1R_1R_2R_3}{R_2R_4+R_1R_3}}{(1+sC_1R_2)(1+sC_2R_3)} =$$

$$= -\frac{1}{2} \cdot \frac{10^6 \cdot 10^4 + 10^3 10^5}{10^3\,10^4} \cdot \frac{1 + s\,\frac{10^{-9}10^6 10^5 10^4 + 10^{-7} 10^3 10^6 10^5}{10^6 10^4 + 10^3 \cdot 10^5}}{(1+s\cdot 10^{-7}10^6)(1+s10^{-9}10^5)} =$$

$$\simeq -505 \cdot \frac{1+10^{-3}\cdot s}{(1+10^{-1}s)(1+10^{-4}s)}$$

$\omega_z = 10^3\ r/s$; $\omega_{p1} = 10\ r/s$; $\omega_{p2} = 10^4\ r/s$

$505 = 54\ dB$



(2) Risp. al grad:

NON È una F.d.T. dalla quale sia nota in maniera immediata la risp. al grad.

Usiamo Teor. del val. iniz. e fin.

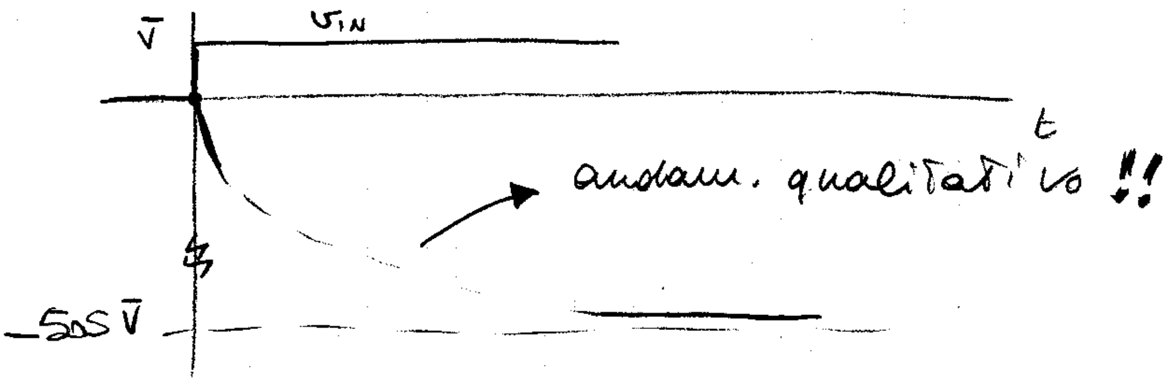
$$F(s) = -505 \frac{1+s\tau_1}{(1+s\tau_2)(1+s\tau_3)}$$

$\tau_1 = 10^{-3}\,s$
$\tau_2 = 10^{-1}\,s$
$\tau_3 = 10^{-4}\,s$

$$v_U(s) = F(s) \cdot v_i(s) = -505 \frac{1+s\tau_1}{(1+s\tau_2)(1+s\tau_2)} \cdot \frac{\overline{V}}{s}$$

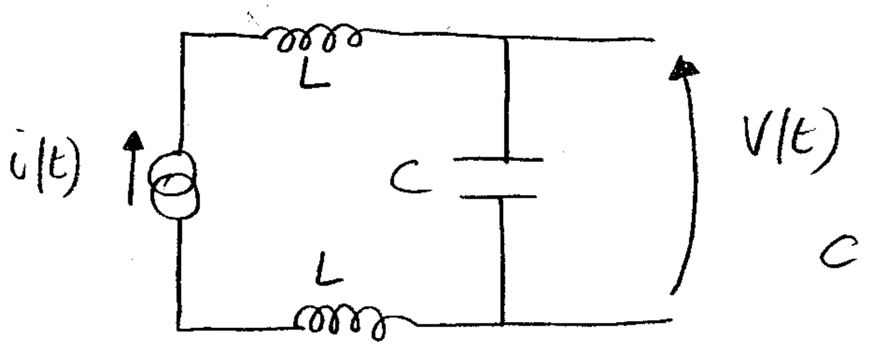
$$\lim_{t \to 0^+} v_U(t) = \lim_{s \to +\infty} s\, v_U(s) = 0$$

$$\lim_{t \to +\infty} v_U(t) = \lim_{s \to 0^+} s \cdot v_U(s) = -505\,\overline{V}$$



! Dal diagr. di Bode del mod.: è ≃ come passa basso -!
- Freq. alte: Risposta → 0
- Freq. bass: Risposta → -50

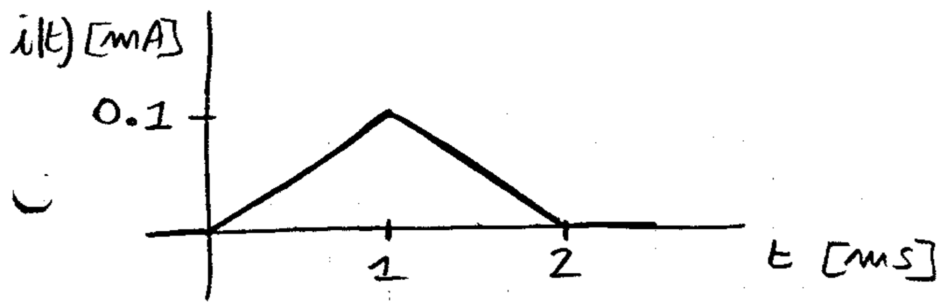
• ES (SCRITTO 3/4/97)



$L = 1\,mH$

$C = 10\,mF$

C scarico a $t=0$



? V(t) ?

Corrente nel condensatore è $i(t)$.

$$i(t) = C\,\frac{dV(t)}{dt}$$ $\rightarrow$ Le induttanze non hanno effetto su $V(t)$ (c'è un gen. id. di corr.).

$$dV(t) = \frac{1}{C}\, i(t)\, dt$$

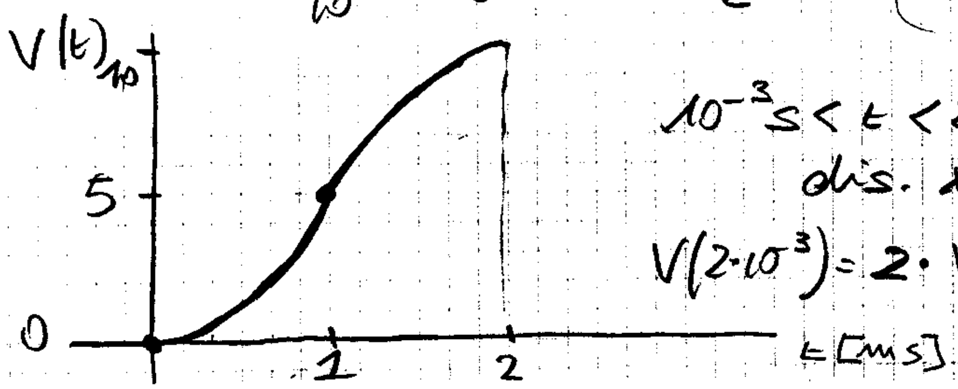
$$\downarrow$$

$$\int_0^t dV(t') = \frac{1}{C}\int_0^t i(t')\, dt'$$

$0 < t < 10^{-3}\,s$: $i(t) = \frac{0.1\,mA}{1\,ms}\cdot t = 10^{-1}\cdot t$ [A] (t in sec.)

$$V(t) = \frac{10^{-1}}{10^{-8}}\int_0^t t'\,dt' = \frac{10^7}{2}\,t^2 \quad [V]$$

$V(10^{-3}) = \frac{10^7}{2}\cdot 10^{-6} = 5\,V$



$10^{-3}\,s < t < 2\cdot 10^{-3}\,s$:

dis. x simmetria

$V(2\cdot 10^{-3}) = 2\cdot V(10^{-3}) = 10\,V$ (2 aree)