ELETTRONICA II

settembre

Prova scritta del 7 ~~giugno~~ 2000

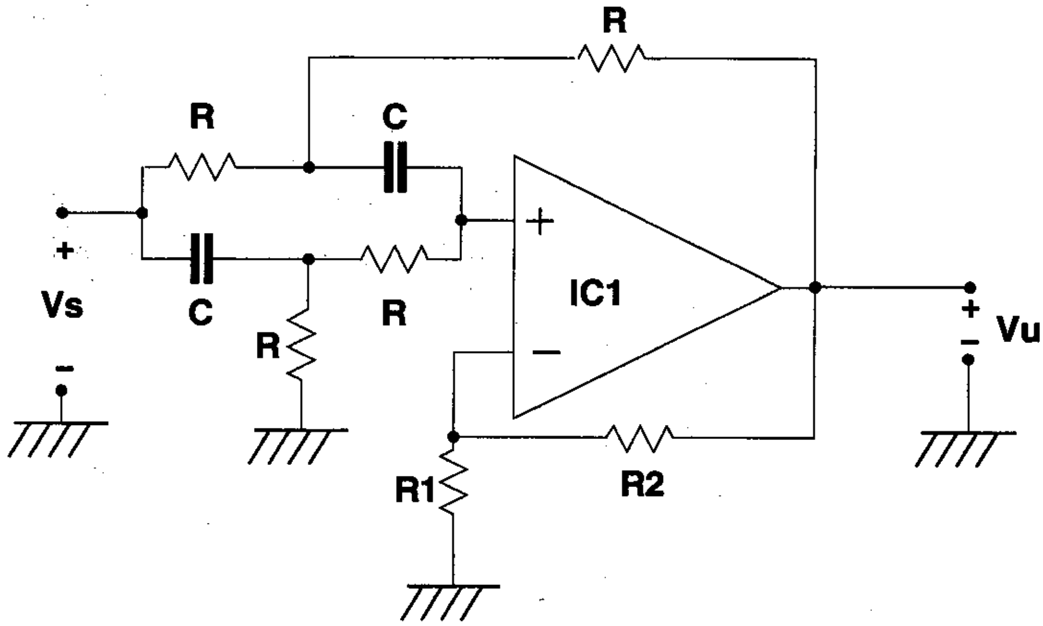
Esercizio A

$R = 10\ \mathrm{k}\Omega$

$R_1 = 10\ \mathrm{k}\Omega$

$R_2 = 20\ \mathrm{k}\Omega$

$C = 1\ \mathrm{nF}$



IC_1 è un μA 741, con $A_{\mathrm{vol0}} = 250 \times 10^3$, $f_p = 4$ Hz, $Z_{in} \to \infty$, $Z_{out} = 0$, alimentato a $+V_{CC} = +15$ V e $-V_{CC} = -15$ V.

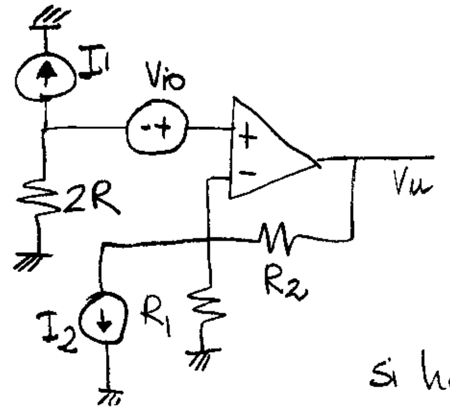
Con riferimento al circuito di figura:

1) Calcolare il massimo sbilanciamento della tensione di uscita.
2) Determinare la funzione di trasferimento V_u/V_s e tracciarne i diagrammi di Bode.
3) Calcolare la densità spettrale di potenza di tensione di rumore all'uscita del circuito, considerando soltanto i generatori equivalenti di rumore dell'operazionale, e trascurando i contributi dipendenti dalla frequenza di tali generatori. Disegnarne il grafico in funzione della frequenza in scala doppiamente logaritmica.

Esercizio B

Disegnare e discutere lo schema circuitale di un sistema elettronico in grado di rappresentare su un oscilloscopio il grafico della fase di un'impedenza qualsiasi — posta tra due terminali di ingresso — in funzione della frequenza.

A1 Max. sbilanciamento



$$V_u = V_{io}\left(1+\frac{R_2}{R_1}\right) - 2RI_1\left(1+\frac{R_2}{R_1}\right) + R_2 I_2$$

$$V_u = 3V_{io} - 60\cdot 10^3 I_1 + 20\cdot 10^3 I_2$$

si ha il max. sbilanciamento quando

$$I_1 = \frac{I_B + I_{io}}{2} = 600\,nA$$

$$I_2 = \frac{I_B - I_{io}}{2} = 400\,nA$$

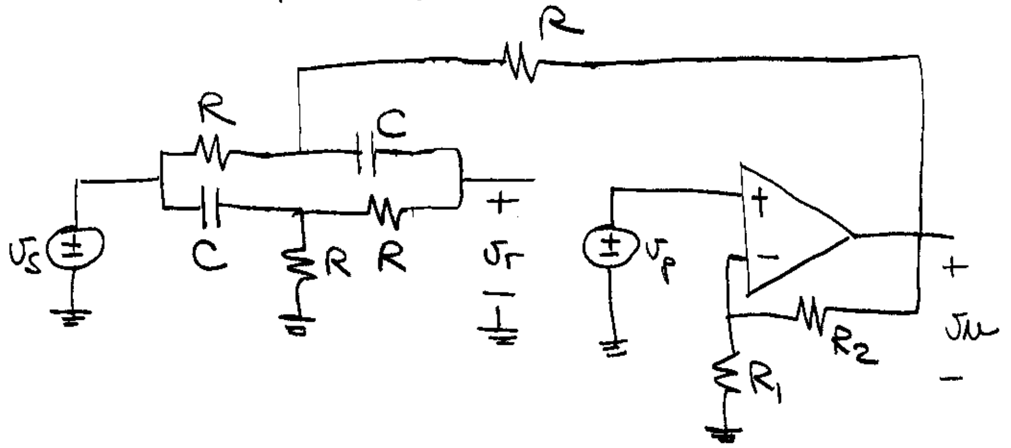
$$V_{io} = -5\,mV$$

$$V_u = -15\cdot 10^{-3} - 0.036 + 0.008 = \boxed{-43\,mV}$$

A2 Funzione di trasferimento

Effettuiamo una scomposizione tra l'ingresso non invertente dell'operazionale e massa

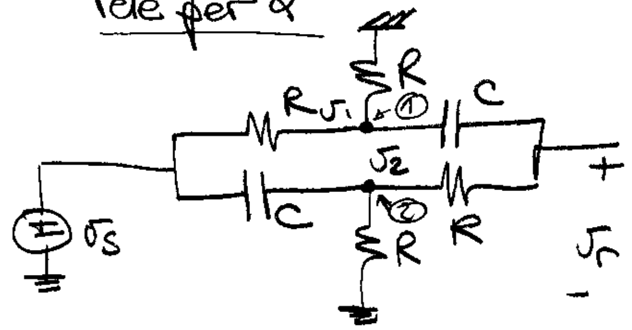
abbiamo $\rho = 0$ $\gamma = 0$ $Z_p = Z_{in} \to \infty$



$$A = \frac{A_0}{1 - s/s_{pA}} \qquad A_0 = 1 + \frac{R_2}{R_1} = 3$$

$$s_{pA} = \frac{-2\pi\, PGB}{1 + \frac{R_2}{R_1}} = -2{,}09\ Mrad/s$$

rete per α



equazioni ai nodi 1 e 2

$$v_1\left(\frac{2}{R}+Cs\right)-v_s\frac{1}{R}-v_r Cs=0 \quad \rightarrow v_1=\frac{v_s+RCs\,v_r}{2+RCs}$$

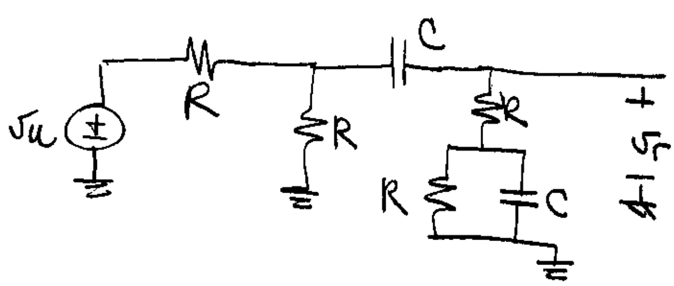
$$v_2\left(\frac{2}{R}+Cs\right)-v_s Cs-\frac{v_r}{R}=0 \quad \rightarrow v_2=\frac{v_s RCs+v_r}{2+RCs}$$

$$v_r=\frac{v_1 RCs+v_2}{RCs+1}=\frac{v_s RCs+R^2C^2s^2 v_r+v_s RCs+v_r}{(2+RCs)(1+RCs)}$$

$$(\cancel{2}^{1}+3RCs+\cancel{R^2C^2s^2})v_r=v_r\cancel{R^2C^2s^2}+\cancel{v_r}+2RCs\,v_s$$

$$\alpha=\frac{v_r}{v_s}=\frac{2RCs}{3RCs+1}$$

rete per β (le catene sono separate)



$$\beta=\frac{1}{R+R/\!/\left[\frac{1}{Cs}+R+\frac{R}{RCs+1}\right]}\times\frac{R}{R+\frac{1}{Cs}+R+\frac{R}{RCs+1}}\times\left[R+\frac{R}{RCs+1}\right]=$$

$$=\frac{\cancel{2R+\frac{1}{Cs}+\frac{R}{RCs+1}}}{\left[2R+\frac{1}{Cs}+\frac{R}{RCs+1}\right]R+R\left(\frac{1}{Cs}+R+\frac{R}{RCs+1}\right)}\times\frac{R\left(R+\frac{R}{RCs+1}\right)}{\cancel{2R+\frac{1}{Cs}+\frac{R}{RCs+1}}}=$$

$$\beta = \frac{\cancel{R}\left[RCs\,(RCs+1) + RCs\right]}{\left[(2RCs+1)(RCs+1) + RCs\right]\cancel{R} + \cancel{R}\left[(RCs+1)^2 + RCs\right]}$$

$$\beta = \frac{RCs\,(RCs+2)}{2R^2C^2s^2 + 3RCs + 1 + RCs + R^2C^2s^2 + 2RCs + 1 + RCs} =$$

$$\beta = \frac{RCs\,(RCs+2)}{3R^2C^2s^2 + 7RCs + 2} = \frac{RCs\,\cancel{(RCs+2)}}{\cancel{(RCs+2)}\,(3RCs+1)} = \frac{RCs}{3RCs+1}$$

$$A_f = \frac{\alpha A}{1-\beta A} = \frac{\dfrac{2RCs}{3RCs+1} \times \dfrac{A_o}{1 - s/s_{pA}}}{1 - \dfrac{RCs}{3RCs+1} \times \dfrac{A_o}{1 - s/s_{pA}}} =$$

$$A_f = \frac{2RCs\,A_o}{(3RCs+1)\left(1 - \frac{s}{s_{pA}}\right) - RCs\,A_o} =$$

$$A_f = \frac{2RCs\,A_o}{-\frac{3RC}{s_{pA}}\,s^2 + \left[(3-A_o)RC - \frac{1}{s_{pA}}\right]s + 1} =$$

$$A_f = \frac{Ks}{\frac{s^2}{\omega_o^2} + \frac{s}{Q\omega_o} + 1}$$

$K = 2RCA_o = 6 \cdot 10^{-5}\,s$

$\omega_o = \sqrt{\dfrac{|s_{pA}|}{3RC}} = 263{,}9\ \text{Krad/s}$

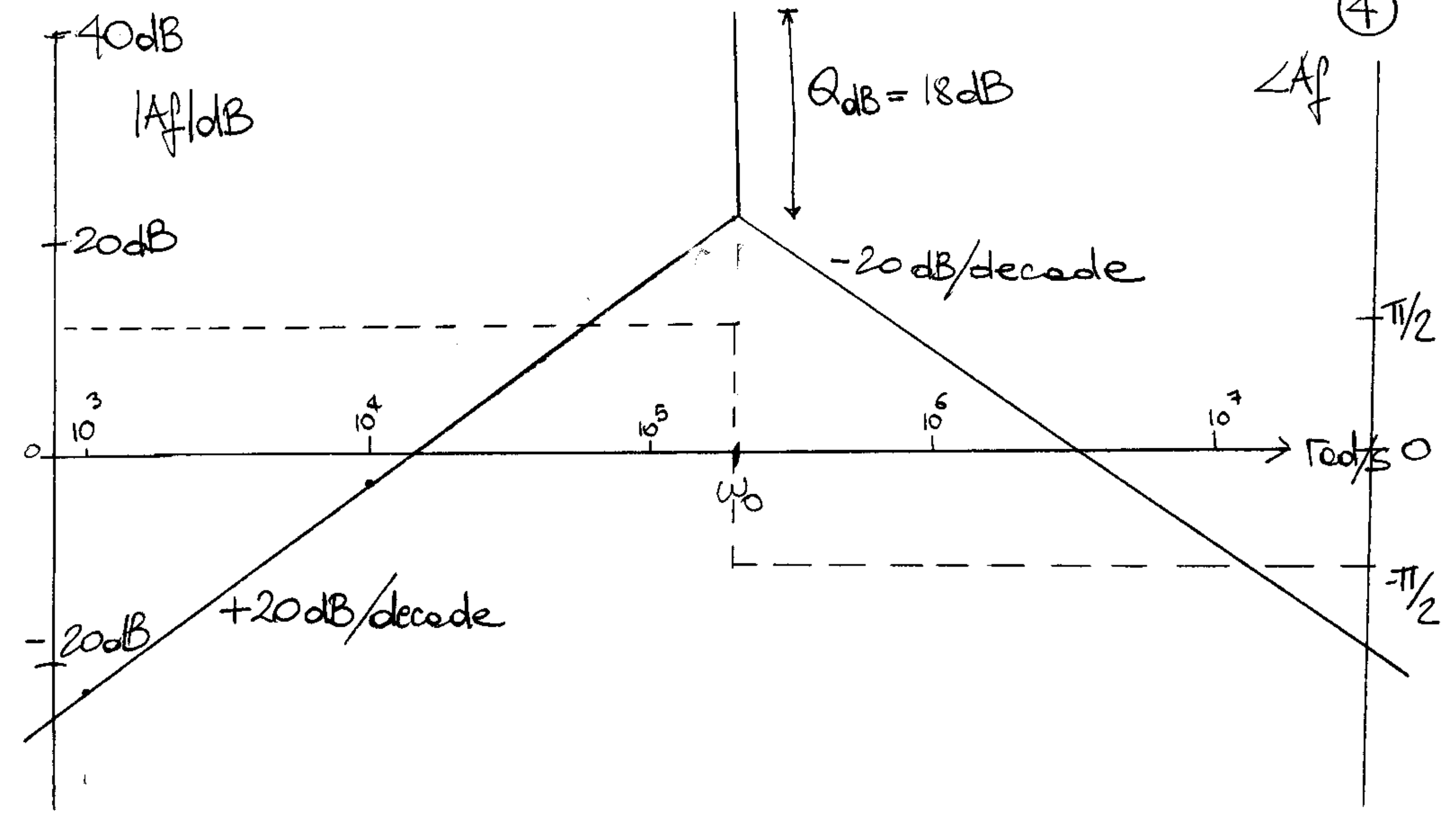
$Q = 7{,}92 \rightarrow 18\ \text{dB}$

se $\omega_1 \ll \omega_o$

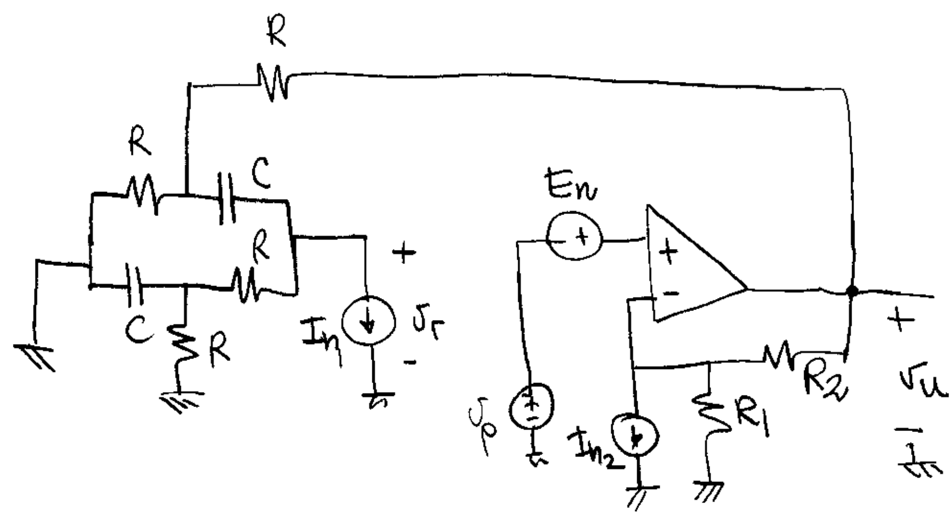
$|A_f(\omega_1)| = K\omega_1$

$\omega_1 = 10^3\ \text{rad/s}$

$A_f(\omega_1) = K\omega_1 = 6 \cdot 10^{-2} \rightarrow -24{,}4\ \text{dB}$



A.3



Contributo di En

$$\gamma_{E_n} = A \qquad \alpha_{E_n} = \beta A$$

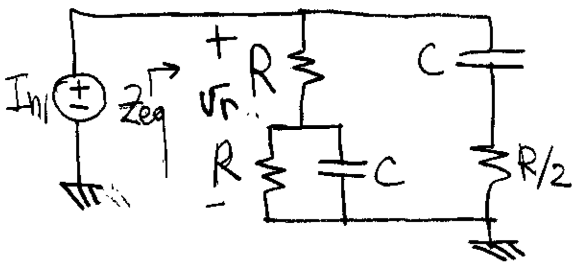
$$Af_{E_n} = \frac{\alpha_{E_n} A}{1-\beta A} + \gamma_{E_n} = \frac{\beta A A}{1-\beta A} + A = \frac{A}{1-\beta A} = \frac{Af}{\alpha}$$

$$Af_{E_n} = \frac{\frac{K}{2RC}\quad(3RCs+1)}{\frac{s^2}{\omega_0^2} + \frac{s}{Q\omega_0} + 1} = Af_{En0}\,\frac{\left(-\frac{s}{s_{z0}}+1\right)}{\frac{s^2}{\omega_0^2} + \frac{s}{Q\omega_0} + 1}$$

$$Af_{En0} = \frac{K}{2RC} = A_0 = 3 \qquad S_{z0} = -33.3\ \text{Krad/s}$$

Contributo di I_{n1}

$\gamma_{In_1} = 0 \qquad \alpha_{In_1} = \frac{v_r}{I_{n1}}$



$$z_{eq} = \left(R + \frac{R}{RCs+1}\right) /\!/ \left(\frac{R}{2}+\frac{1}{Cs}\right) = \frac{\frac{R(RCs+2)}{RCs+1}\cdot\frac{RCs+2}{2Cs}}{\frac{R(RCs+2)}{RCs+1}+\frac{RCs+2}{2Cs}} =$$

$$= \frac{R(RCs+2)^2}{2RCs(RCs+2)+(RCs+1)(RCs+2)} = \frac{R(2+RCs)}{3RCs+1}$$

$$\alpha_{In} = -\frac{R(2+RCs)}{3RCs+1} = -R\alpha\,\frac{2+RCs}{2RCs}$$

$$Af_{In_1} = Af\left(-R\,\frac{(2+RCs)}{2RCs}\right) = \frac{-\frac{K}{C}\left(\frac{2+RCs}{2}\right)}{\frac{s^2}{\omega_0^2}+\frac{s}{Q\omega_0}+1}$$

$$= \frac{Af_{In_1 0}\left(1-s/s_{z1}\right)}{\frac{s^2}{\omega_0^2}+\frac{s}{Q\omega_0}+1} \qquad Af_{In_1 0} = -\frac{K}{C} = -2RA_0 = -60K\Omega$$

$$s_{z1} = -\frac{2}{RC} = 2\cdot 10^5 \text{ rad/s}$$

Contributo di I_{n2}

$$\gamma_{In_2} = \frac{R_2}{1 - s/s_{pA}} \qquad \alpha_{In_2} = \gamma_{In_2}\beta$$

$$Af_{In_2} = \frac{\alpha_{In_2} A}{1-\beta A} + \gamma_{In_2} = \frac{\gamma_{In_2}\beta A}{1-\beta A} + \gamma_{In_2} = \frac{\gamma_{In_2}}{1-\beta A}$$

$$Af_{In_2} = Af\frac{\gamma_{In_2}}{\alpha A} = \frac{\cancel{2RCA_0 s}}{\frac{s^2}{\omega_0^2}+\frac{s}{Q\omega_0}+1} \cdot \frac{3RCs+1}{\cancel{2RCs}} \cdot \frac{1-\cancel{s/s_{pA}}}{\cancel{A_0}} \cdot \frac{R_2}{\cancel{1-s/s_{pA}}} =$$

$$Af_{In_2} = \frac{R_2(3RCs+1)}{\frac{s^2}{\omega_0^2}+\frac{s}{Q\omega_0}+1} = \frac{\overset{20K\Omega}{\overset{\parallel}{Af_{In_2 0}}}\left(-s/s_{z0}+1\right)}{\frac{s^2}{\omega_0^2}+\frac{s}{Q\omega_0}+1}$$

$$S_{Vu} = |Af_{In_1}|^2 S_{In} + |Af_{In_2}|^2 S_{In} + |Af_{En}|^2 S_{En}$$

dalle caratteristiche si ha

$S_{In} = 3\cdot 10^{-25}\, A^2/Hz$ $\quad$ $S_{En} = 4\cdot 10^{-16}\, V^2/Hz$

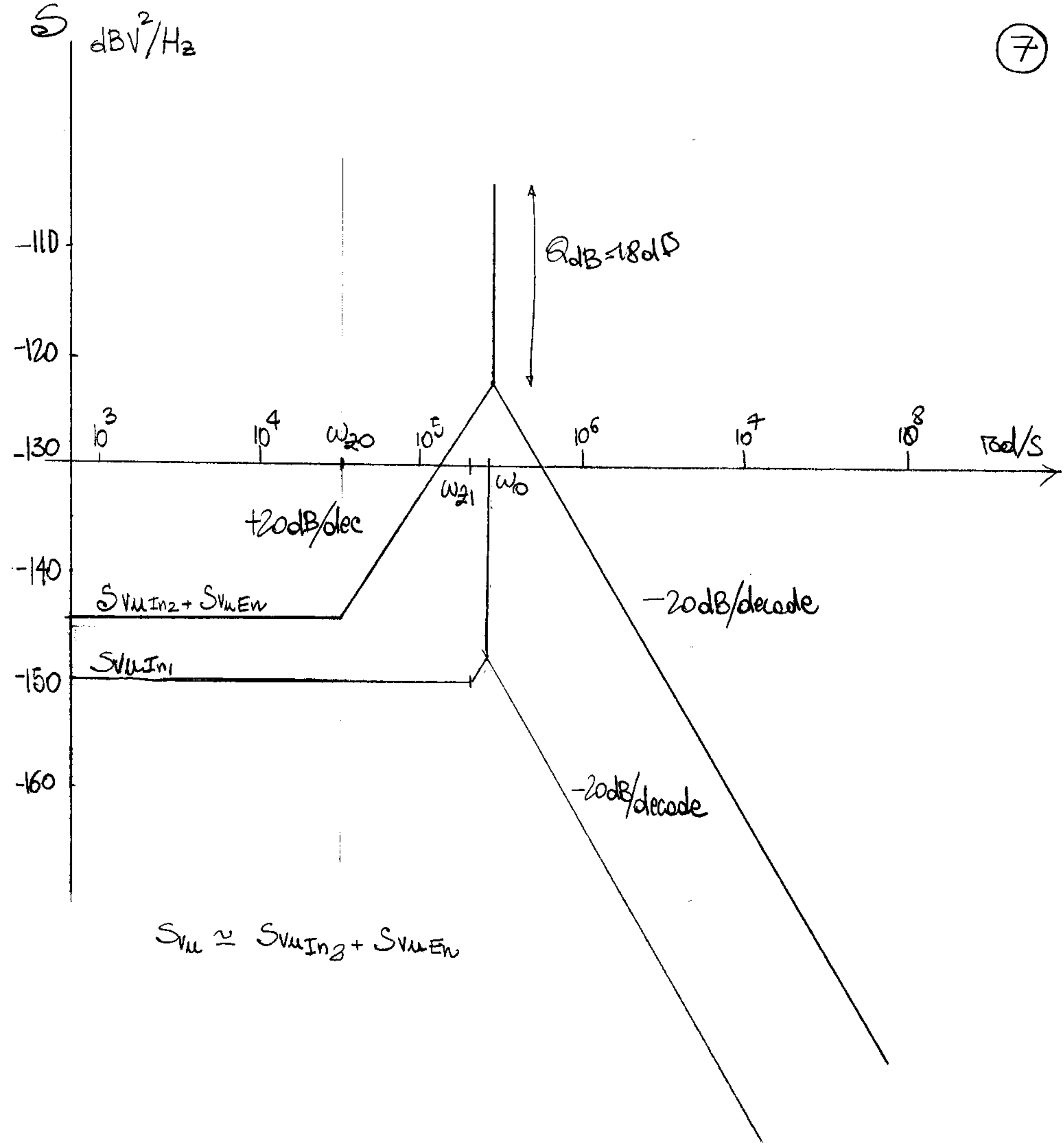
$$S_{Vu} = S_{Vu\,In_1} + S_{Vu\,In_2} + S_{Vu\,En}$$

$$S_{Vu\,In_1}(0) = |Af_{In_1}(0)|^2 S_{In} = 1.08\cdot 10^{-15}\, V^2/Hz \rightarrow -149.6\ dB\,V^2/Hz$$

$$S_{Vu\,In_2}(0) + S_{Vu\,En}(0) = |Af_{In_2}(0)|^2 S_{In} + |Af_{En}(0)|^2 S_{En}$$

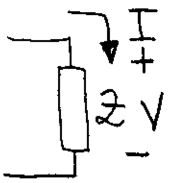
$$= 1.2\cdot 10^{-16} + 3.6\cdot 10^{-15} = 3{,}72\cdot 10^{-15}\, V^2/Hz$$

$$= -144\ dBV^2/Hz$$



$S_{vu} \simeq S_{vuIn2} + S_{vuEn}$

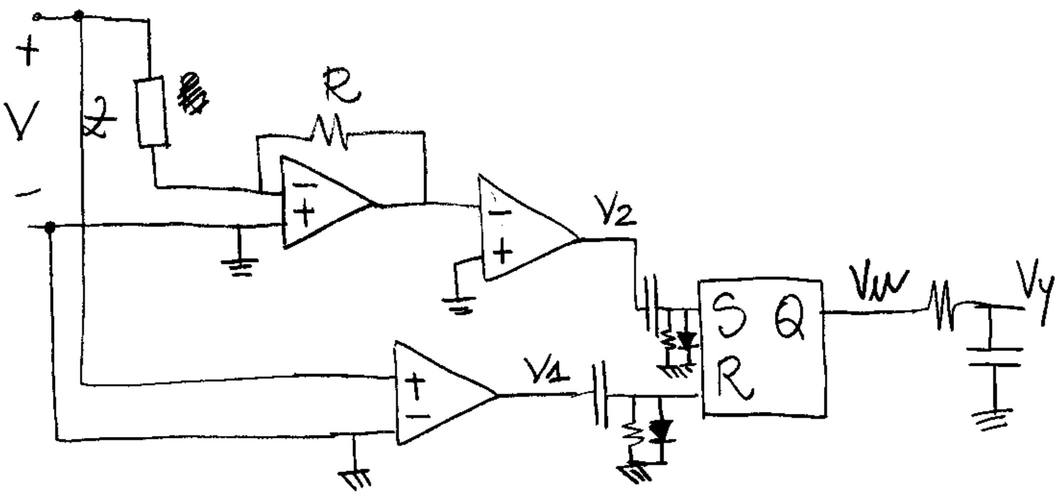
B Una possibile soluzione è la seguente:

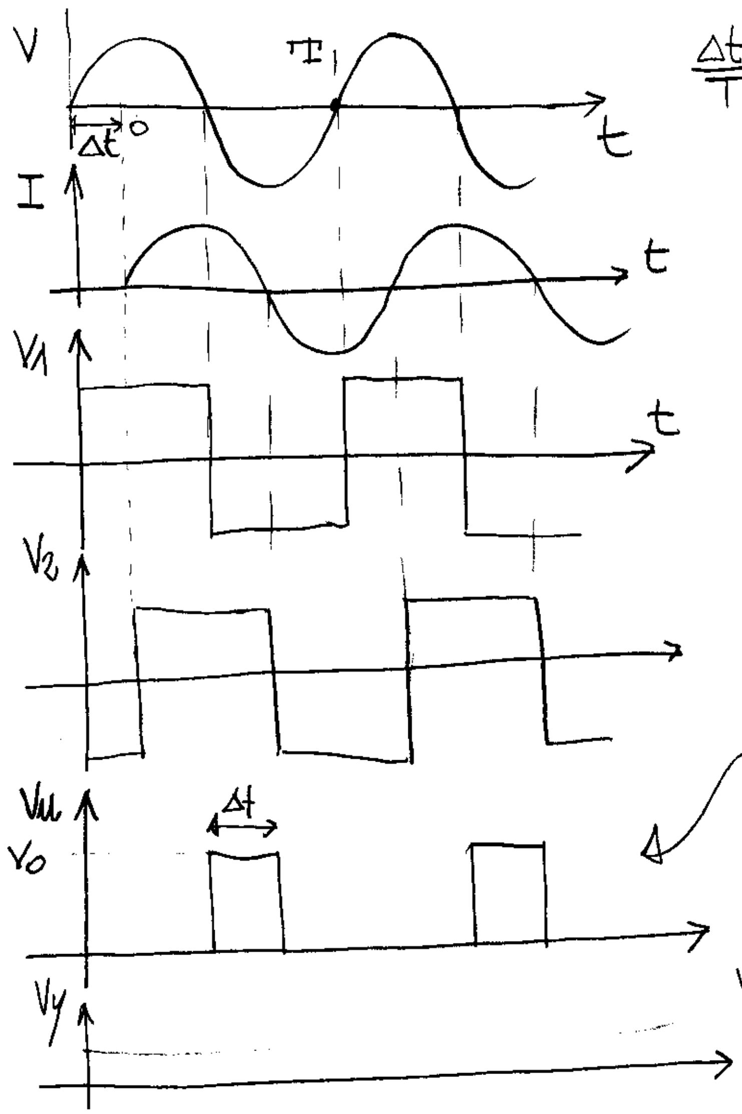


$V = ZI$

$\angle V = \angle Z + \angle I$

la fase di Z è la differenza tra la fase di V e la fase di I



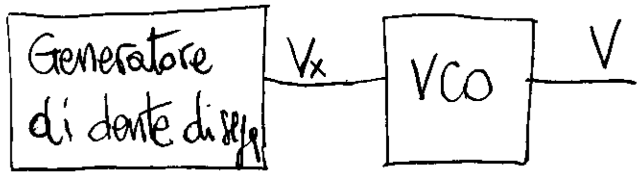


$$\frac{\Delta t}{T} = \frac{\phi}{2\pi} = \frac{\angle Z}{2\pi}$$

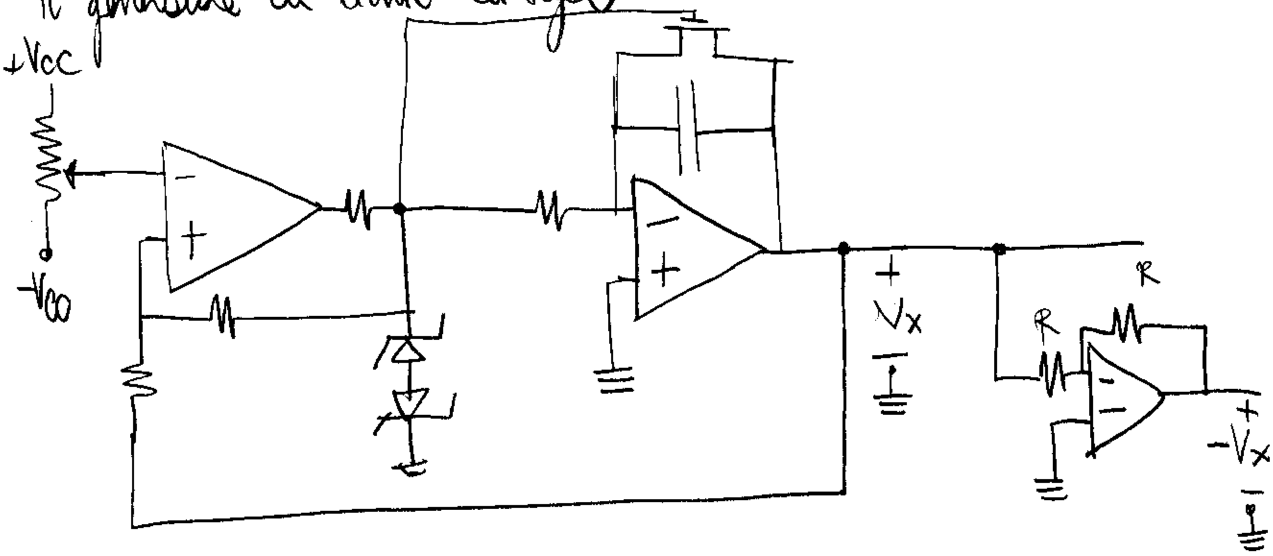
la componente continua di Vu è proporzionale alla fase di Z

$$V_y = \frac{\Delta t}{T} V_0 = \frac{\phi}{2\pi} V_0$$

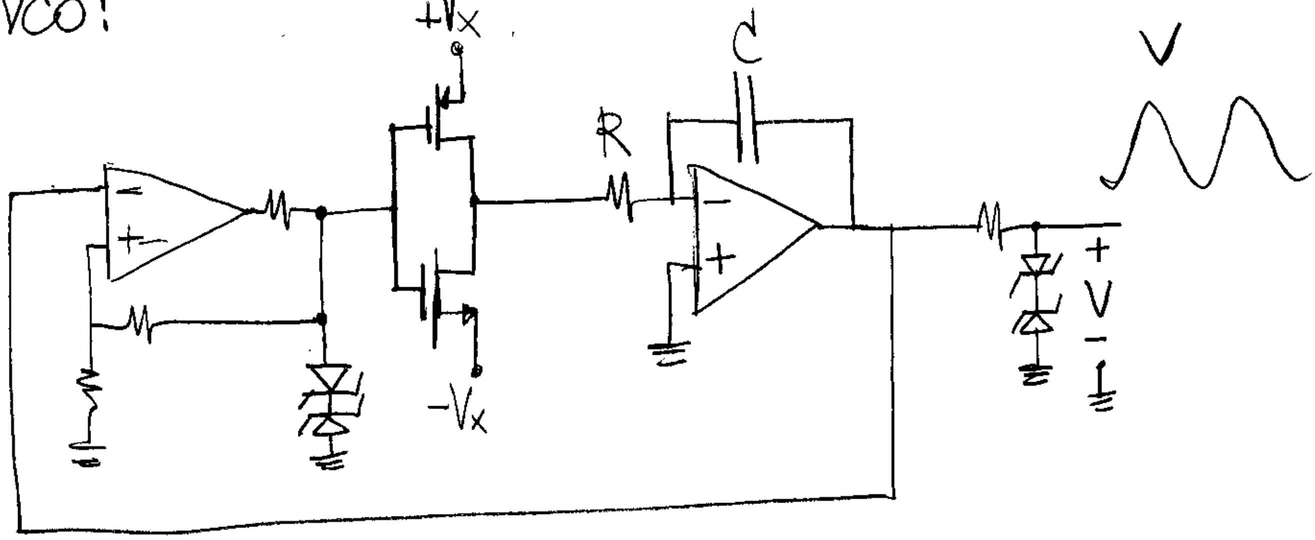
V si puo ottenere con un VCo



il gennotae di dente di sega,



VCO:



i segnali V_x e V_y vanno alle plecche di deflessione orizzontale e verticale dell'oscilloscopio, rispettivamente.