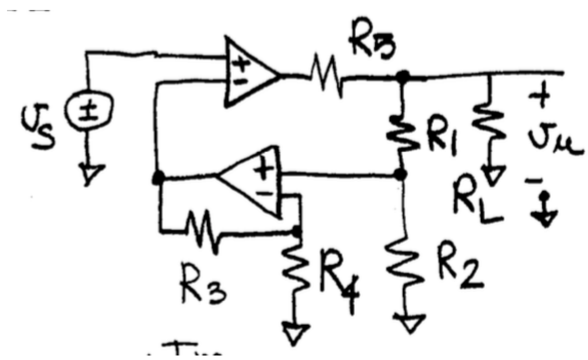
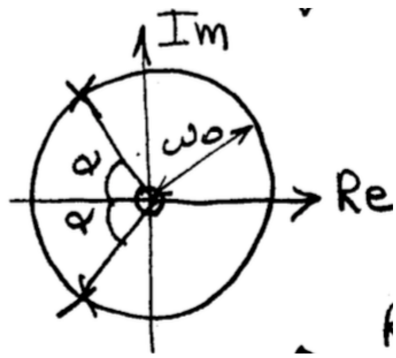
Esame di Elettronica - Corso di Laurea in Ingegneria delle Telecomunicazioni
19 settembre 2016

1. Calcolare la funzione di trasferimento e la resistenza di uscita del circuito in reazione mostrato a lato. Si supponga che i due amplificatori operazionali siano amplificatori di tensione ideali, con A_V=1000. Altri dati del problema R_1=1KΩ, R_2=2KΩ, R_3=3KΩ, R_4=4KΩ, R_5=5KΩ, R_L=500Ω.

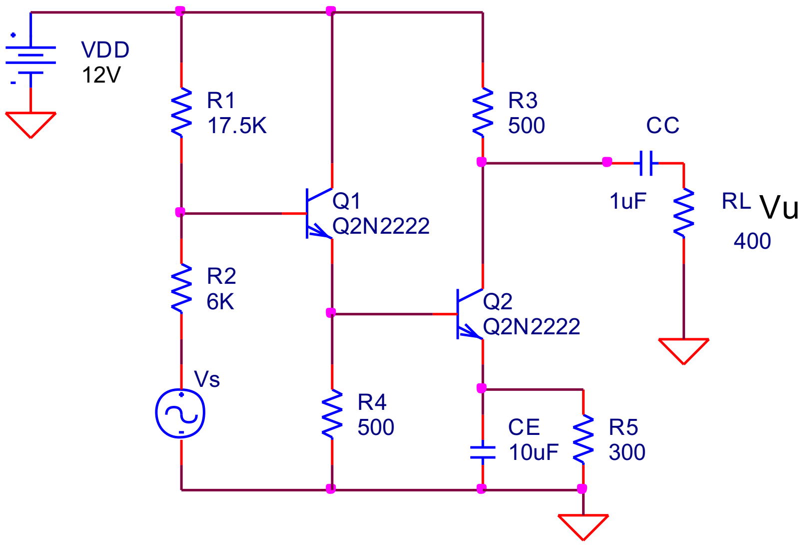


2. Si realizzi il filtro che abbia i poli e gli zeri illustrati in figura. Ricavare la funzione di trasferimento del filtro e quotare tutti i componenti per ottenere le singolarità richieste.
ω_0 = 6.28Krad/s, $\alpha = \pi/3$.

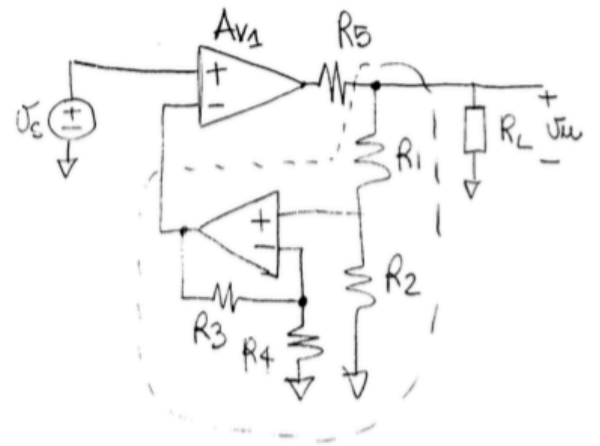


3. Con riferimento al circuito mostrato a lato, calcolare:

- il punto di riposo dei due transistori Q1 e Q2 e i parametri del circuito di piccolo segnale.
- la funzione di trasferimento a centro banda.
- il limite superiore di banda



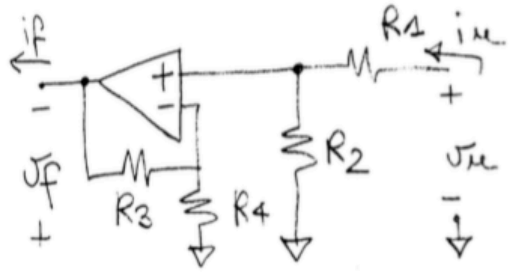
Esercizio 1



$R_1 = 1K\Omega$
$R_2 = 2K\Omega$
$R_3 = 3K\Omega$
$R_4 = 4K\Omega$
$R_5 = 5K\Omega$
$R_L = 500\,\Omega$
$A_{V_1} = 600$

Prelievo di tensione e inserzione di tensione

Rete per β



$v_f = \beta v_u + R_{of} i_f$

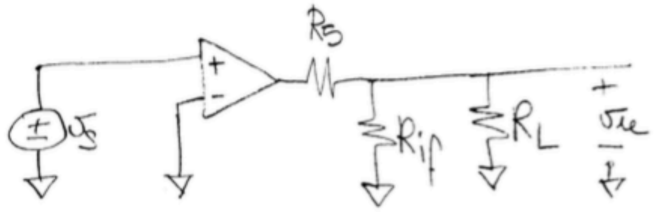
$i_u = \frac{v_u}{R_{o\beta}} + \cancel{K i_f}$

$$\beta = \left.\frac{v_f}{v_u}\right|_{i_f=0} = \frac{R_2}{R_1+R_2}\left(1+\frac{R_3}{R_4}\right) = \frac{2}{3}\left(1+\frac{3}{4}\right) = \frac{7}{6} = 1.17$$

$$R_{of} = \left.\frac{v_f}{i_f}\right|_{v_u=0} = 0$$

$$R_{if} = \left.\frac{v_u}{i_u}\right|_{i_f=0} = R_1 + R_2 = 3K\Omega$$

Rete per A_e



$$A_e = \frac{v_u}{v_S} = \frac{A_{V1}\, R_L /\!/ R_{if}}{R_L /\!/ R_{if} + R_5} = \frac{428.6 \cdot 10^3}{428.6 + 5000} = 78.9$$

$$A_F = \frac{A_e}{1-\beta A_e} = \underline{0.846}$$

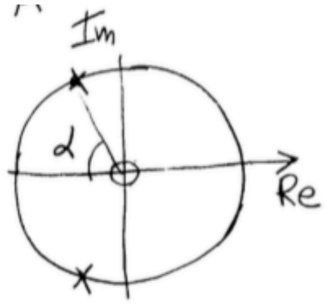
Resistenza di uscita

$$A_{eo} = A_{v1} \frac{R_{if}}{R_{if}+R_5} = 10^3 \cdot \frac{3}{8} = \underline{\underline{375}}$$

R_L rimosso

$$R_{OF} = \frac{(R_{if} /\!/ R_5)}{1-\beta A_e} = \frac{1875}{439.75} = \underline{\underline{4.26\ \Omega}}$$

Esercizio 2



$\alpha = \pi/3$

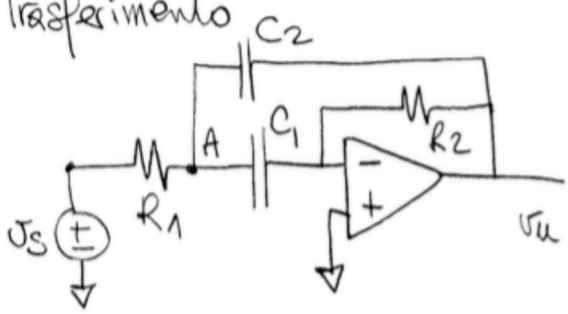
il filtro che vogliamo ottenere è un passabanda

$$H(s) = \frac{H_{CB} \frac{s}{\omega_0 Q}}{\frac{s^2}{\omega_0^2} + \frac{s}{\omega_0 Q} + 1}$$

$$\frac{\omega_0}{Q} = 2\cos\alpha\, \omega_0 \rightarrow \quad Q = \frac{1}{2\cos\alpha} \Rightarrow 1$$

$$\omega_0 = 6.28 \cdot 10^3 \text{ rad/s}$$

usiamo un filtro passabanda e ricaviamo la funzione di trasferimento



$$v_u = -R_2 C_1 s\ v_A$$

$$v_A\left(\frac{1}{R_1}+C_1 s+C_2 s\right)-\frac{v_S}{R_1}-C_2 s\, v_u=0$$

$$v_u\left(1+R_1C_1s+R_1C_2s\right)+R_2C_1 s\, v_S+R_1R_2C_1C_2s^2\, v_u=0$$

$$\frac{v_u}{v_S}=\frac{-R_2C_1 s}{R_1R_2C_1C_2s^2+\left(R_1C_1+R_1C_2\right)s+1}$$

$$\omega_0^2=\frac{1}{R_1R_2C_1C_2}$$

$$\omega_0 Q=\frac{1}{R_1\left(C_1+C_2\right)}\rightarrow Q=\frac{\sqrt{R_1R_2C_1C_2}}{R_1\left(C_1+C_2\right)}$$

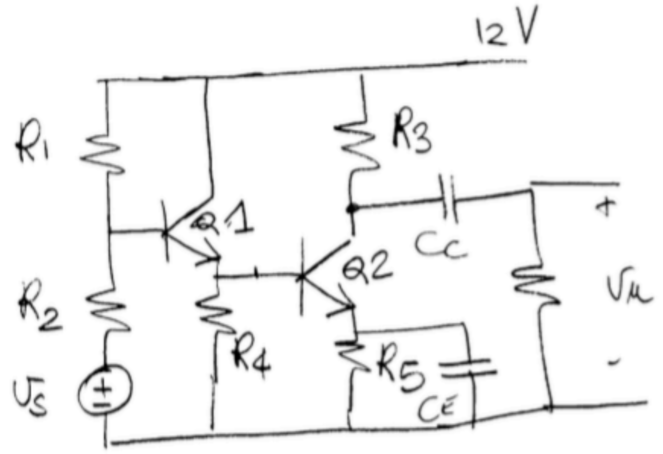
poniamo $C_1=C_2=C$

$$\omega_0^2=\frac{1}{R_1R_2C^2}\qquad Q=\frac{1}{2}\sqrt{\frac{R_2}{R_1}}$$

se vogliamo $Q=1 \rightarrow R_2=4R_1$

$$\omega_0^2=\frac{1}{4R_1^2C^2}\rightarrow \omega_0=\frac{1}{2R_1C}$$

poniamo $R_1=1k\Omega \rightarrow C=\frac{1}{2R_1\omega_0}=79.6$ nF



$R_1 = 17{,}5\,k\Omega$
$R_2 = 6\,k\Omega$
$V = 12\,V$
$R_4 = 500\,\Omega$
$R_5 = 300\,\Omega$
$R_3 = 500\,\Omega$
$R_L = 400\,\Omega$
$C_C = 1\mu F$
$C_E = 10\mu F$

$$V_{B1} = \frac{R_2}{R_1+R_2} V_{CC} = \frac{6}{6+17{,}5} \cdot 12 = 3{,}06V$$ Hp partitore pesante Q1

$$V_{E1} = V_{B1} - V_\gamma = 2{,}36V$$

Hp: $I_{R_4} \gg I_{B2}$

$$I_{C_1} \cong I_{R_4} = \frac{V_{E1}}{R_4} = 4.72\ mA$$

$$V_{CE_1} = 12 - 2{,}36 = 9{,}64V$$

$$h_{FE_1} = 180$$

$$I_{B_1} = \frac{I_{C1}}{h_{FE_1}} = 26.2\mu A \qquad \frac{V_{CC}}{R_1+R_2} = 510.7\mu A \gg I_{B1}$$ → Verificata l'Hp per il partitore A

$$V_{E2} = V_{E1} - V_\gamma = 2{,}36 - 0{,}7 = 1{,}66V$$

$$I_{E_2} \sim I_{C_2} = \frac{V_{E2}}{R_5} = \frac{1{,}66}{300} = 5{,}53 \cdot 10^{-3}A$$

$$h_{FE_2} = 190$$

$$I_{B_2} = \frac{I_{C2}}{h_{FE_2}} = \frac{5{,}53 \cdot 10^{-3}}{190} = 29.1\mu A \ll I_{R_4}$$

$$V_{C_2} = V_{CC} - R_3 I_{C_2} = 12 - 500 \cdot 5{,}53 \cdot 10^{-3} = 9{,}235V$$

$$V_{CE_2} = V_{C2} - V_{E2} = 7{,}575V$$

prendiamo $r_b @ 1\,mA = h_{ie}@1mA - h_{fe}@1mA \cdot \frac{V_T}{I_{C_1} 1mA} =$

$$= 5000 - \frac{175 \cdot 26 \cdot 10^{-3}}{10^{-3}} = \underline{\underline{450\,\Omega}}$$

usiamo $r_b = 450$ anche per i punti di riposo di circa 5mA

$$g_{m_1} = \frac{I_{C_1}}{V_T} = \frac{4{,}72 \cdot \cancel{10^{-3}}}{26 \cancel{10^{-3}}} = 0{,}181\ A/V$$

$$r_{\pi_1} = \frac{h_{fe_1}}{g_{m_1}} = \frac{175}{0{,}181} = 966{,}9\,\Omega$$

$$h_{ie_1} = r_b + r_{\pi_1} = 450 + 966{,}9 = \underline{1416{,}9\,\Omega}$$

$$V_A = \frac{1mA}{h_{oe}@1mA} = \frac{10^{-3}}{20 \cdot 10^{-6}} = 50\,V$$

$\frac{1}{h_{oe_1}} = \frac{V_A}{I_{C_1}} = \frac{50}{4{,}72 \cdot 10^{-3}} = 10{,}6\,K\Omega \gg R_4$ quindi è trascurabile

$$g_{m_2} = \frac{I_{C_2}}{V_T} = \frac{5{,}53 \cdot 10^{-3}}{26\ 10^{-3}} = 0{,}213\ \Omega^{-1}$$

$$r_{\pi_2} = \frac{h_{fe_2}}{g_{m_2}} = \frac{175}{0{,}213} = 821{,}6\,\Omega$$

$$h_{ie_2} = r_{\pi_2} + r_b = 821{,}6 + 450 = 1271{,}6\,\Omega$$

$$\frac{1}{h_{oe_2}} = \frac{V_A}{I_{C_2}} = \frac{50}{5{,}53 \cdot 10^{-3}} = 9041{,}6\,\Omega$$

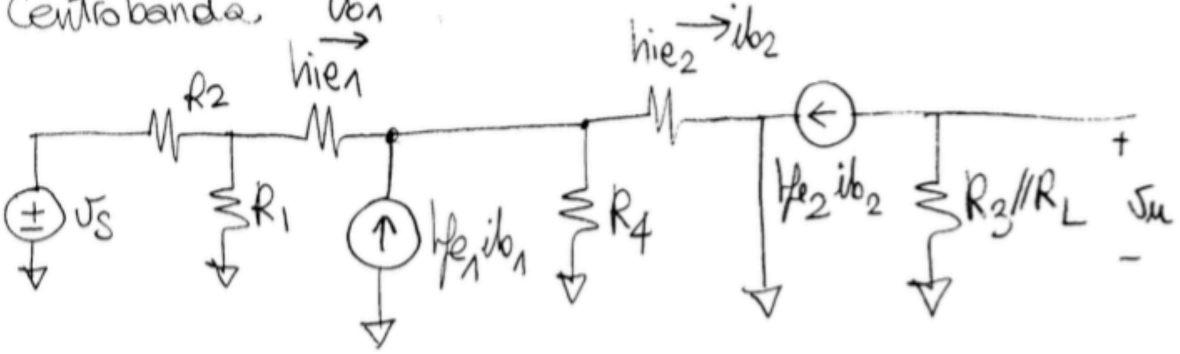
$$V_{CB_1} = V_{CE_1} - V_\gamma = 8{,}94\,V \rightarrow C_{\mu_1} = 4pF$$

$$V_{CB_2} = V_{CE_2} - V_\gamma = 6{,}875\,V \rightarrow C_{\mu_2} = 4{,}3pF$$

$$f_{T_1} \simeq f_{T_2} = 230\ MHz \rightarrow C_{\pi_1} = \frac{g_{m_1}}{2\pi f_{T_1}} - C_{\mu_1} = 125{,}3 - 4 = 121{,}3\,pF$$

$$f_{T_1} = \frac{g_{m_1}}{2\pi (C_{\pi_1} + C_{\mu_1})} \qquad C_{\pi_2} = \frac{g_{m_2}}{2\pi f_{T_2}} - C_{\mu_2} = 147{,}5 - 4{,}3 = 143{,}2\,pF$$

Centrobanda.

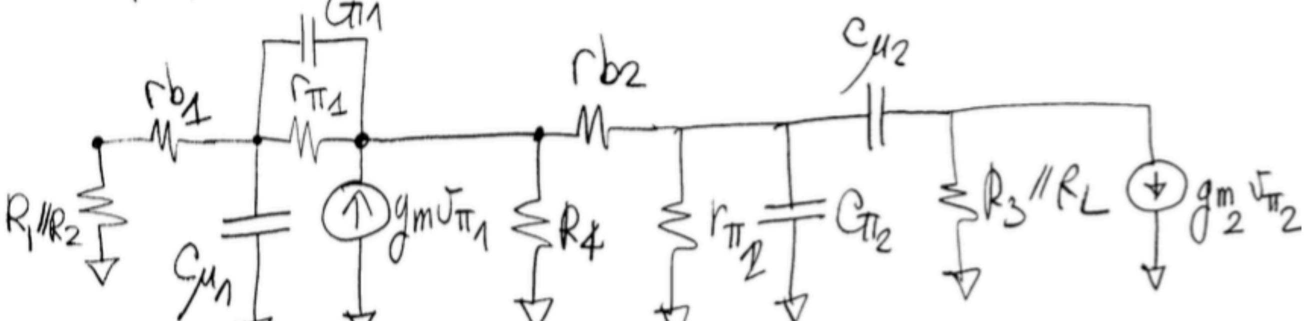


$$\frac{v_u}{v_s} = -\frac{R_1}{R_1+R_2} \cdot \frac{(R_4 /\!/ h_{ie2})(h_{fe1}+1)}{R_2 /\!/ R_1 + h_{ie1} + R_4 /\!/ h_{ie}(h_{fe}+1)} \cdot \frac{h_{fe2}\, R_3 /\!/ R_L}{h_{ie2}}$$

$$= -\frac{17{,}5}{17.5+6} \cdot \frac{358.9\,(176)}{4468 + 1416{,}9 + 358.9\,(176)} \cdot \frac{176 \cdot 222}{1271.6} =$$

$$\frac{v_u}{v_s} = -0{,}7447 \cdot 0{,}915 \cdot 30.73 = -20.93$$

Alte frequenze



$$R_{V\pi_2} = + r_{\pi_2} /\!/ \left[r_{b_2} + R_4 /\!/ \left[\frac{r_{\pi_1} + r_{b_1} + R_1 /\!/ R_2}{1 + g_m r_{\pi_1}} \right] \right] =$$

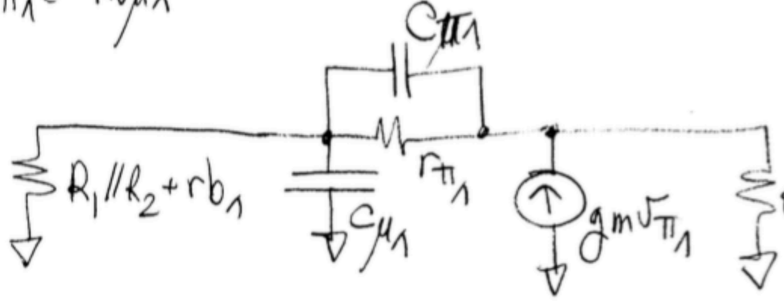
$$= 821.6 /\!/ \left[450 + 500 /\!/ 33.4 \right] =$$

$$= 821.6 /\!/ 481{,}34 = 303.5\ \Omega$$

$$R_{V\mu_2} = R_{V\pi_2}\left(1 + g_{m_2}(R_3 /\!/ R_L)\right) + R_3 /\!/ R_L =$$

$$303.5\,(1 + 47.3) + 222 = 14.88\ \mathrm{k\Omega}$$

$R_{V\pi_1}$ e $R_{V\mu_1}$



$$R' = R_4 /\!/ \left[r_{b2} + r_{\pi 2}\right] = 500 /\!/ 1271.6 = 358.9\ \Omega$$

$$R_{V\pi_1} = r_{\pi_1} /\!/ \left[\frac{R' + R_1 /\!/ R_2 + r_{b1}}{1 + g_{m_1} R'}\right] =$$

$$= 966.9 /\!/ \left[\frac{358.9 + 4468 + 450}{65{,}96}\right] = 966{,}9 /\!/ 80 = \underline{73{,}9\ \Omega}$$

(13)

$$R_{V\mu_1} = \left(R_1 /\!/ R_2 + r_{b1}\right) /\!/ \left[r_{\pi_1} + \left(1 + g_{m_1} r_{\pi_1}\right) R'\right] =$$

$$= (4468 + 450) /\!/ (966{,}9 + 176 \cdot 358{,}9) = \underline{4567{,}7\ \Omega}$$

$$f_H = \frac{1}{2\pi}\left[\frac{1}{R_{V\mu_1} C_{\mu_1} + R_{V\pi_1} C_{\pi_1} + R_{V\mu_2} C_{\mu_2} + R_{V\pi_2} C_{\pi_2}}\right] =$$

$$\frac{1}{2\pi}\left[4567{,}7 \cdot 4 \cdot 10^{-12} + 73{,}9 \cdot 121{,}3 \cdot 10^{-12} + 14880 \cdot 4{,}3 \cdot 10^{-12} + 303.5 \cdot 143.2 \cdot 10^{-12}\right]^{-1} =$$

$$= \underline{1{,}182\ \mathrm{MHz}}$$