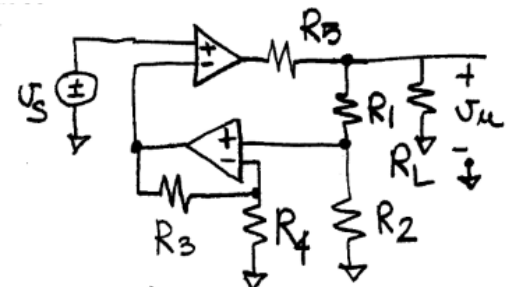
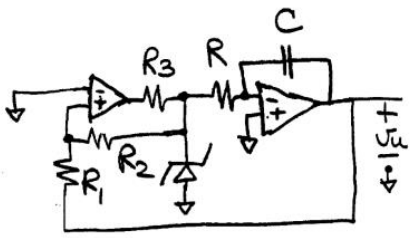
Esame di Elettronica - Corso di Laurea in Ingegneria delle Telecomunicazioni
3 luglio 2008

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.

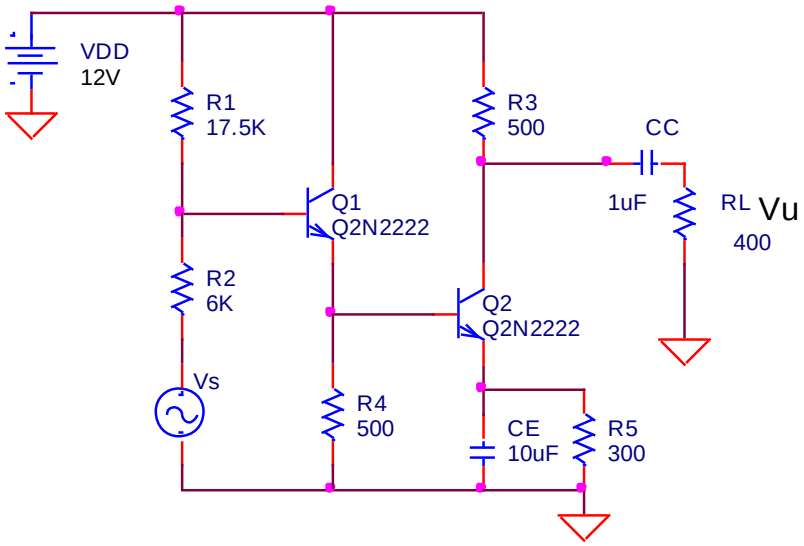


2. Mostrare il funzionamento del circuito mostrato a lato, disegnando e quotando l'andamento delle tensioni all'uscita dei due operazionali. Giustificare il procedimento. [R_1=10KΩ, R_2=10KΩ, R_3=3KΩ, R=1KΩ, C=1μF, Vz=4.7V]

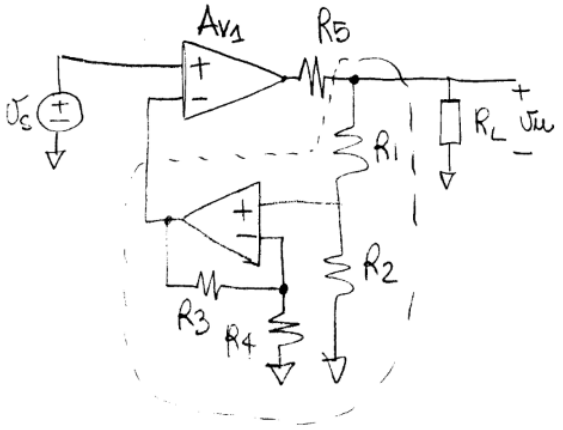


3. Con riferimento al circuito mostrato a lato, calcolare:

- 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



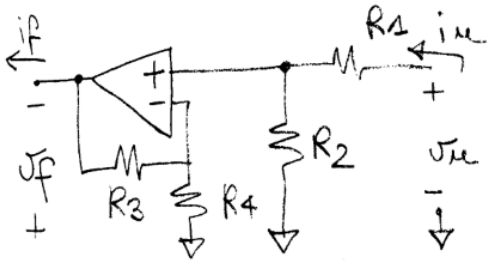
Esercizio 1



$R_1 = 1K\Omega$
$R_2 = 2K\Omega$
$R_3 = 3K\Omega$
$R_4 = 4K\Omega$
$R_5 = 5K\Omega$
$R_L = 500\Omega$
$A_{V1} = 1000$

Prelievo di tensione e inserzione di tensione

Rete per β



$V_f = \beta V_u + R_{of} i_f$

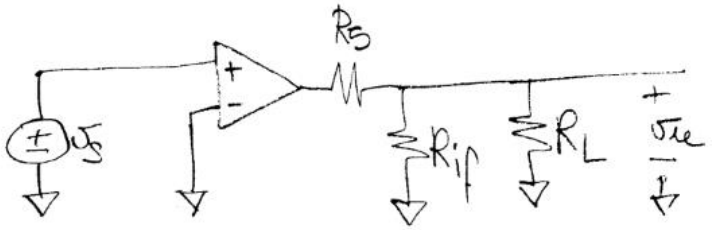
$i_u = \frac{V_u}{R_o \beta} + K i_f$

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

$$R_{of} = \left.\frac{V_f}{i_f}\right|_{V_u=0} = 0$$

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

Rete per A_e



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

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

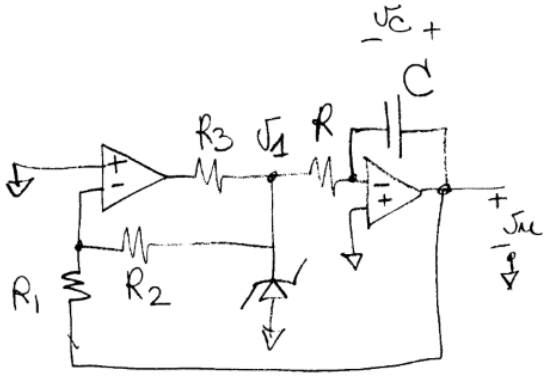
Resistenza di uscita

$$A_{eo} = A_{v_1} \frac{R_{if}}{R_{if}+R_5} = 10^3 \cdot \frac{3}{8} = \underline{375}$$

(A_{eo}: R_L rimosso)

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

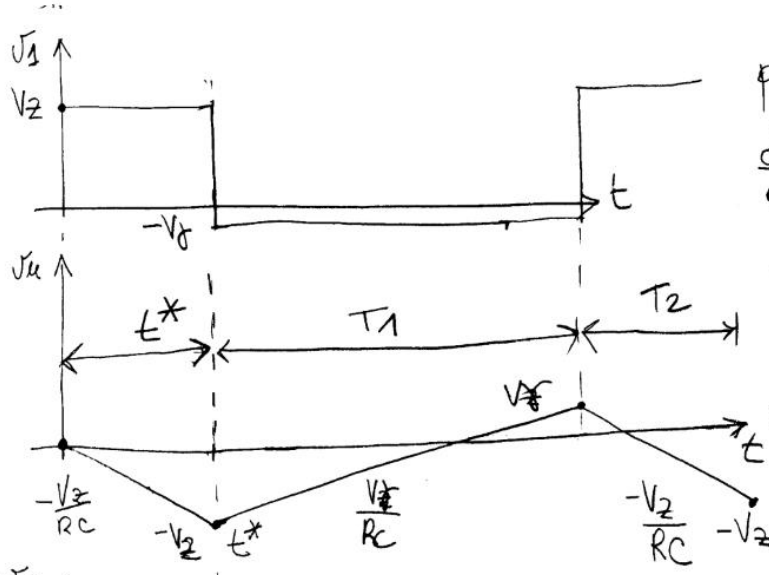
Esercizio 2



$R_1 = 10K\Omega$
$R_2 = 10K\Omega$
$R_3 = 3K\Omega$
$R = 1K\Omega$
$C = 1\mu F$

$RC = 10^{-3}\,s$

poniamo che per $t=0$ $v_c = v_u = 0$, e $v_1 = V_z$



per $t>0$

$$\frac{dv_u}{dt} = -\frac{1}{RC} V_z$$

$$v^- = \frac{v_1 + v_u}{2}$$

quando $v^- = 0$ si ha la commutazione (cioè per $v_u = V_z$)

se $v_1 = -V_\gamma$ ... $\frac{dv_u}{dt} = \frac{V_\gamma}{RC}$

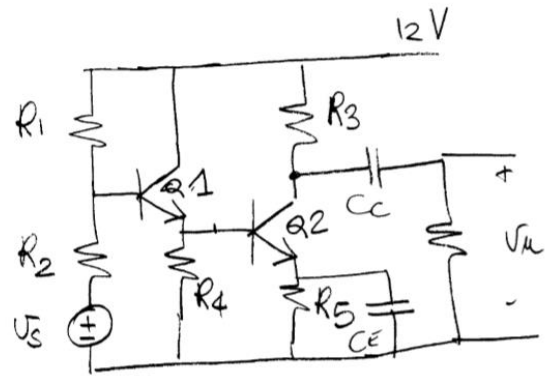
[nuova commutazione per $v_u = V_\gamma$]

$$T_1 = \frac{V_z + V_\gamma}{V_\gamma / RC} = RC\,\frac{V_z + V_\gamma}{V_\gamma} = 10^{-3}\,\frac{5.4}{0.7} = 7{,}7\ \text{ms}$$

$$T_2 = \frac{V_\gamma + V_z}{V_z / RC} = RC\,\frac{V_z + V_\gamma}{V_z} = 10^{-3}\,\frac{5.4}{4.7} = 1.15\ \text{ms}$$

$$t^* = \frac{V_z}{V_z}\,RC = \underline{1\text{ms}}$$

Esercizio 3



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

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

Hp partitore pesante Q1

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

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

$$I_{C_1} \cong I_{R_4} = \frac{V_{E1}}{R4} = 4.72\ \text{mA}$$

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

$$h_{FE_1} = 180$$

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

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

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

$h_{FE_2} = 190$

$I_{B2} = \frac{I_{C2}}{h_{FE_2}} = \frac{5{,}53 \cdot 10^{-3}}{190} = 29.1\,\mu A \ll I_{R4}$

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

$V_{CE_2} = V_{C_2} - V_{E_2} = 7{,}575\,V$

prendiamo r_{b_1}@ 1mA $= h_{ie}$@1mA $- h_{fe}$@1mA $\cdot \frac{V_T}{I_{B_1}}$ 1mA $=$

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

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

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

$r_{\pi_1} = \frac{h_{fe_1}}{g_{m_1}} = \frac{175}{0{,}181} = 966.9\,\Omega$

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

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

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

$g_{m_2} = \frac{I_{C2}}{V_T} = \frac{5{,}53 \cdot 10^{-3}}{26\ 10^{-2}} = 0.213\,\Omega^{-1}$

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

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

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

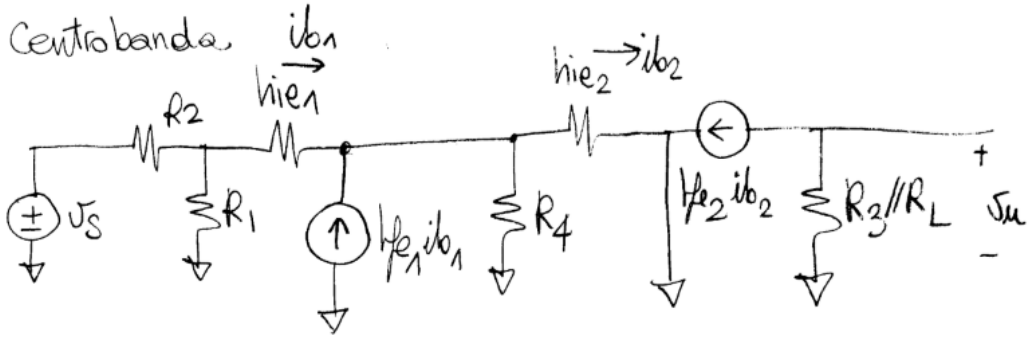
$V_{CB_1} = V_{CE_1} - V_\gamma = 8.94V \rightarrow C_{\mu_1} = 4pF$

$V_{CB_2} = V_{CE_2} - V_\gamma = 6.875V \rightarrow C_{\mu_2} = 4.3pF$

$f_{T_1} \simeq f_{T_2} = 230\ MHz \rightarrow C_{\pi_1} = \frac{g_{m_1}}{2\pi f_{T_1}} - C_{\mu_1} = 125.3 - 4 = 121.3pF$

$f_{T_1} = \frac{g_{m_1}}{2\pi(C_{\pi_1} + C_{\mu_1})}$ $\qquad C_{\pi_2} = \frac{g_{m_2}}{2\pi f_{T_2}} - C_{\mu_2} = 147.5 - 4.3 = 143.2pF$

Centrobanda

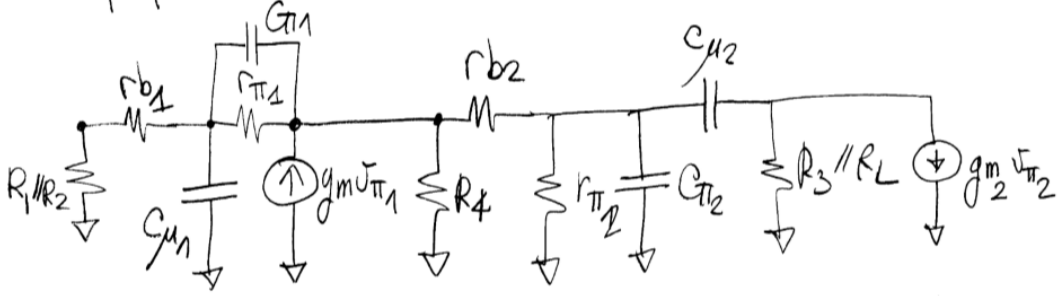


$$\frac{V_u}{V_s} = -\frac{R_1}{R_1+R_2} \cdot \frac{(R_4 // h_{ie_2})(h_{fe_1}+1)}{R_2 // R_1 + h_{ie_1} + R_4 // h_{ie_2}(h_{fe}+1)} \cdot \frac{h_{fe_2} R_3 // R_L}{h_{ie_2}}$$

$$= -\frac{17.5}{17.5+6} \cdot \frac{358.9\,(176)}{4468 + 1416.9 + 358.9\,(176)} \cdot \frac{176 \cdot 222}{1271.6} =$$

$$\frac{V_u}{V_s} = -0.7447 \cdot 0.915 \cdot 30.73 = -20.93$$

Alte frequenze



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

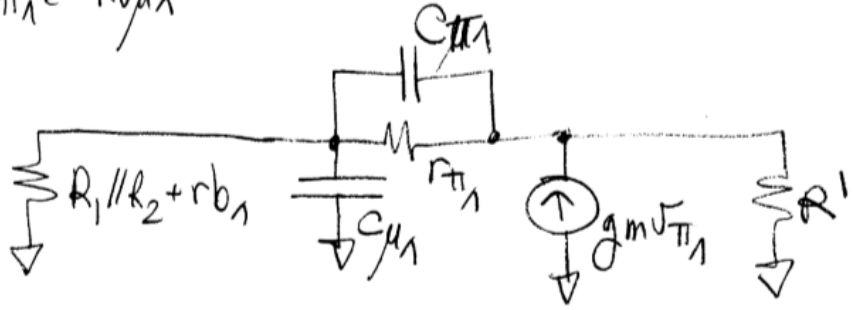
$$= 821.6 // \left[450 + 500 // 33.4 \right] =$$

$$= 821.6 // 481.34 \simeq 303.5\ \Omega$$

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

$$303.5\left(1 + 47.3\right) + 222 = 14.88\ K\Omega$$

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



$$R' = R_4 /\!/ \left[r_{b_2} + r_{\pi_2}\right] = 500 /\!/ 1271.6 = 358.9\ \Omega$$

$$R_{V\pi_1} = r_{\pi_1} /\!/ \left[\frac{R' + R_1 /\!/ R_2 + r_{b_1}}{1 + g_{m_1} R'}\right] =$$

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

$$R_{V\mu_1} = \left(R_1 /\!/ R_2 + r_{b_1}\right) /\!/ \left[r_{\pi_1} + \left(1 + g_{m_1} r_{\pi_1}\right) R'\right] =$$

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

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

$$\frac{1}{2\pi}\left[4567.7 \cdot 4 \cdot 10^{-12} + 73.9 \cdot 121{,}3 \cdot 10^{-12} + 14880 \cdot 4{,}3 \cdot 10^{-12} + 303.5 \cdot 1432 \cdot 10^{-12}\right]^{-1} =$$

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