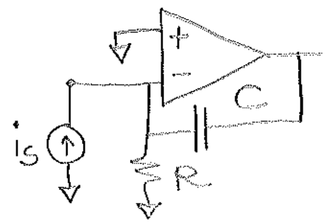
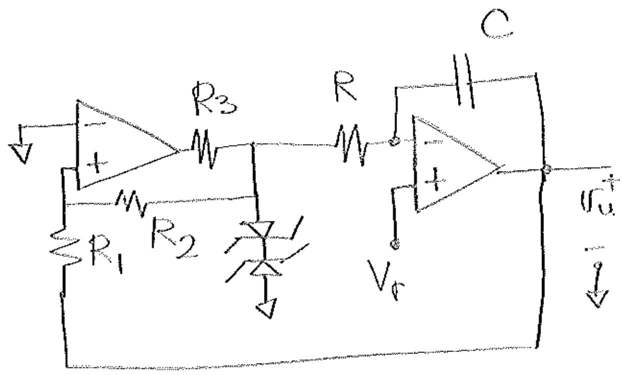
Prova scritta di Elettronica – Corso di Laurea in Ingegneria delle Telecomunicazioni
6 Luglio 2011

1. Si consideri il circuito a lato, si riconosca il tipo di reazione e si calcoli l'impedenza d'ingresso. L'amplificatore ha amplificazione di tensione A_{vo}=1000, R_{in} = 1 MΩ, R_{out} = 0 Ω. Inoltre sia R = 2 KΩ e C = 2 nF.

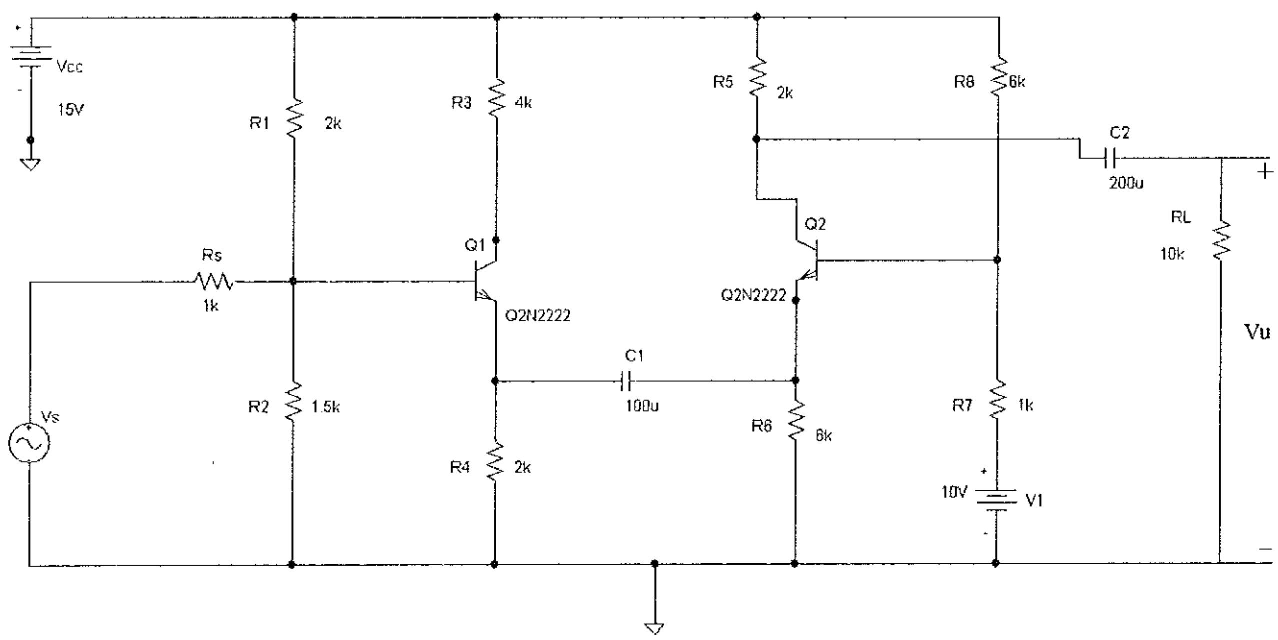


2. Sia dato il circuito a lato, si calcoli la forma d'onda in uscita giustificando il procedimento. Le resistenze R_1 = R_2 = R_3 = R = 1 KΩ, la capacità C = 100 nF, la tensione V_r=2 V, e la tensione zener = 5 V.

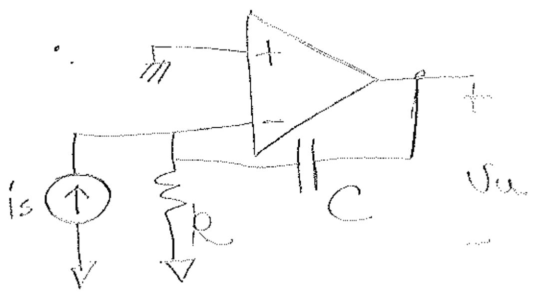


3. Dato l'amplificatore disegnato in figura, calcolare:
   - Il punto di riposo dei 2 transistori e i parametri per piccolo segnale (*punteggio 5/30*);
   - L'amplificazione Vu/Vs a centrobanda (*punteggio 4/30*);
   - Il limite inferiore e il limite superiore di banda (*punteggio 8/30*);

Si considerino le seguenti semplificazioni:
- I BJT sono QN2222 con hoe = 0
- Q2 resistivo



Es. 1.



$R_{in} \to 1\,M\Omega$

$R_{out} = 0$

$A_{vo} = 1000$

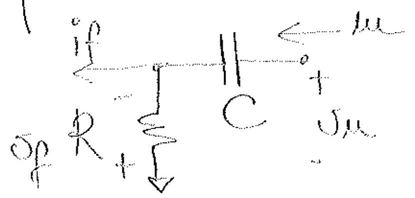
$R = 2\,k\Omega$

$C = 2\,nF$

Abbiamo nel circuito una reazione con prelievo di tensione e inserzione di corrente

$$R_{IF} = \frac{R_{in} /\!/ R_{of}}{1 - \beta A_e}$$

Rete per β



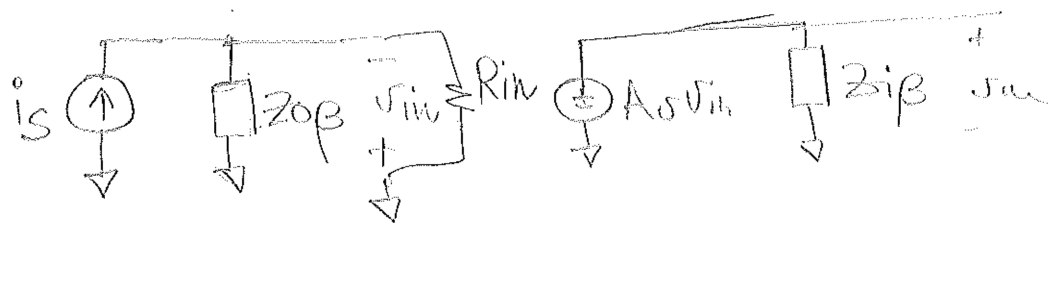
$$i_f = \beta v_u + v_f / Z_{o\beta}$$

$$i_u = \frac{v_u}{Z_{i\beta}} + \cancel{k}\, v_f$$

$$\beta = \left.\frac{i_f}{v_u}\right|_{v_f = 0} = Cs$$

$$Z_{o\beta} = \left.\frac{v_f}{i_f}\right|_{v_u = 0} = \frac{R}{RCs + 1} \qquad Z_{i\beta} = \left.\frac{v_u}{i_u}\right|_{v_f = 0} = \frac{1}{Cs}$$

Rete per A_e



$$A_e = (R_{in} // Z_{o\beta}) A_v$$

$$1 - \beta A_e = 1 + \frac{C s A_v R_{in} R}{R R_{in} C s + R_{in} + R}$$

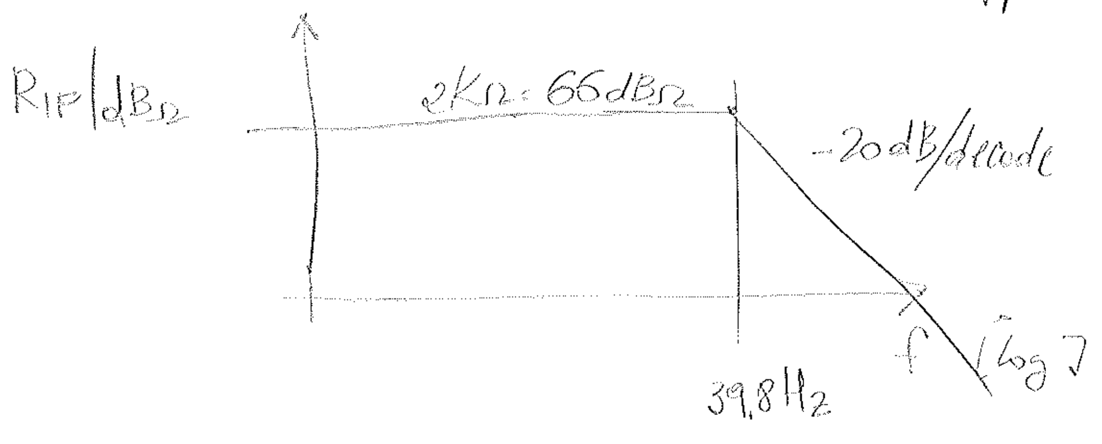
$$R_{IF} = \frac{R_{in} // Z_{o\beta}}{1 - \beta A_e} = \frac{R_{in} R}{R_{in} C s + R_{in} + R} \cdot \frac{1}{1 + \frac{C s A_v R_{in} R}{(R R_{in} C s + R_{in} + R)}} =$$

$$R_{IF} = \frac{R_{in} R}{R R_{in} C s + R_{in} + R + R_{in} R C s A_v} = \frac{R_{in} R}{R_{in} + R + R R_{in} C s (1 + A_v)}$$

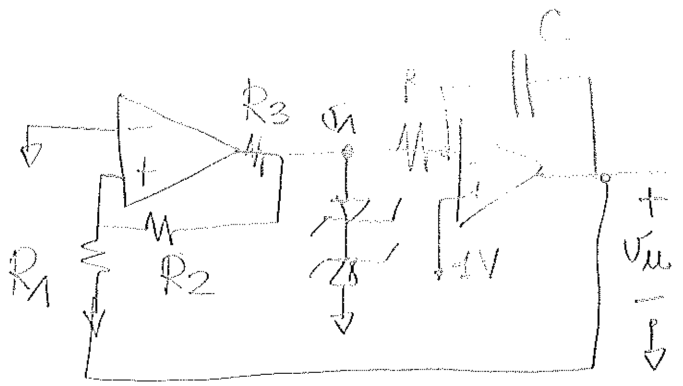
$$R_{IF} = \frac{R_{in} // R}{1 + (R_{in} // R) C s (1 + A_v)}$$

$R_{IF0} = 2 k\Omega$ $\qquad s_p = -\frac{1}{(R_{in} // R) C (1 + A_v)} = -250$ rad/s

$f_p = 39.8$ ''

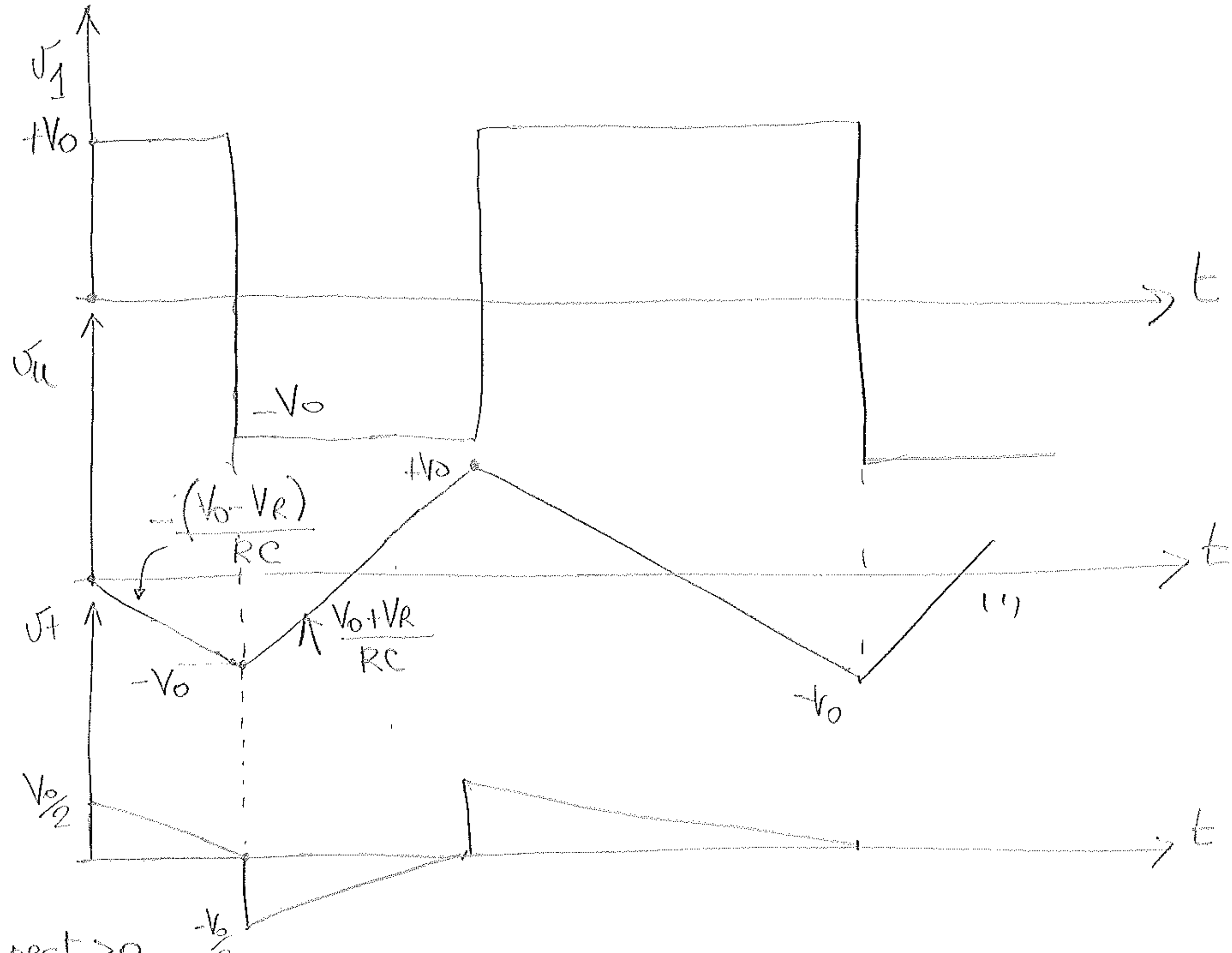


Es 2



$R = 1k\Omega$
$C = 100nF$
$V_R = 1V$

Vediamo il transitorio. Poniamo che per $t=0$ la C sia scarica e l'uscita del comparatore sia alta : $v_1 = V_\gamma + V_Z = 5.7\,V = V_0$



per $t>0$

$\frac{dv_u}{dt} = -\frac{(V_0-V_R)}{RC}$ e $v^+ = \frac{v_1+v_u}{2}$

abbiamo la commutazione quando $v^+=0 \rightarrow v_u = -V_1 = -V_0$

la pendenza di v_u diventa $\frac{dv_u}{dt} = \frac{V_0+V_R}{RC}$

semionda con rampa crescente

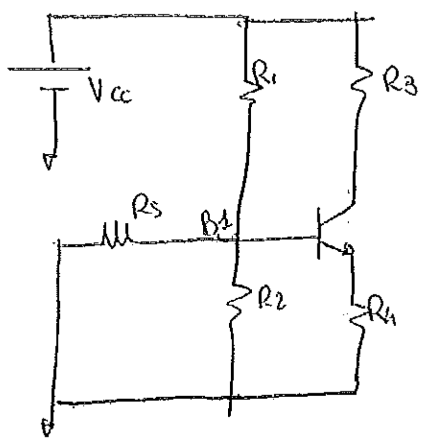
$$T_1 = \frac{(2V_0)}{V_0+V_R} RC = \frac{2\cdot 5{,}7}{7{,}7} \cdot 10^{3} \cdot 10^{-7} = \underline{1{,}48 \cdot 10^{-4}\ s}$$

Semionda con rampa decrescente

$$T_2 = \frac{2V_0}{(V_0-V_R)} RC = \frac{2\cdot 5{,}7}{3{,}7} \cdot 10^{3} \cdot 10^{-7} = \underline{3{,}08 \cdot 10^{-4}\ s}$$

Periodo $T = T_1 + T_2 = \underline{4{,}56 \cdot 10^{-4}\ s}$

PUNTO DI RIPOSO BJT 1



Hp. P.P.

$$V_{B1} = V_{cc} \cdot \frac{R_S // R_2}{R_1 + R_S // R_2} = 3.46\,V$$

$$V_{BE1} = V_{B1} - V_{E1}$$

$$V_{E1} = V_{B1} - V_{BE1} = 3.46 - 0.7 = 2.76\,V$$

$$I_{E1} \cong I_{C1} = \frac{V_{E1}}{R_4} = 1.38\,mA$$

$$V_{CE1} = V_{CC} - (R_3 + R_4) I_C = 6.72\,V$$

caratt.

$h_{FE} \cong 150$

$$I_{B_1} = \frac{I_{C1}}{h_{FE}} \cong 9.2\,\mu A$$

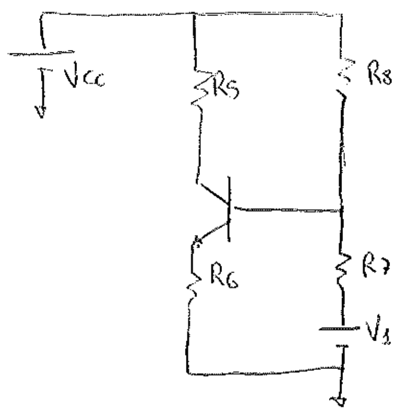
$$I_{R1} = \frac{V_{CC} - V_{B1}}{R_1} = \frac{15 - 3.46}{2} = 5.77\,mA$$

$$I_{R2} = \frac{V_{B1}}{R_2} = 2.3\,mA$$

$$I_{RS} = \frac{V_B}{R_S} = 3.46\,mA$$

verifica hp. P.P. $\quad I_B \ll I_{R1}, I_{R2}, I_{RS}$ OK

PUNTO DI RIPOSO BJT 2



Hp. P.P. e Sovrapposizione degli effetti

$V_{B2} = V_{B2}' + V_{B2}''$

$$V_{B2}' = V_{CC} \cdot \frac{R_7}{R_7+R_8} = 2.14 V$$

$$V_{B2}'' = V_1 \cdot \frac{R_8}{R_7+R_8} = 8.57 V$$

$V_{B2} = 10.71 V$

$V_{BE2} = V_{B2} - V_{E2}$

$V_{E2} = V_{B2} - V_{BE2} = 10.01 V$

$$I_{E2} \cong I_{C2} = \frac{V_{E2}}{R_6} \simeq 1.67 mA$$

$V_{CE2} = V_{CC} - (R_5 + R_6) I_{C2} = 1.64 V$

$h_{FE} \cong 155$

$$I_{B2} \cong \frac{I_{C2}}{h_{FE}} \cong 10.7 \mu A$$

$$I_{R8} = \frac{V_{CC} - V_{B2}}{R_8} = 715 \mu A$$

$$I_{R7} = \frac{V_{B2} - V_1}{R_7} = 700 \mu A$$

verifica hp. P.P. $\quad I_{B2} << I_{R7}, I_{R8}$ OK

PARAMETRI PICCOLO SEGNALE

BJT 1

$$h_{fe1} = \frac{50+300}{2} = 175$$

$$h_{ie1} @ 1\,mA = \frac{2+8}{2} = 5\,k\Omega$$

$$r_{b'e_1} @ 1\,mA = \frac{V_T \cdot h_{fe}}{I_C @ 1\,mA} = 4.55\,k\Omega$$

$$r_{bb'_1} = h_{ie_1} - r_{b'e_1} = 450\,\Omega$$

$$r_{b'e_1} = \frac{V_T h_{fe}}{I_{C1}} = 3.3\,k\Omega$$

$$h_{ie1} = r_{b'e1} + r_{bb'1} = 3.75\,k\Omega$$

$$V_{CB} = V_{CE} - V_{BE} = 6.02\,V$$

$$f_{T_1} \cong 100\,MHz$$

$$g_{m1} = \frac{I_{C1}}{V_T} = 53\,mS$$

$$C_{b'c1} \cong 4.5\,pF$$

$$C_{b'e1} = \frac{g_{m1}}{2\pi f_{T1}} - C_{b'c1} = \frac{53 \times 10^{-3}}{2\pi \times 100 \times 10^{6}} - 4.5\,pF \cong 79.85\,pF$$

BJT 2

$$\beta_{fe2} = \frac{50+300}{2} = 175$$

$h_{ie_2} @ 1mA = 5k\Omega$

$r_{b'e_2} @ 1mA = 4.55k\Omega$

$r_{bb'2} = 450\,\Omega$

$$r_{b'e2} = \frac{V_T h_{fe}}{I_{C2}} = 2.72\ k\Omega$$

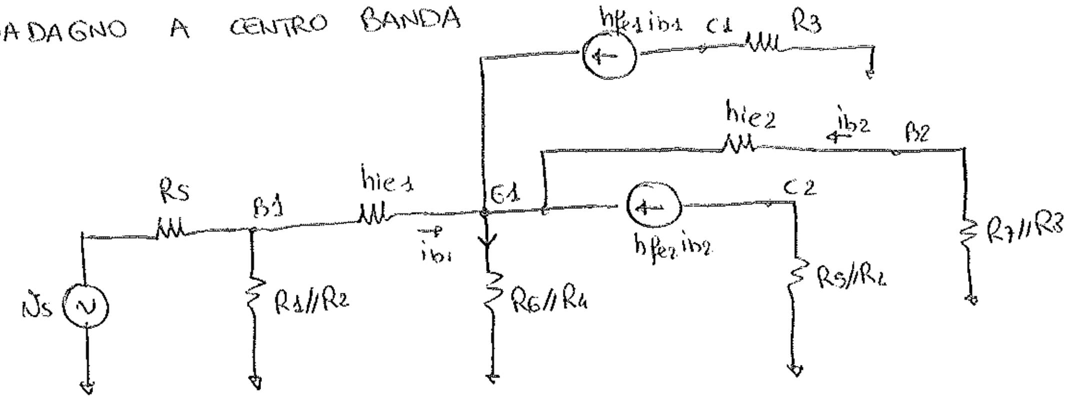
$h_{ie2} = r_{b'e2} + r_{bb'2} = 3.17\ k\Omega$

$V_{CB_2} = V_{CE} - V_{BE} = 1.64 - 0.7 = 0.94\ V$

$f_T \cong 125\ MHz$

$$g_{m2} = \frac{I_{C2}}{V_T} = 64.23\ mS$$

GUADAGNO A CENTRO BANDA

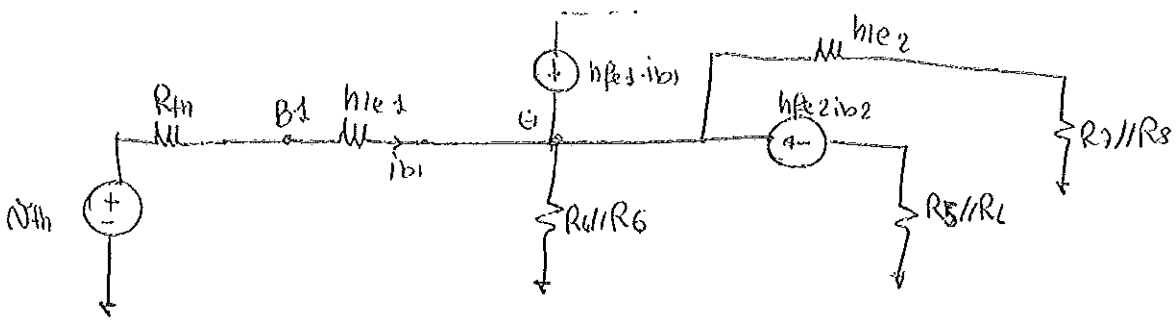


$$v_u = -R_5 // R_L \quad h_{fe2} \cdot i_{b2}$$

modo E1

$$h_{fe1} \cdot i_{b1} + i_{b1} + h_{fe2} \cdot i_{b2} + i_{b2} - \frac{v_{E1}}{R_6 // R_4} = 0$$

$$v_{E1} = -(h_{ie2} + R_7 // R_8)\, i_{b2}$$



$$v_{th} = v_S \cdot \frac{R_1//R_2}{R_1//R_2 + R_S}$$

$$R_{th} = R_S//R_1//R_2 = 0.46\,K\Omega$$

$$v_{th} = (R_{th} + h_{ie1})\,i_{b1} + v_{E1}$$

$$i_{b1} = \frac{v_{th} - v_{E1}}{R_{th} + h_{ie1}}$$

$$(h_{fe2}+1)\,i_{b2} = -(h_{fe1}+1)\left(\frac{v_{th} - v_{E1}}{R_{th} + h_{ie1}}\right) + \frac{v_{E1}}{R_6//R_4}$$

$$(h_{fe2}+1)\,i_{b2} = -\frac{(h_{fe}+1)\,v_{th}}{R_{th} + h_{ie1}} + \frac{(h_{fe1}+1)\,v_{E1}}{R_{th} + h_{ie1}} + \frac{v_{E1}}{R_6//R_4}$$

$$(h_{fe2}+1)\,i_{b2} - \left[\frac{h_{fe1}+1}{R_{th}+h_{ie1}} + \frac{1}{R_6//R_4}\right] v_{E1} = -\frac{(h_{fe}+1)}{R_{th}+h_{ie1}}\, v_{th}$$

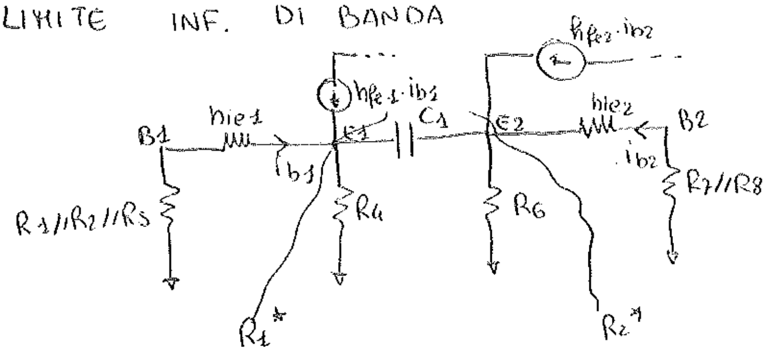
$$i_{b2}(h_{fe2}+1) - \left[\left(\frac{h_{fe1}+1}{R_{th}+h_{ie1}} + \frac{1}{R_6//R_4}\right)\left[-(h_{ie2} + R_7//R_8)\right]\right] i_{b2} = -\frac{h_{fe}+1}{R_{th}+h_{ie1}}\, v_{th}$$

$$i_{b2} = \frac{-\dfrac{h_{fe1}+1}{R_{th}+h_{ie1}} \cdot v_{th}}{(h_{fe2}+1) + \left[\left(\dfrac{h_{fe1}+1}{R_{th}+h_{ie1}} + \dfrac{1}{R_6 // R_4}\right) \cdot (h_{ie2} + R_7 // R_8)\right]}$$

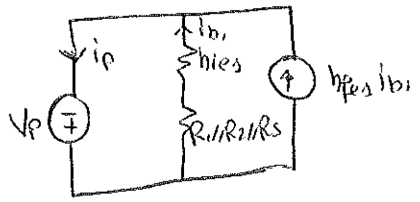
$$A_v = \frac{v_u}{v_s} = -\underset{1.67k}{(R_5 // R_L)}\, h_{fe2} \cdot \frac{\overset{-41.81}{\left(-\dfrac{h_{fe1}+1}{R_{th}+h_{ie1}}\right)} \overset{0.46}{\left(\dfrac{R_1 // R_2}{R_1 // R_2 + R_S}\right)}}{\underbrace{(h_{fe2}+1) + \left[\underbrace{\left(\dfrac{h_{fe1}+1}{R_{th}+h_{ie1}} + \dfrac{1}{R_6 // R_4}\right)}_{27.87} \underbrace{(h_{ie2} + R_7 // R_8)}_{4.03}\right]}_{288.32}}$$

$$\cong 19.5$$

LIMITE INF. DI BANDA



Per R_1^*



$$V_p = (R_1 // R_2 // R_S + h_{ie1})\, i_{b1}$$

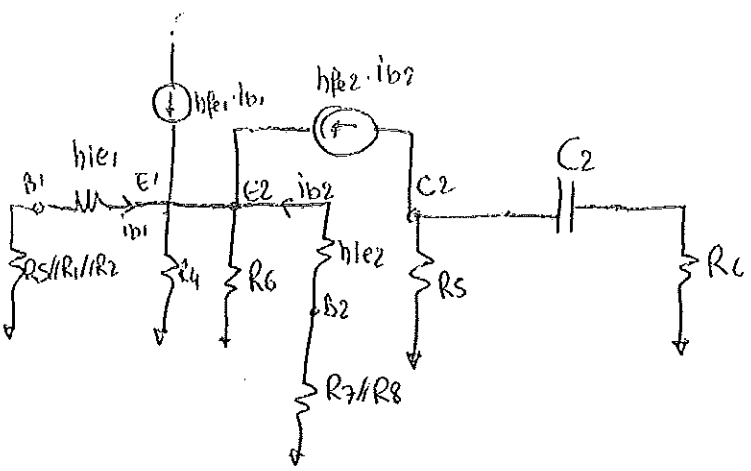
$$i_p = i_{b1} + h_{fe1} \cdot i_{b1}$$

$$R_1^* = \frac{V_p}{i_p} = \frac{R_1 // R_2 // R_S + h_{ie1}}{1 + h_{fe1}} \cong 24\,\Omega$$

Lo stesso vale per R_2^*

$$R_2^* = \frac{h_{ie2} + R_7 // R_8}{1 + h_{fe2}} \cong 23\,\Omega$$

$$R_{VC1} = (R_4 // R_1^*) + (R_6 // R_2^*) \cong 23.72 + 22.91 \cong 46.63\,\Omega$$

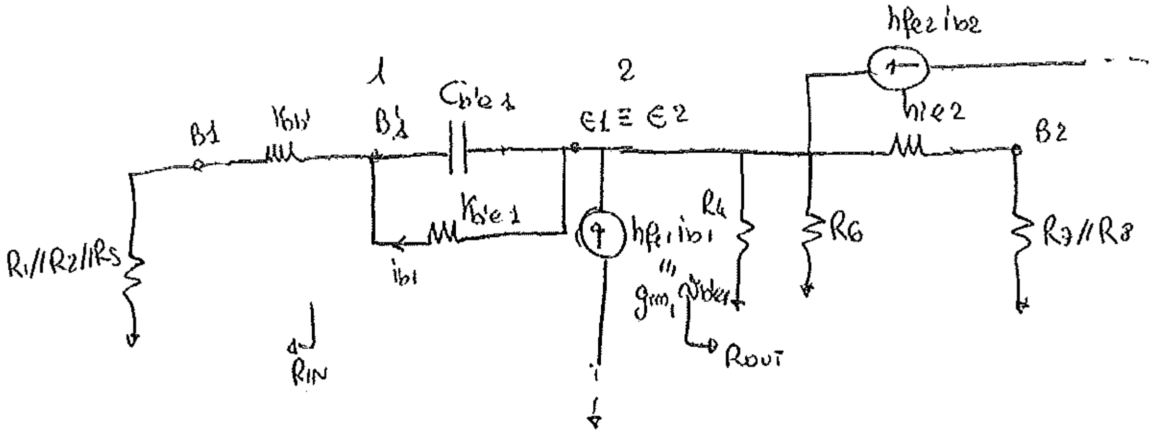


$i_{b1} = 0 \ , \ i_{b2} = 0 \rightarrow h_{fe2} \cdot i_{b2} = 0$

$R_{VC2} = R_S + R_L = 12\,K\Omega$

$$f_L = \frac{1}{2\pi}\left[\frac{1}{C_1 \cdot R_{VC1}} + \frac{1}{C_2 \cdot R_{VC2}}\right]$$

$$= \frac{1}{2\pi}\left[\frac{1}{100\times10^{-6}\times 46.63} + \frac{1}{200\times10^{-6}\times 12000}\right] \simeq 34.2\ Hz$$



togo $r_{b'e_1}$ e lo metto dopo

$$R_{OUT} = R_4 // R_6 // \frac{(h_{ie2} + R_7 // R_8)}{h_{fe2}+1} \simeq 1.02\ k\Omega$$

$$R_{IN} = r_{bb'} + R_1 // R_2 // R_S \cong 0.91 k\Omega$$

$$A_V = \left|\frac{V_2}{V_1}\right| = \frac{-R_{OUT}\, g_{m_1}\, v_{be_1}}{v_{b_1}}$$

$$v_{b'e_1} = v_{b'_1} - v_{e_1} = v_{b'} - (+R_{OUT}\, g_{m_1}\, v_{b'e})$$

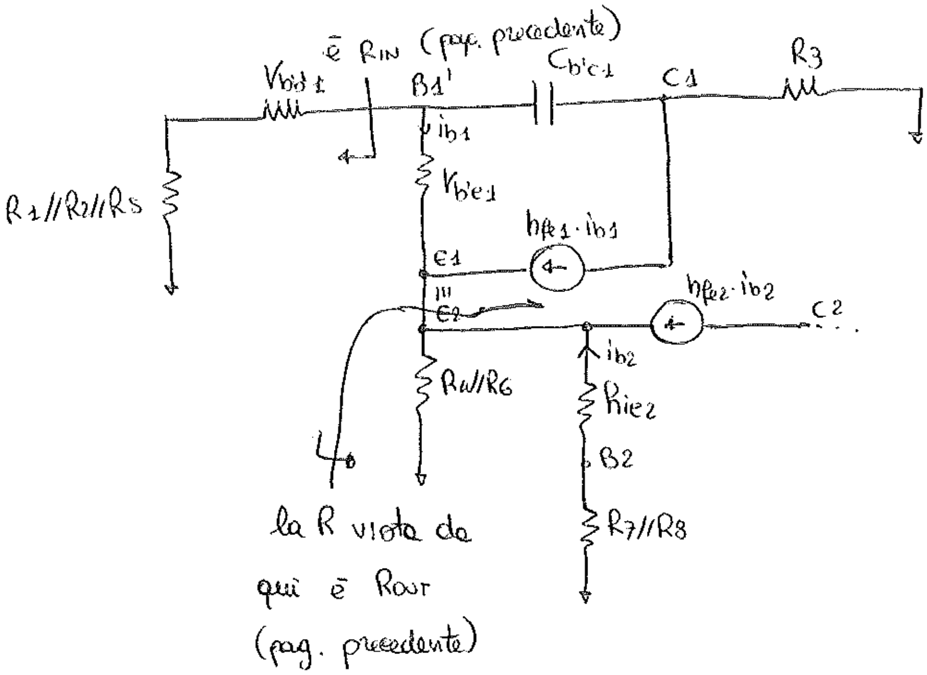
$$v_{b'e} = v_{b'} - R_{OUT}\, g_{m_1}\, v_{b'e}$$

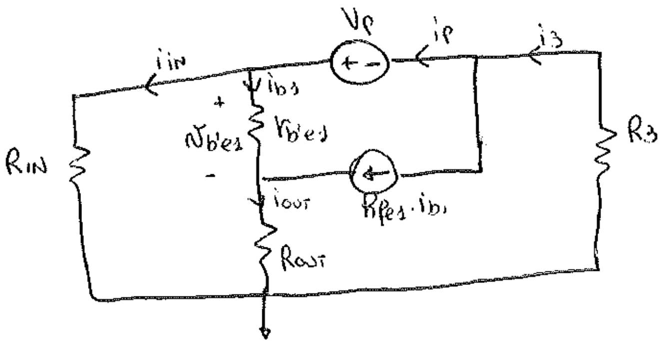
$$v_{b'e} = \frac{v_{b'}}{1+R_{OUT}\, g_{m_1}}$$

$$A_V = \left| \frac{-R_{OUT}\, g_{m_1}}{\cancel{v_{b'}}} \cdot \frac{\cancel{v_{b'}}}{1+R_{OUT}\, g_{m_1}} \right| = \left| \frac{-1.02}{1+1.02\times 53} \right| \cong 17.5$$

$$R_V = R_{IN}(1+|A_V|) + R_{OUT} = 0.91(1+17.5) + 1.02 = 17.855\,K\Omega$$

$$R_{V\,C_{b'e1}} = r_{b'e1} // R_V \cong 2.8\,K\Omega$$





$$\begin{cases} i_P = i_{IN} + i_{b1} & \Rightarrow \quad i_{IN} = i_P - i_{b1} \\ i_P = i_3 - h_{fe1} \cdot i_{b1} & \Rightarrow \quad i_3 = i_P + h_{fe1} \cdot i_{b1} \\ i_{OUT} = (h_{fe1}+1)\, i_{b1} \\ V_P = r_{b'e1} \cdot i_{b1} + R_{OUT} \cdot i_{OUT} + R_3 \cdot i_3 \\ V_P = R_{IN} \cdot i_{IN} + R_3 \cdot i_3 \end{cases}$$

$$r_{b'e1} \cdot i_{b1} + R_{OUT} \cdot i_{OUT} = R_{IN} \cdot i_{in}$$

$$r_{b'e1} \cdot i_{b1} + R_{OUT}\,(h_{fe1}+1)\,i_{b1} = R_{in} \cdot (i_p - i_{b1})$$

$$i_{b1}\left[r_{b'e1} + R_{OUT}(h_{fe1}+1) + R_{in}\right] = R_{in} \cdot i_p$$

$$i_{b1} = \frac{R_{in} \quad i_p}{r_{b'e1} + R_{OUT}\,(h_{fe1}+1) + R_{in}}$$

$$V_p = R_{in} \cdot \left[i_p - i_{b1}\right] + R_3 \left[i_p + h_{fe1} \cdot i_{b1}\right]$$

$$V_p = i_p\,(R_{in} + R_3) + i_{b1}\left[h_{fe1} \cdot R_3 - R_{in}\right]$$

$$V_p = i_p\left[R_{in} + R_3 + (h_{fe1} R_3 - R_{in})\left(\frac{R_{in}}{r_{b'e1} + R_{OUT}\,(h_{fe1}+1) + R_{in}}\right)\right]$$

$$\frac{V_p}{i_p} = R_{in} + R_3 + \left[(h_{fe1} R_3 - R_{in})\left(\frac{R_{in}}{r_{b'e1} + R_{OUT}(h_{fe1}+1) + R_{in}}\right)\right] =$$

$$= 0.91 + 4 + \left[(175 \times 4 - 0.91)\left(\frac{0.91}{3.3 + 1.02\,(175+1) + 0.91}\right)\right] \cong 8.37\,K\Omega$$

$$f_H = \frac{1}{2\pi\left[R_{VCb'e} \cdot C_{b'e} + R_{VCb'c} \cdot C_{b'c}\right]} \simeq \frac{1}{2\pi\left[2.8 \times 10^3 \times 79.85 \times 10^{-12} + 8.37 \times 10^{3} \times 4.5 \times 10^{-12}\right]} \cong 609\ KHz$$