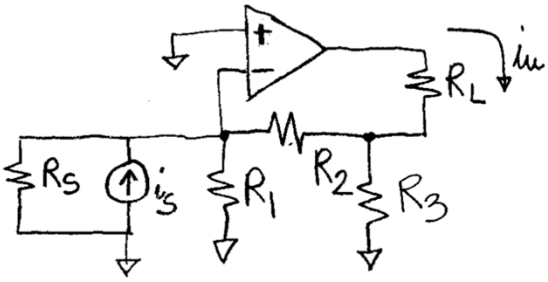
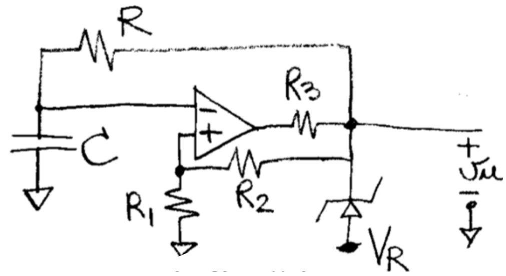
Esame di Elettronica - Corso di Laurea in Ingegneria delle Telecomunicazioni
22 febbraio 2018

1. Si consideri il circuito a lato. R_s = 1 KΩ è la resistenza del generatore di segnale, R_L = 100 Ω è il carico. Si calcoli la resistenza di ingresso, la resistenza di uscita, la funzione del trasferimento i_u/i_s e il limite superiore di banda del circuito completo. L'amplificatore nello schema ha amplificazione di tensione $A_{VO}=10^4$, R_{in} = 200 KΩ, R_{out} = 300 Ω, un polo a frequenza f_p = 100 Hz. Inoltre si consideri R_1 = 10 KΩ, R_2 = 20 KΩ, R_3 = 30 KΩ.



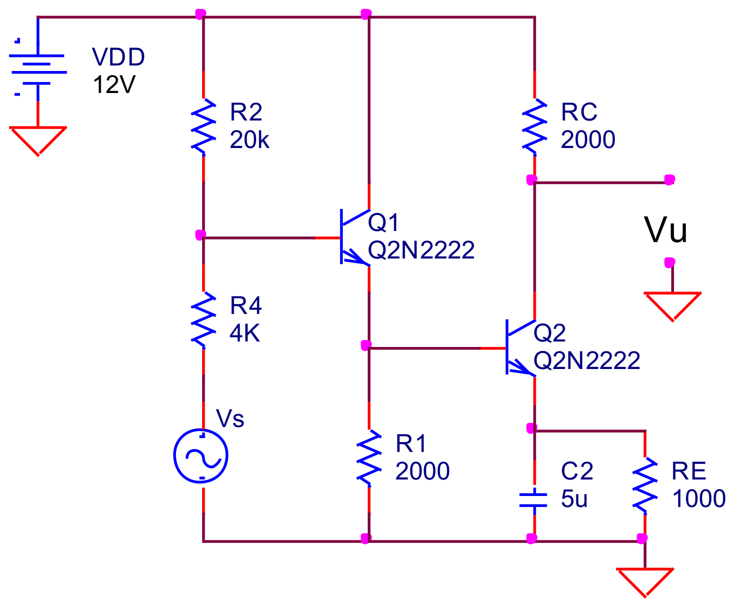
2. Sia dato il circuito mostrato a lato. Ricavare la forma d'onda ottenuta in uscita, giustificando il procedimento. Disegnare e quotare correttamente l'andamento della tensione sul condensatore e all'uscita del circuito nel tempo, sullo stesso asse dei tempi (R = 10 KΩ, C = 47 nF, R_1 = R_2 = 10 KΩ, R_3 = 3 KΩ, V_Z = 4.7 V, V_R = -3 V).



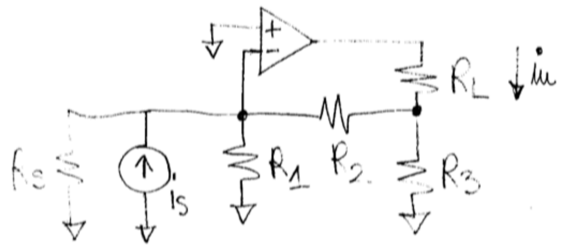
3.

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

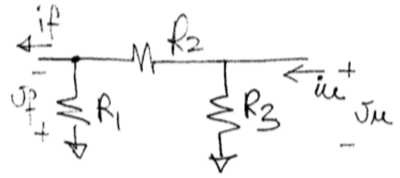


Esercizio 1



$R_1 = 10 K\Omega$
$R_2 = 20 K\Omega$
$R_3 = 30 K\Omega$

Rete x β



$$i_f = \beta\, i_u + \frac{v_f}{R_{o\beta}}$$

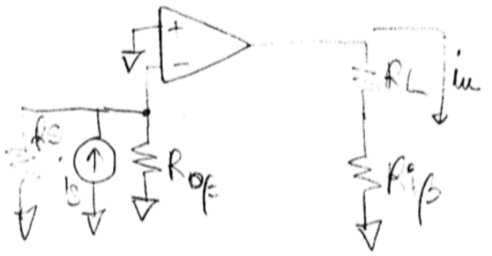
$$v_u = R_{i\beta}\, i_u + k\, v_f$$

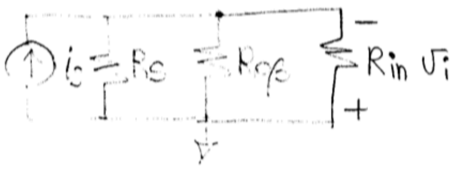
$$\beta = \left.\frac{i_f}{i_u}\right|_{v_f=0} = \frac{R_3}{R_2+R_3} = 0{,}6$$

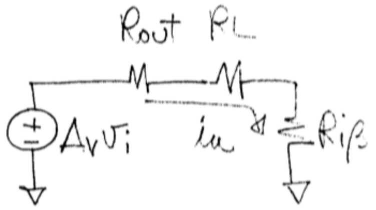
$$R_{o\beta} = \left.\frac{v_f}{i_f}\right|_{i_u=0} = R_1 /\!/ (R_2+R_3) = 8{,}3 K\Omega$$

$$R_{i\beta} = \left.\frac{v_u}{i_u}\right|_{v_f=0} = R_2 /\!/ R_3 = 12 K\Omega$$

Ae







$$v_i = -i_s\,(R_S /\!/ R_{o\beta} /\!/ R_{in}) \qquad i_u = \frac{A_v\, v_i}{R_{out} + R_L + R_{i\beta}}$$

$$A_e = \left.\frac{i_u}{i_s}\right|_{\beta=0} = \frac{-A_v\,(R_S /\!/ R_{o\beta} /\!/ R_{in})}{R_{out} + R_L + R_{i\beta}} = -716.9$$

$$\left[\; A_e\big|_{R_S\to\infty} = -6451 \qquad A_e\big|_{R_L=0} = -722{,}7 \right.$$

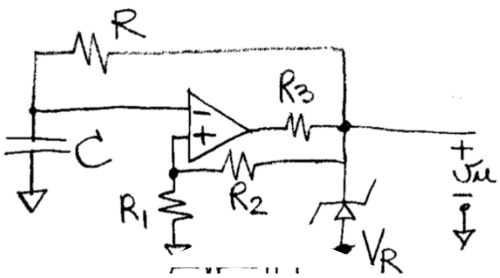
$$R_{IF} = \frac{(R_{o\beta} /\!/ R_{in})}{1 - \beta A_e\big|_{R_S\to\infty}} = 2{,}07\ \Omega$$

$$R_{OF} = (R_{i\beta} + R_{out})\left(1 - \beta A_e\big|_{R_L=0}\right) = 5{,}35\ M\Omega$$

$$A_F = \frac{i_u}{i_s} = \frac{A_e}{1-\beta A_e} = -1{,}66$$

$$f_H = f_p(1-\beta A_e) = 43{,}1\ KHz$$

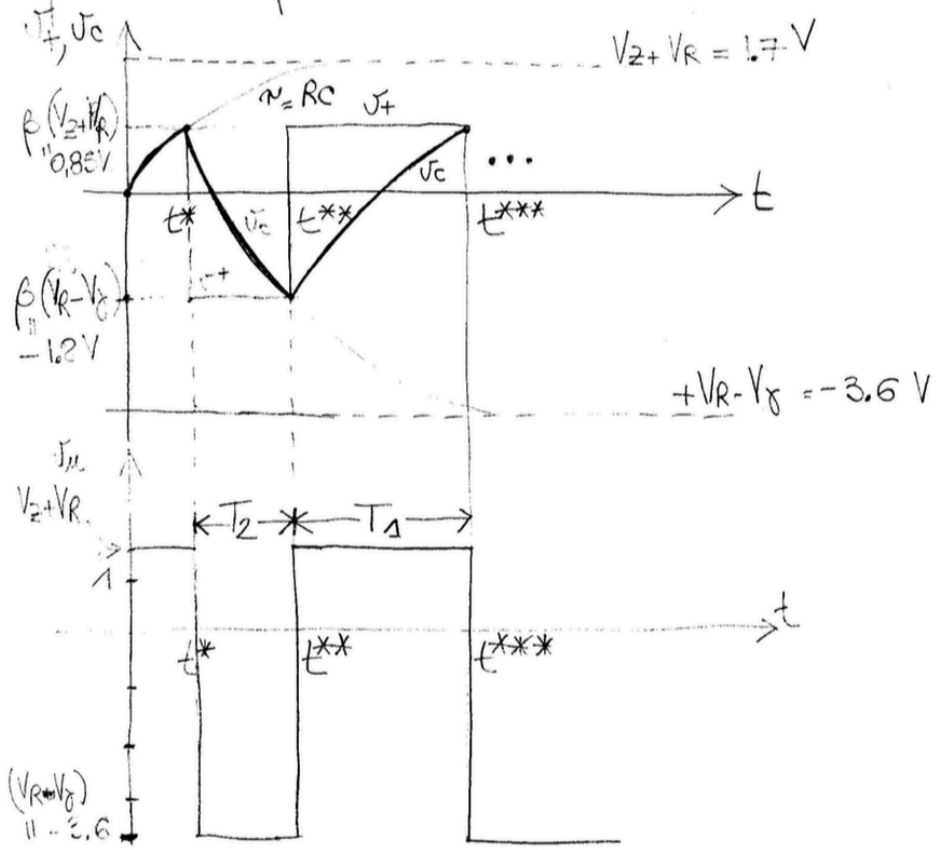
Esercizio 2



uscite: ALTA $v_u = V_R + V_Z$, $v_+ = \frac{R_1}{R_1+R_2}(V_R+V_Z) = \beta(V_R+V_Z)$

BASSA $v_u = V_R - V_\gamma$, $v_+ = \frac{R_1}{R_1+R_2}(V_R-V_\gamma) = \beta(V_R-V_\gamma)$

poniamo che per $t=0$ $v_c = 0 = v^-$



Calcolo di T_1

$$\beta(V_Z+V_R) = v_C(t^{***}) = \beta(V_R - V_\gamma) + \left[(V_Z+V_R) - \beta(V_R - V_\gamma)\right]\left[1 - e^{-\frac{T_1}{RC}}\right]$$

$$\beta(V_Z+V_R) = (V_Z+V_R) - \left[V_Z + (1-\beta)V_R + \beta V_\gamma\right] e^{-T_1/RC}$$

$$(V_Z+V_R)(1-\beta) = \left[V_Z + (1-\beta)V_R + \beta V_\gamma\right] e^{-T_1/RC}$$

$$T_1 = RC \ln\left[\frac{V_Z + (1-\beta)V_R + \beta V_\gamma}{(V_Z+V_R)(1-\beta)}\right] = 6{,}652 \times 10^{-4} s$$

Calcolo di T_2

$$\beta(V_R - V_\gamma) = v_C(t^{**}) = \beta(V_Z+V_R) + \left[V_R - V_\gamma - \beta(V_Z+V_R)\right]\left[1 - e^{-\frac{T_2}{RC}}\right]$$

$$\beta(V_R - V_\gamma) = V_R - V_\gamma - \left[V_R(1-\beta) - V_\gamma - \beta V_Z\right] e^{-T_2/RC}$$

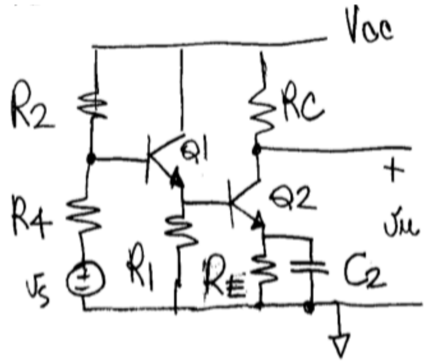
$$(1-\beta)(V_R - V_\gamma) = \left(V_R(1-\beta) - V_\gamma - \beta V_Z\right) e^{-T_2/RC}$$

$$T_2 = RC \ln\left[\frac{V_R(1-\beta) - V_\gamma - \beta V_Z}{(1-\beta)(V_R - V_\gamma)}\right] = 4{,}254 \times 10^{-4} s$$

$T = T_1 + T_2$ $\qquad \delta = \frac{T_1}{T} = 0{,}61$

$T = 1{,}09 ms$

Esercizio 3



$V_{B1} = \frac{R_4}{R_4+R_2} V_{CC} = \frac{4}{24} \times 12 = 2V$ (approssimazione di partitore pesante)

$V_{E1} = V_{B1} - V_{BEON} = 1{,}3V$

$I_{C1} = \frac{V_{E1}}{R_1} = \frac{1{,}3}{2000} = 0{,}65$ mA (approssimazione $I_{B2} \ll I_{C1}$)

$V_{CE1} = V_{CC} - V_{E1} = 10.7V$

$V_{E2} = V_{E1} - V_{BEON} = 0{,}6V$

$I_{E2} = \frac{V_{E2}}{R_E} = 0{,}6 \text{ mA} \sim I_{C2}$ $\qquad V_{CE2} = V_{CC} - I_{C2}R_C - V_{E2} =$

$= 12 - 0{,}6 \cdot 2 - 0.6 = 10.2$ V

$h_{FE1} \cong h_{FE2} = 140$

$I_{B1} = \frac{I_{C1}}{h_{FE1}} \ll \frac{V_{CC}}{R_2+R_4} = \frac{12}{24 \cdot 10^3} = 0{,}5mA$

↑ $4{,}3\mu A$

$I_{B2} = \frac{I_{C2}}{h_{FE2}} \ll I_{C1} = 0{,}65mA$

↑ $4{,}3\mu A$

$r_{bb} = 450\Omega$ (valore a 1mA) $\qquad h_{fe1} = h_{fe2} \cong h_{fe}@1mA = 175$

$r_{\pi1} = \frac{h_{fe1} V_T}{I_{C1}} = \frac{175 \cdot 25{,}9}{0{,}65} = 6973\Omega$ $\qquad g_{m1} = \frac{I_{C1}}{V_T} = 25 \cdot 10^{-3} \Omega^{-1}$

$h_{ie1} = r_{bb} + r_{\pi1} = 7423\Omega$

$$r_{\pi 2} = \frac{h_{fe2} V_T}{I_{C2}} = \frac{175 \cdot 25{,}9}{0{,}6} = 7554 \qquad h_{ie2} = r_{\pi 2} + r_{bb'} = 8004\,\Omega$$

$$g_{m2} = \frac{I_{C2}}{V_T} = 23 \cdot 10^{-3}\,\Omega^{-1}$$

V_A dalle caratteristiche a 1mA $\qquad V_A = \frac{I_C}{h_{oe}} = \frac{1\,mA}{20 \cdot 10^{-6}\,\Omega} = 50\,V$

$$\frac{1}{h_{oe1}} = \frac{V_A}{I_{C1}} = \frac{50}{0{,}65 \cdot 10^{-3}} = 76{,}9\,K\Omega$$

$$\frac{1}{h_{oe2}} = \frac{V_A}{I_{C2}} = \frac{50}{0{,}6 \cdot 10^{-3}} = 83{,}3\,K\Omega$$

possiamo trascurare $\frac{1}{h_{oe1}} \gg R_1$, $\frac{1}{h_{oe2}} \gg R_E, R_C$

$V_{CB1} = 10V \quad C_{\mu 1} = 4pF \quad f_{T1} = 70\,MHz$

$$f_{T1} = \frac{g_{m1}}{2\pi (C_{\mu 1} + C_{\pi 1})} \rightarrow C_{\pi 1} = \frac{g_{m1}}{2\pi f_{T1}} - C_{\mu 1} = \frac{I_{C1}}{V_T 2\pi f_T} - C_{\mu 1}$$

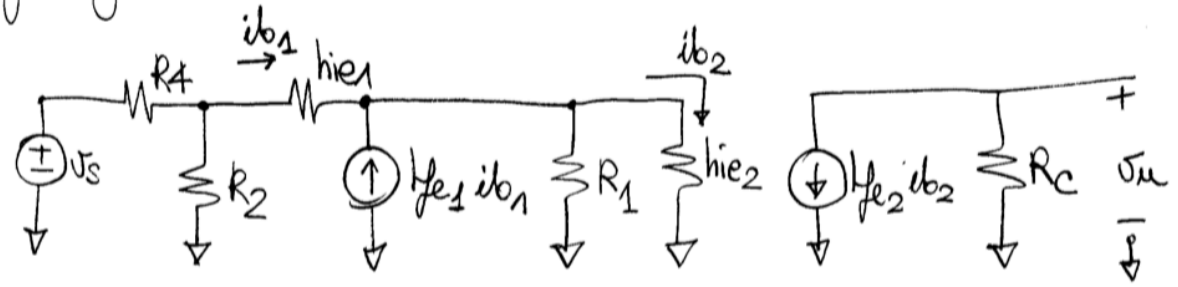
$$= \frac{0{,}65 \cdot 10^{-3}}{25{,}9 \cdot 10^{-3} \cdot 6{,}28 \cdot 70 \cdot 10^{6}} - 4 \cdot 10^{-12}$$

$$= (57{,}1 - 4)\,10^{-12} = \underline{\underline{53{,}1\,pF}}$$

$V_{CB2} = 9{,}5V \quad C_{\mu 2} = 4pF \quad f_{T2} = 70\,MHz$

$$C_{\pi 2} = \frac{g_{m2}}{2\pi f_{T2}} - C_{\mu 2} = \frac{0{,}7 \cdot 10^{-3}}{25{,}9 \cdot 10^{-3} \cdot 6{,}28 \cdot 70 \cdot 10^{6}} - 4 \cdot 10^{-12} = 48{,}7\,pF$$

guadagno a centrobanda



$$i_{b_1} = v_S \cdot \frac{R_2}{R_2+R_4} \cdot \frac{1}{R_2 /\!/ R_4 + hie_1 + (R_1 /\!/ hie_2)(hfe_1+1)} =$$

$$i_{b_2} = i_{b_1}(hfe_1+1)\frac{R_1}{R_1+hie_2}$$

$$v_u = -hfe_2 R_C\, i_{b_2}$$

$$A_f = \frac{v_u}{v_S} = \underset{\substack{\uparrow \\ 175}}{-hfe_2} R_C (hfe_1+1)\frac{R_1}{R_1+hie_2} \cdot \frac{R_2}{R_2+R_4} \cdot \frac{1}{R_2 /\!/ R_4 + hie_1 + (R_1 /\!/ hie_2)(hfe_1+1)}$$

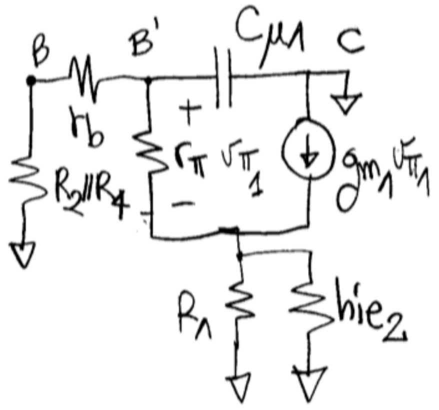
$$= -175 \cdot 2000 \cdot 176 \cdot \frac{2000}{2000+8004} \cdot \frac{20}{20+4} \cdot \frac{1}{\frac{80000}{24} + 7423 + 1600 \cdot 176}$$

$$= -35.1$$

---

limite superiore di banda

$R_{V\mu_1}$

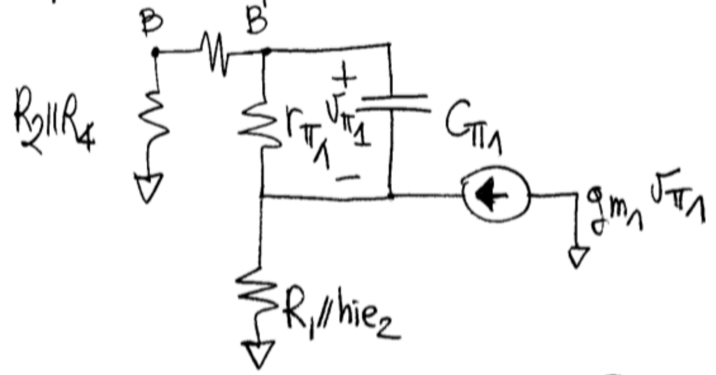


$$R_{V\mu_1} = \left[r_{\pi_1} + (1 + g_{m_1} r_{\pi_1})(R_1 /\!/ hie_2)\right] /\!/ (r_b + R_2 /\!/ R_4)$$

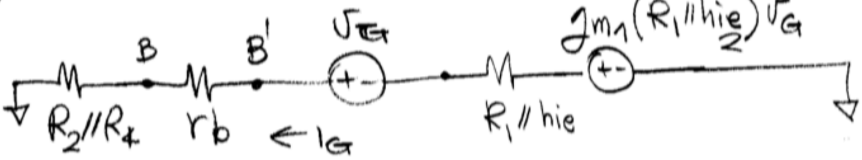
$$= [6973 + 176 \cdot 1600] /\!/ [450 + 3333] =$$

$$= 288573 /\!/ 3783 = 3734\,\Omega$$

Rv_{π_1}



rimuovo r_{π_1}

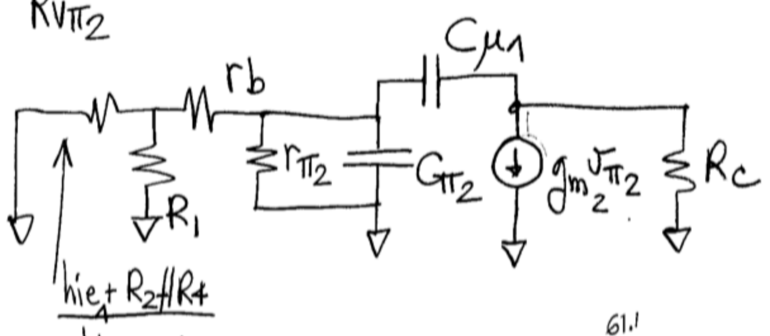


$$i_G = \frac{v_G \left(1 + g_{m_1} (R_1 // hie_2)\right)}{R_2 // R_4 + rb + R_1 // hie_2}$$

$$Rv_{\pi_1} = \underset{6973}{r_{\pi_1}} // \left[\frac{\underset{3333}{R_2 // R_4} + \underset{450}{rb} + \underset{1600}{R_1 // hie_2}}{1 + \underset{25 \cdot 10^{-3}}{g_{m_1}} (\underset{1600}{R_1 // hie_2})} \right] = r_{\pi_1} // \left[\frac{5383}{1 + 40} \right] =$$

$$= 6973 // 131{,}3 = 128{,}9\ \Omega$$

Rv_{π_2}



$$Rv_{\pi_2} = \underset{7554}{r_{\pi_2}} // \underbrace{\left[\underset{450}{rb} + R_1 // \overbrace{\left(\frac{hie_1 + R_2 // R_4}{hfe_1 + 1} \right)}^{61.1} \right]}_{509} = 476{,}9\ \Omega$$

$$Rv_{\mu_2} = Rv_{\pi_2} (1 + g_{m_2} R_C) + R_C = 476{,}9\,(1 + 46) + 2000 = 24{,}4\ K\Omega$$

$$f_H = \frac{1}{2\pi \left[Rv_{\pi_1} C_{\pi_1} + Rv_{\mu_1} C_{\mu_1} + Rv_{\pi_2} C_{\pi_2} + Rv_{\mu_1} C_{\mu_1} \right]} = 1.08\ MHz$$