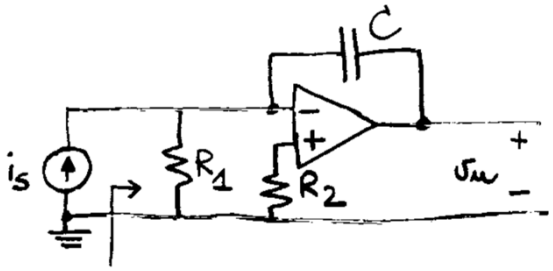
Esame di Elettronica
Corso di Laurea in Ingegneria delle Telecomunicazioni
15 gennaio 2019

Parte A

1. Calcolare, giustificando il procedimento, l'impedenza di ingresso del circuito a lato, e disegnarne il diagramma di Bode. Dati: R1=10 KΩ, R2 = 5 KΩ, C = 10 μF; l'amplificatore operazionale ha impedenza di ingresso infinita, impedenza di uscita nulla, amplificazione di tensione Av = 2000.



2. Disegnare e dimensionare lo schema del circuito elettronico che abbia due poli complessi coniugati sp1,sp2 = -1000 ± j 500 rad/s, e uno zero nell'origine.

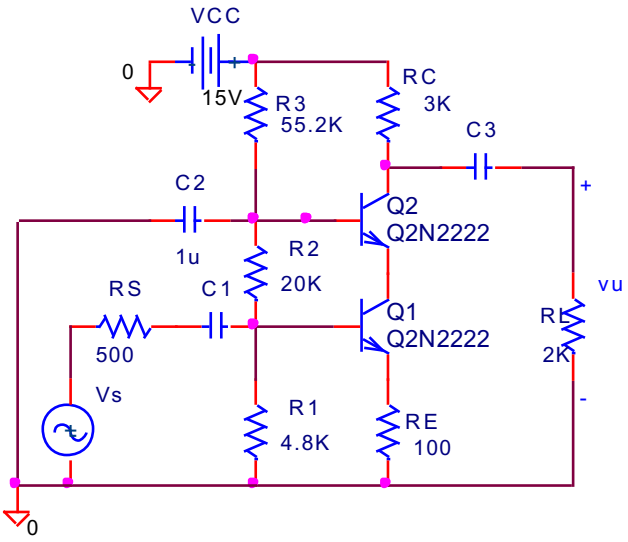
Dato l'amplificatore disegnato in figura, calcolare:

- il punto di riposo dei due transistori,
- l'amplificazione Vu/Vs a centrobanda,
- il limite superiore di banda e il limite inferiore di banda

Ipotesi semplificative:

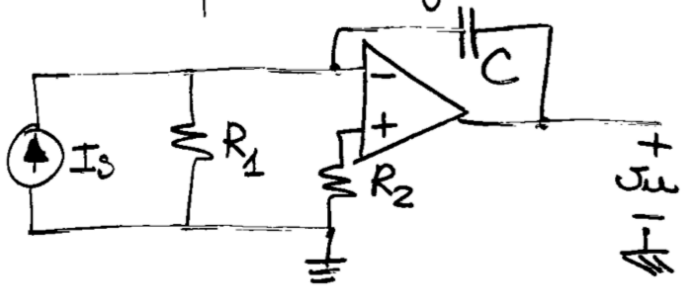
- i due transistori hanno h_{oe}=0, $r_{bb'}$ = 0.
- Q1 e' completamente resistivo.
- C1 e C3 hanno valore praticamente infinito (sono un corto circuito a frequenza diversa da zero).

Punteggio totale Parte B: 14



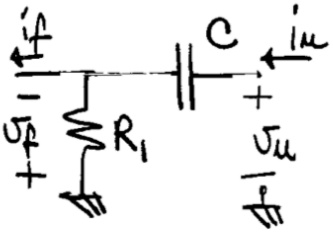
Esercizio 1

Calcolare l'impedenza d'ingresso del circuito



Reazione con prelievo di tensione e inserzione di corrente

Rete per il β:



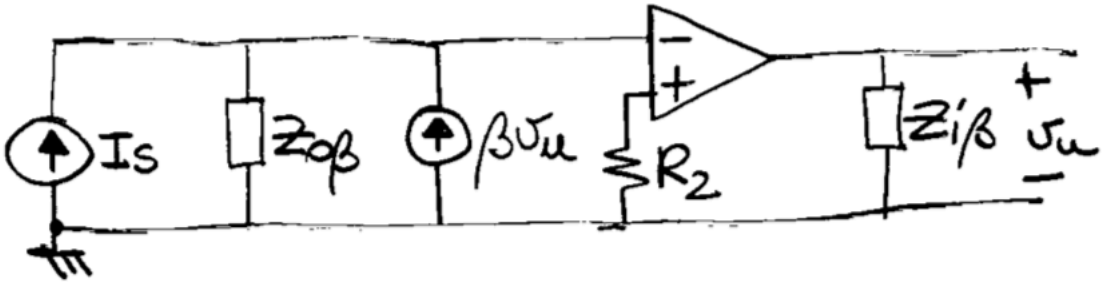
$$i_f = \beta v_u + \frac{v_f}{R_{o\beta}}$$

$$i_u = \frac{v_u}{R_{i\beta}} + K v_f$$

$$\beta = \frac{i_f}{v_u}\Big|_{v_f=0} = Cs \qquad R_{i\beta} = \frac{v_u}{i_u}\Big|_{v_f=0} \quad \frac{1}{Cs}$$

$$R_{o\beta} = \frac{v_f}{i_f}\Big|_{v_u=0} = R_1 /\!/ \frac{1}{Cs} = \frac{R_1}{R_1 Cs + 1}$$

$R_{o\beta} \equiv Z_{o\beta}$



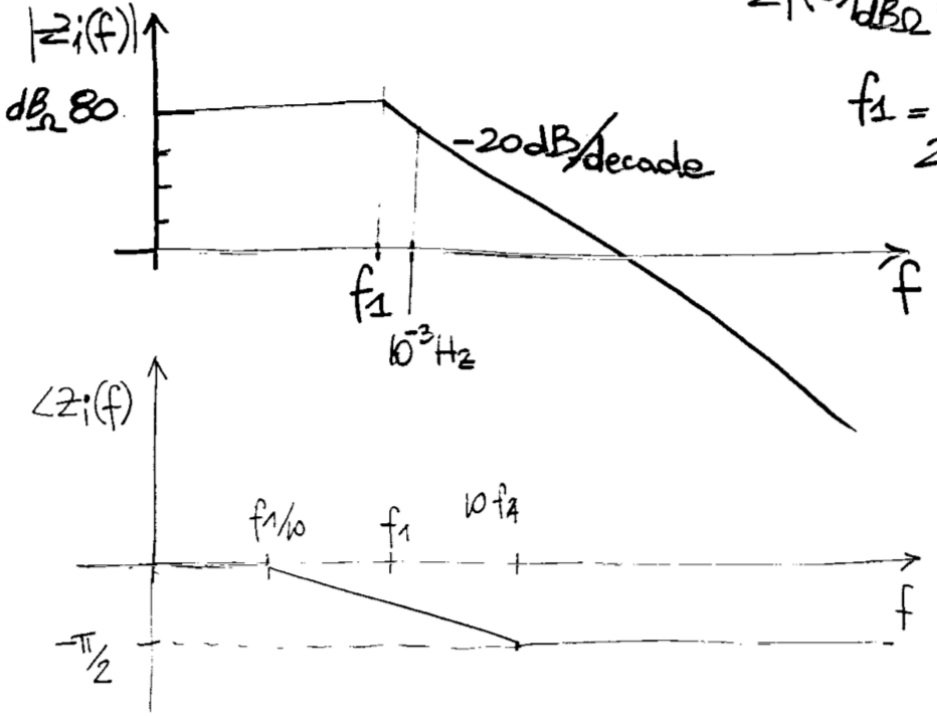
$$A_e = \frac{v_u}{I_s} = -Z_{o\beta} A_v$$

$$Z_i = \frac{Z_{0\beta}}{1-\beta A_e} = \frac{Z_{0\beta}}{1+CsZ_{0\beta}A_V} = \frac{R_1}{R_1Cs+1+R_1CsA_V} =$$

$$= \frac{R_1}{1+R_1C(A_V+1)s}$$

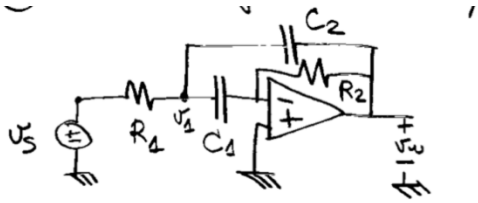
$$Z_i(0)\big|_{dB\Omega} = 20\log 10^4 = 80$$

$$f_1 = \frac{\pm 1}{2\pi R_1 C(A_V+1)} = \pm 7.96\times10^{-4}\,Hz$$



Esercizio 2

Usiamo il filtro di Delyannis



$$V_1\left(C_1s+C_2s+\frac{1}{R_1}\right) - V_s\frac{1}{R_1} - V_u C_2 s = 0$$

$$V_1 C_1 s = -\frac{V_u}{R_2} \qquad V_1 = -\frac{V_u}{R_2C_1s}$$

$$\frac{-V_u}{R_2C_1s}\left(R_1C_1s+R_1C_2s+1\right) - V_s - V_u R_1C_2 s = 0$$

$$T_u = \frac{-R_2 C_1 s}{R_1 R_2 C_1 C_2 s^2 + R_1 (C_1 + C_2) s + 1}$$

Vogliamo $s_{p1}, s_{p2} = -1000 \pm j500$ rad/s

$$R_1 R_2 C_1 C_2 = \frac{1}{|s_{p1}|^2} = \left(10^6 + 250000\right)^{-1} s^2 = \frac{1}{1250000} s^2$$

$$R_1 (C_1 + C_2) = \frac{1}{s_{p1}} + \frac{1}{s_{p2}} = \frac{s_{p2} + s_{p1}}{s_{p1} s_{p2}} = \frac{2000}{1250000}$$

poniamo $C_1 = C_2 = C$

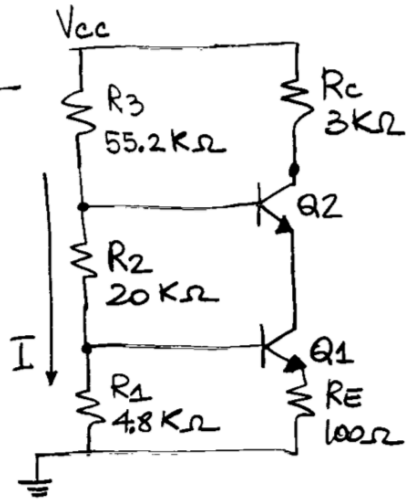
$$\frac{R_1 (C_1 + C_2)}{R_1 R_2 C_1 C_2} = \frac{2}{R_2 C_2} = 2000 \qquad C = 10^{-6} F$$

$$R_2 = \frac{2}{2000 \cdot 10^{-6}} = 10^3 \Omega$$

$$R_1 = \frac{1}{R_2 C^2} \cdot \frac{1}{1250000} = 800 \Omega$$

Esercizio 3

Punto di riposo



Trascurando le correnti di base dei transistori

$$I = \frac{V_{cc}}{R_1 + R_2 + R_3} = \frac{15}{55.2 + 20 + 4.8} = 0.1875 \text{ mA}$$

$$V_{B1} = R_1 I = 0.9V$$

$$V_{E1} = V_{B1} - V_{BE\_ON} = 0.2V$$

$$I_{E1} = \frac{V_{E1}}{R_E} = \frac{0.2}{0.1} = 2 \text{ mA} \cong I_{E2} \cong I_{C2}$$

$V_{B2} = (R_1 + R_2) I = 4.65\,V$

$V_{C2} = V_{CC} - R_C I_{C_2} = 15 - 3 \cdot 2 = 9\,V$

dai datasheet $h_{FE} = 150$

$I_{B1} = I_{B2} = \frac{I_{E1}}{h_{FE}} = \frac{2}{150} = 13.3\,\mu A \ll I$

$V_{CE1} = V_{E2} - V_{E1} = 3.95 - 0.2 = 3.75\,V$

$V_{CE2} = V_{C2} - V_{E2} = 9 - 3.95 = 5.05\,V$

Q1: $I_{C_1} = 2mA$ $V_{CE_1} = 3.75\,V$ Q2: $I_{C_2} = 2mA$ $V_{CE_2} = 5.05\,V$

$h_{fe}@1mA\ medio = \frac{300+50}{2} = 175$

assumiamo che per $I_{C_1} = I_{C_2} = 2mA$ $h_{fe_1} = h_{fe_2} = 175$

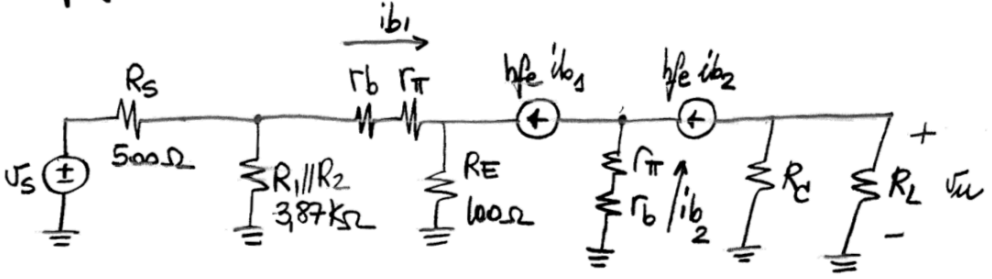
$g_{m_1} = g_{m_2} = \frac{I_{C1}}{V_T} = \frac{2 \cdot 10^{-3}}{0.026} = 0.077\,\Omega^{-1} = g_m$

$r_{\pi_1} = r_{\pi_2} = \frac{h_{fe}}{g_{m1}} = 2273\,\Omega = r_\pi$ $f_T = 140\,MHz$

$r_b \approx 0$, dal testo del problema. Da ora in poi facciamo i conti con $r_b = 450\,\Omega$ (il valore che si può ricavare dalle caratteristiche). I calcoli con $r_b = 0$ si possono ricavare in modo semplice

$C_{\mu_2} = 5pF$ $C_{\mu_2} + C_{\pi_2} = g_m / 2\pi f_T = 87.6pF \rightarrow C_{\pi_2} = 82.6pF$

Amplificazione a centrobanda



$i_{b_1} = v_S \frac{R_1 /\!/ R_2}{R_2 /\!/ R_1 + R_S} \frac{1}{R_2 /\!/ R_1 /\!/ R_S + r_b + r_\pi + R_E (1 + h_{fe})}$

$i_{b_2} = \frac{h_{fe}}{h_{fe}+1} i_{b_1}$

$$v_u = -h_{fe}\,(R_C /\!/ R_L)\, i_{b_2}$$

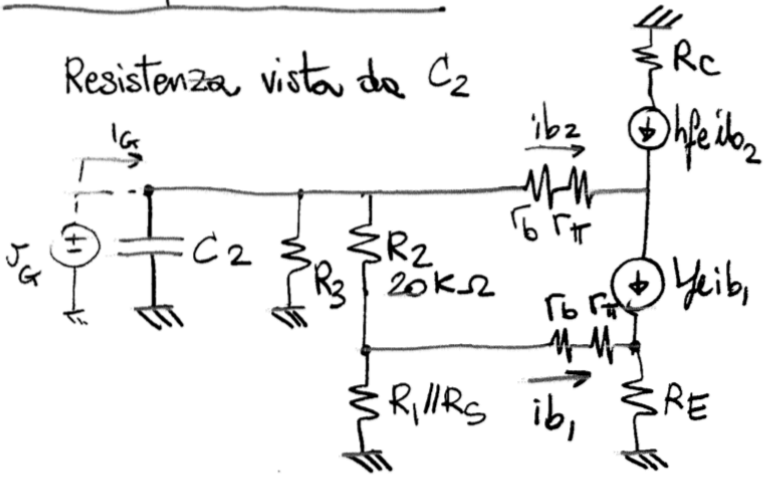
$$\frac{v_u}{v_S} = -h_{fe}\,(R_C /\!/ R_L)\,\frac{h_{fe}}{h_{fe}+1}\,\frac{R_1 /\!/ R_2}{R_1 /\!/ R_2 + R_S}\cdot\frac{1}{R_2 /\!/ R_1 /\!/ R_S + r_b + r_\pi + R_E(1+h_{fe})}$$

$$\frac{v_u}{v_S} = -175\cdot 1200\cdot\frac{175}{176}\cdot\frac{3{,}87}{3{,}87+0.5}\cdot\frac{1}{442+450+2273+100(176)} =$$

$$= -8.9$$

Limite inferiore di banda

Resistenza vista da C_2



sostituiamo a C_2 un generatore di tensione v_G

$$i_G = I_{R_3} + I_{R_2} + i_{b_2}$$

$$I_{R_3} = v_G / R_3$$

$$I_{R_2} = v_G \Big/ \left[R_2 + R_1 /\!/ R_S /\!/ \left(r_b + r_\pi + (h_{fe}+1) R_E\right)\right]$$

$$i_{b_1} = I_{R_2}\cdot\frac{R_1 /\!/ R_S}{R_1 /\!/ R_S + r_b + r_\pi + R_E(h_{fe}+1)} = I_{R_2}\cdot 2.18\cdot 10^{-2}$$

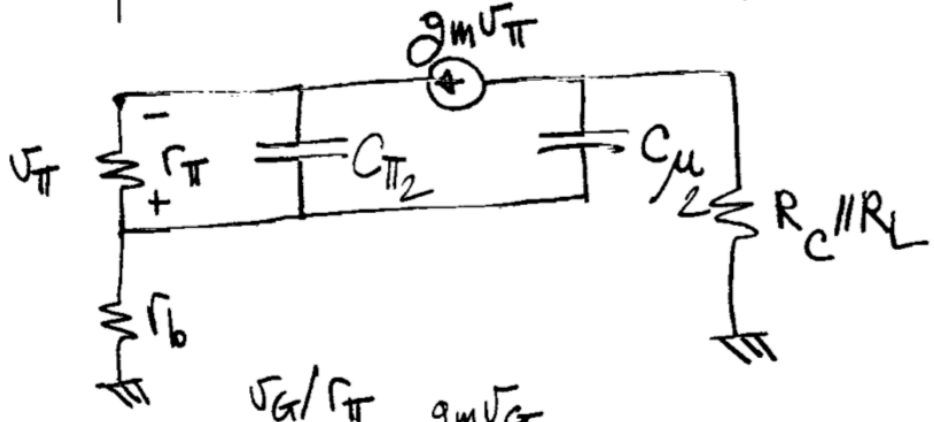
$$i_{b_2}(h_{fe}+1) = h_{fe}\, i_{b_1} \rightarrow i_{b_2} \sim i_{b_1}$$

$$R_{VC_2} = \frac{v_G}{i_G} = \frac{v_G}{I_{R_3} + I_{R_2} + i_{b_2}} \simeq \frac{v_G}{I_{R_3} + I_{R_2}} =$$

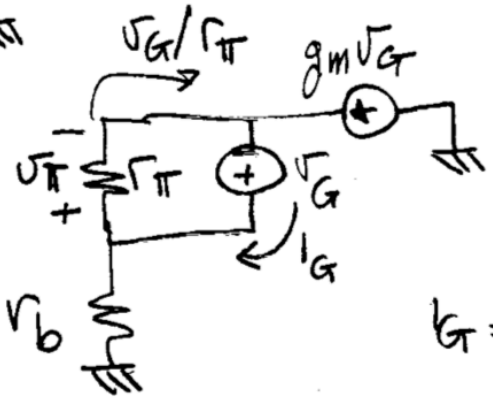
$$R_{VC_2} = R_3 /\!/ \left[R_2 + R_1 /\!/ R_S /\!/ \left(r_b + r_\pi + (h_{fe}+1) R_E\right)\right] = 14918\,\Omega$$

$$f_L = \frac{1}{2\pi R_{V_{C_2}} C_2} = \frac{1}{2\pi \cdot 14918 \cdot 10^{-6}} = 10.67\ Hz$$

Limite superiore di banda



R_{V_π}:

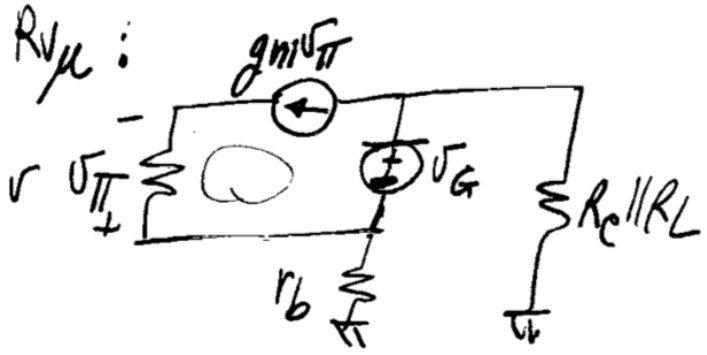


$$i_G = \frac{v_G}{r_\pi} + g_m v_G \qquad (\mu_e)$$

$$i_G = v_G \frac{(1 + g_m r_\pi)}{r_\pi}$$

$$R_{V_\pi} = \frac{v_G}{i_G} = \frac{r_\pi}{1 + h_{fe}} = \underline{12.9\ \Omega}$$

R_{V_μ}:



$v_\pi = 0$

$$R_{V_\mu} = r_b + R_C \| R_L$$

$$= 450 + 1200 =$$

$$= 1650\ \Omega$$

$$f_H = \frac{1}{2\pi \left(C_{\frac{\pi}{2}} R_{V_\pi} + C_{\frac{\mu}{2}} R_{V_\mu} \right)} = \underline{\underline{4\ MHz}}$$