Esercizio 1

Punto di riposo.

$V_U = V^+ - R_C I_C \Rightarrow I_C = \dfrac{V^+ - V_U}{R_C} = 2.67$ mA

$V_{CE} = V^+ - R_C I_C - R_E(I_C + I_B) \simeq V^+ - (R_C + R_E) I_C = 6.19$ V

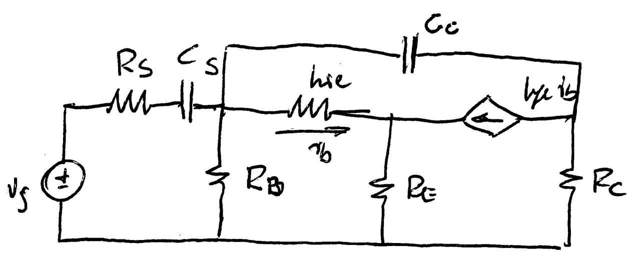
dalle caratteristiche del transistor segue $I_B \simeq 9\,\mu A$

Applicando il t. di Thévenin sulla base

$V^+ \dfrac{R_2}{R_1+R_2} - (R_1+R_2) I_B - V_\gamma - R_E(I_C+I_B)$, nota la somma di R_1 ed R_2 si ricava $R_1 = 31.4$ kΩ $R_2 = 8.6$ kΩ

Nel pr. si ha $h_{fe} \simeq 312$ $h_{ie} = r_{bb'} + \dfrac{V_T}{I_C} h_{fe} = 3.39$ kΩ

Circuito per le variazioni



$h_{fe} i_b$

$R_B = R_1 \| R_2 = 6.75$ kΩ

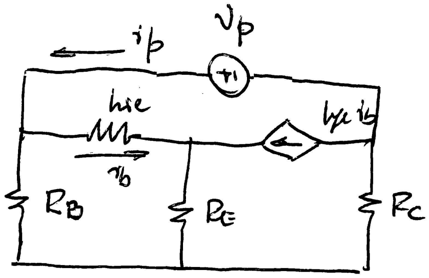
C_S: zero nell'origine + polo

C_C: polo + zero ($f_p < f_z$)

$R_S^0 = R_S + \{R_B \| [h_{ie} + R_E(h_{fe}+1)]\} = 6.80$ kΩ

$R_S^C = R_S + \left[R_B \| R_C \| \left(R_E + \dfrac{h_{ie}}{h_{fe}+1}\right)\right] = 692\ \Omega$

R_C^0:



$v_p = [h_{ie} + R_E(h_{fe}+1) + R_C h_{fe}] i_b + R_C i_p$

$i_b = i_p \dfrac{R_B}{R_B + h_{ie} + R_E(h_{fe}+1)}$

Segue $\quad v_p = \left\{ \left[h_{ie} + R_E(h_{fe}+1) + R_C \right] \dfrac{R_B}{R_B + h_{ie} + R_E(h_{fe}+1)} + R_C \right\} i_p$

e dunque $\quad R_C^o = \dfrac{v_p}{i_p} = \dfrac{R_B\left[h_{ie} + R_E(h_{fe}+1) + R_C \right]}{R_B + h_{ie} + R_E(h_{fe}+1)} + R_C = 22.22\ k\Omega$

$$R_C^S = \frac{(R_B /\!/ R_S)\left[h_{ie} + R_E(h_{fe}+1) + R_C \right]}{(R_B /\!/ R_S) + h_{ie} + R_E(h_{fe}+1)} + R_C = 2.26\ k\Omega$$

($R_B /\!/ R_S$ al posto di R_B)

$a_1 = C_S R_S^o + C_C R_C^o = 68.2\ ms$

$a_2 = C_S C_C R_S^o R_C^S = 1.54 \times 10^{-6}\ s^2$

poli $\quad s_{p1,2} = \begin{cases} -14.66\ rad/s \\ -44.35\ krad/s \end{cases}$

$f_{Polo} = \begin{cases} 2.33\ Hz = f_1 \\ 7.06\ kHz = f_2 \end{cases}$

Con l'ipotesi di separazione tra bande si ottiene

$$f_{PCS} = \frac{1}{2\pi C_S R_S^o} = 2.34\ Hz$$

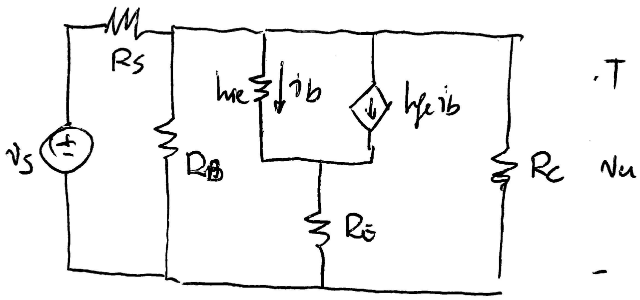
$$f_{PCC} = \frac{1}{2\pi C_C R_C^S} = 7.04\ kHz$$

Guadagno a centro banda (Cs chiuso, Cc aperto)

$$A_{CB} = -\frac{R_C h_{fe}}{(R_S /\!/ R_B) + h_{ie} + R_E (h_{fe}+1)} \cdot \frac{R_B}{R_B + R_S} = -2.08$$

(6.38 dB)

con tutti i condensatori chiusi



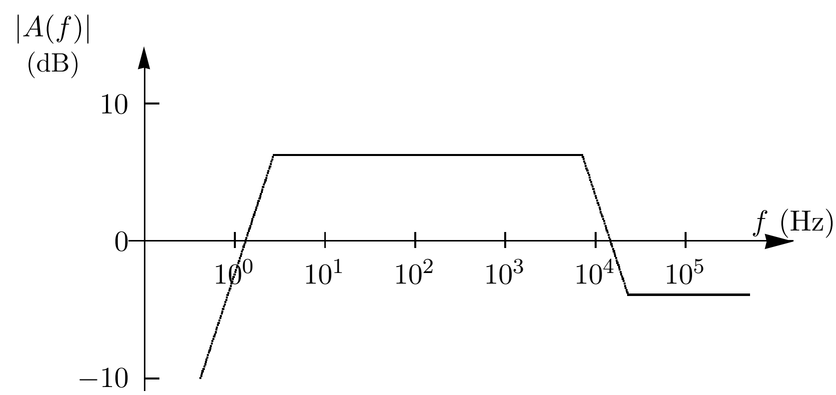
$$A_\infty = \frac{v_u}{v_s} = \frac{R_C /\!/ R_B /\!/ (R_E + h_{ib})}{R_S + \left[R_C /\!/ R_B /\!/ (R_E + h_{ib})\right]}$$

$$= 0.639 \quad (= -3.89 \text{ dB})$$

Nella risposta c'è anche uno zero (positivo) alla frequenza $f_0 = f_2 \left| \frac{A_{CB}}{A_\infty} \right| = 22.96$ kHz

$$A(f) = A_{CB} \frac{j \frac{f}{f_1} \left(1 - j \frac{f}{f_0}\right)}{\left(1 + j\frac{f}{f_1}\right)\left(1 + j \frac{f}{f_2}\right)}$$

Diagramma di Bode:



ESERCIZIO 2

$$A_1(s) = -\frac{R_4}{R_3}\left[1+\frac{R_2}{R_1(1+R_2C_1s)}\right] = -\frac{R_4}{R_3}\,\frac{R_1+R_2+R_1R_2C_1s}{R_1(1+R_2C_1s)}$$

$$= -\frac{R_4}{R_3}\,\frac{R_1+R_2}{R_1}\,\frac{1+R_pC_1s}{1+R_2C_1s}$$

$R_p = R_1 \parallel R_2 = 968\,\Omega$

$$A_1(f) = A_{10}\,\frac{1+j\,f/f_{z1}}{1+j\,f/f_{p1}}$$

$$A_{10} = -\frac{R_4}{R_3}\left(1+\frac{R_2}{R_1}\right) = -6{,}2$$

$(= 15.8\ dB)$

$$f_{z1} = \frac{1}{2\pi C_1 R_p} = 8{,}22\ kHz$$

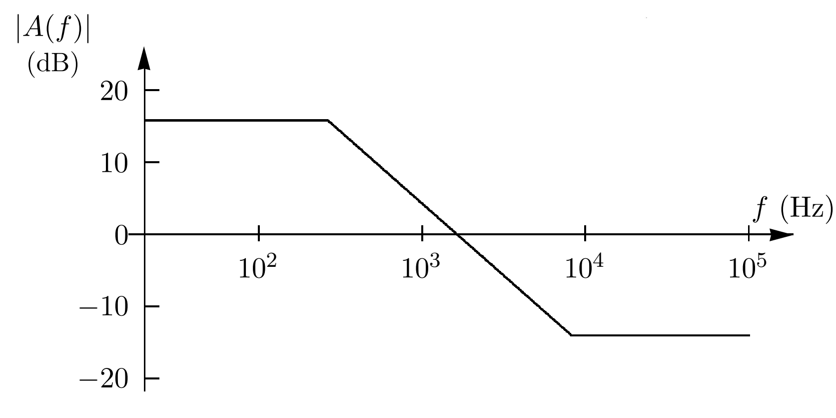
$$f_{p1} = \frac{1}{2\pi C_1 R_2} = 265.\ Hz$$

$$A_2(s) = \frac{1}{1+R_5C_2s}\left(1+\frac{R_4}{R_3}\right)$$

$$A_1(f) = A_{20}\,\frac{1}{1+j\,f/f_{p2}}$$

$$A_{20} = 1+\frac{R_4}{R_3} = 1.2 \quad (= 1.58\ dB)$$

$$f_{p2} = \frac{1}{2\pi R_5C_2} = 318{,}3\ Hz$$



$$A_C(s) = A_1(s) + A_2(s) = A_{10}\,\frac{1 + R_pC_1 s}{1 + R_2C_1 s} + A_{20}\,\frac{1}{1 + R_5C_2 s}$$

$$= \frac{A_{10}(1 + R_pC_1 s)(1 + R_5C_2 s) + A_{20}(1 + R_2C_1 s)}{(1 + R_2C_1 s)(1 + R_5C_2 s)}$$

$$= (A_{10} + A_{20})\,\frac{1 + \frac{A_{10}(R_pC_1 + R_5C_2) + A_{20}R_2C_1}{A_{10} + A_{20}}\,s + \frac{A_{10}R_pR_5C_1C_2 s^2}{A_{10} + A_{20}}}{(1 + R_2C_1 s)(1 + R_5C_2 s)}$$

Gli zeri di $A_C(s)$ sono le radici del polinomio a numeratore

$$1 + a_1 s + a_2 s^2 = 0 \qquad a_1 = \frac{A_{10}(R_pC_1 + R_5C_2) + A_{20}\cancel{R_2}C_1}{A_{10} + A_{10}} = 500 \times 10^{-6}\,s$$

$$a_2 = \frac{A_{10}R_pR_5C_1C_2}{A_{10} + A_{20}} = 12 \times 10^{-9}\,s^2$$

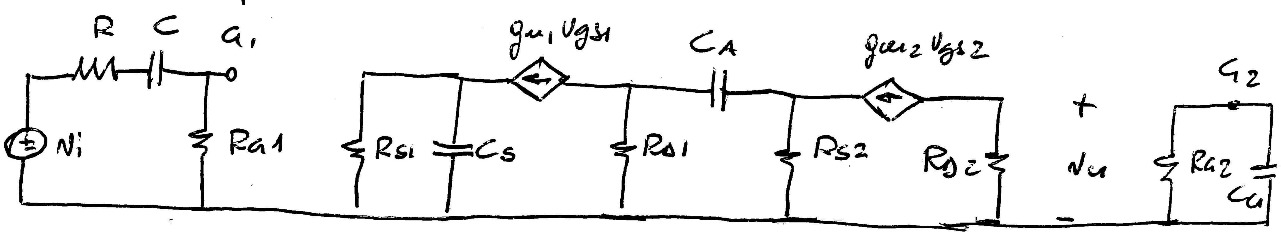
$$s_{z1,2} = \begin{cases} -2{,}106\ \text{krad/s} \\ -39.56\ \text{krad/s} \end{cases}$$

cui corrispondono le frequenze di zero

$$f_{z1} = \frac{|s_{z1}|}{2\pi} = 335{,}3\ \text{Hz} \qquad \text{ed} \qquad f_{z2} = \frac{|s_{z2}|}{2\pi} = 6{,}30\ \text{kHz}$$

ESERCIZIO 3

Circuito per le variazioni



i condensatori sono tutti indipendenti fra loro

C: zero nell'origine + polo

$R_{VC} = R + R_{G1} = 200{,}5\,k\Omega \qquad f_{P_C} = 2.65\ Hz = \dfrac{1}{2\pi C R_{VC}}$

C_S: zero + polo finiti (by-pass, $f_{ZCS} < f_{PCS}$)

$R_{VCS} = R_{S1} /\!/ \dfrac{1}{g_{m1}} = 333\,\Omega \qquad f_{PCS} = \dfrac{1}{2\pi R_{VCS} C_S} = 47.75\ Hz$

C_A: zero nell'origine + polo

$R_{VCA} = R_{D1} + \left(R_{S2} /\!/ \dfrac{1}{g_{m2}}\right) = 3.88\,k\Omega \qquad f_{PCA} = \dfrac{1}{2\pi C_A R_{VCA}} = 82\ Hz$

C_G: zero e polo coincidenti

$R_{VCG} = R_{G2} \qquad f_{PCG} = f_{ZCG} = \dfrac{1}{2\pi C_G R_{VCG}} = 796\ mHz$

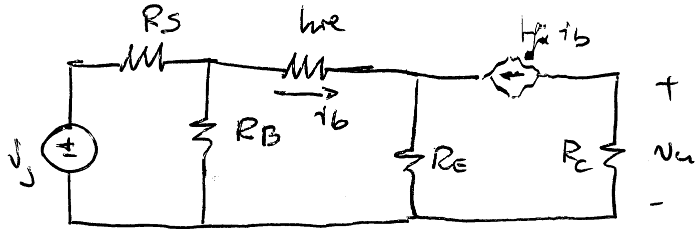
a centro banda (condensatori tutti chiusi):

$$A_{CB} = \frac{v_u}{v_i} = -R_{D2}\, g_{m1} g_{m2} \left(R_{D1} /\!/ R_{S2} /\!/ \frac{1}{g_{m2}}\right) \cdot \frac{R_{G1}}{R_{G1}+R} = -4.68$$

$= 13{,}4\ dB$

ESERCIZIO 4

circuito equivalente



$$A = \frac{-R_C h_{fe}}{(R_S /\!/ R_B) + h_{ie} + R_E(h_{fe}+1)} \quad \frac{R_B}{R_B + R_S}$$

$$S^{A}_{h_{fe}} = \frac{\partial A}{\partial h_{fe}} \frac{h_{fe}}{A} = \frac{(R_S /\!/ R_B) + h_{ie} + R_E}{(R_S /\!/ R_B) + h_{ie} + R_E(h_{fe}+1)}$$

Si tratta di una funzione del tipo $f(R_E) = \dfrac{a + R_E}{a + R_E(h_{fe}+1)}$,

la cui derivata rispetto a R_E $\quad \dfrac{df}{dR_E} = - \dfrac{a\, h_{fe}}{\left[a + R_E(h_{fe}+1)\right]^2}$

è sempre negativa. Dunque $f(R_E)$ è decrescente per ogni valore di R_E, e il suo minimo, che si ha per $R_E \to \infty$ è

$$\min\left[f(R_E)\right] = \frac{1}{h_{fe}+1}.$$

ESERCIZIO 5

$$A(s) = \frac{R_3 C s}{1 + R_3 C s}\left(1 + \frac{R_2}{R_1}\right) - \frac{R_2}{R_1} = \frac{(R_1 + R_2) R_3 C s - R_2(1 + R_3 C s)}{R_1(1 + R_3 C s)}$$

$$= -\frac{R_2}{R_1} \, \frac{1 - \frac{R_1 R_3}{R_2} C s}{1 + R_3 C s}$$

$$A_0 = -\frac{R_2}{R_1} = -4 \quad (12.04\,dB)$$

$$A(f) = A_0 \, \frac{1 - j\, f/f_z}{1 + j\, f/f_p}$$

$$f_z = \frac{R_2}{2\pi R_1 R_3 C} = 3.18\,kHz$$

$$f_p = \frac{1}{2\pi R_3 C} = 796\,Hz$$

Imponendo $|A(f)| = \frac{|A_0|}{2}$ si ottiene

$$f^2\left(\frac{1}{f_p^2} - \frac{4}{f_z^2}\right) - 3 = 0 \quad \Rightarrow \quad f_2 = \sqrt{3\left(\frac{1}{f_p^2} - \frac{4}{f_z^2}\right)^{-1}} = 1.59\,kHz$$