ESERCIZIO 1 (A) 16.11.13

1/7

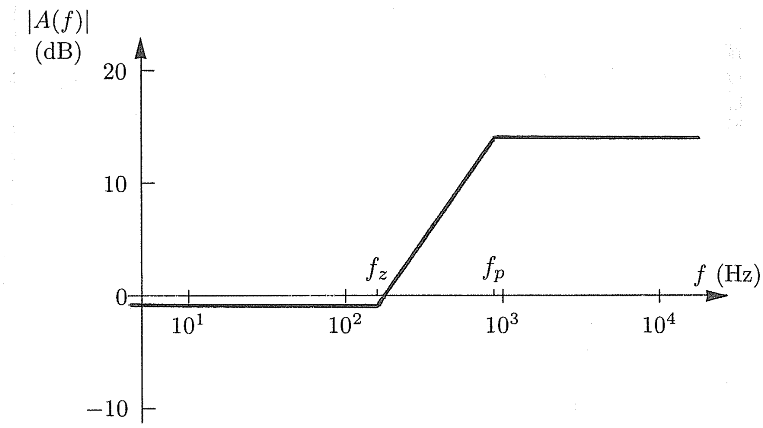
$$A(s) = \frac{R_1}{2R_1}\left(1+\frac{R_4}{R_2+\frac{R_3}{1+R_3Cs}}\right) = \frac{1}{2}\left[1+\frac{R_4(1+R_3Cs)}{R_2+R_3+R_2R_3Cs}\right]$$

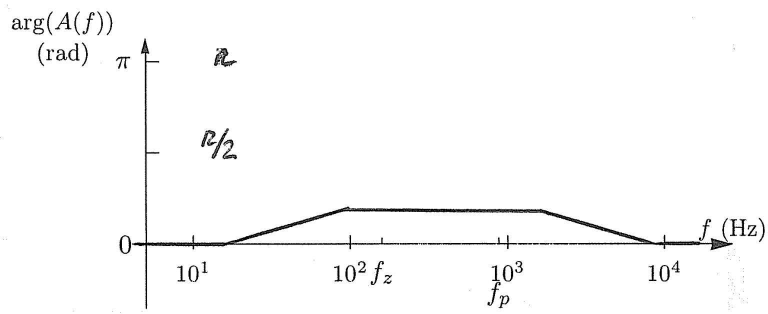
$$= \frac{1}{2}\,\frac{R_2+R_3+R_4+R_3(R_2+R_4)Cs}{R_2+R_3+R_2R_3Cs} = \frac{1}{2}\left(1+\frac{R_4}{R_2+R_3}\right)\frac{1+[R_3 /\!/ (R_2+R_4)]Cs}{1+(R_2 /\!/ R_3)Cs}$$

$$A(f) = A_0\,\frac{1+j\,f/f_z}{1+j\,f/f_p} \qquad A_0 = \frac{1}{2}\left(1+\frac{R_4}{R_2+R_3}\right) = 0{,}909 \quad (= -0{,}828\ \mathrm{dB})$$

$$f_p = \frac{1}{2\pi C(R_2 /\!/ R_3)} = 875{,}35\ \mathrm{Hz} \qquad f_z = \frac{1}{2\pi C[R_3 /\!/ (R_2+R_4)]} = 159.15\ \mathrm{Hz}$$

Diagramma di Bode:





Calcolo del valore di f_d

Imponendo $|A(f)| = 2A_0$, cioè

$$\sqrt{\frac{1+\frac{f^2}{f_z^2}}{1+\frac{f^2}{f_p^2}}} = 2\,, \qquad \text{risolvendo segue} \quad f_d = \sqrt{3\left(\frac{1}{f_z^2}-\frac{4}{f_p^2}\right)^{-1}} = 295{,}9\ \mathrm{Hz}$$

Esercizio 2

$V_U = V^+/2 \Rightarrow I_C = \frac{V^+ - V_U}{R_C} = \frac{V^+}{2R_C} = 3\,mA$ $\quad V_{CE} \simeq V^+ - (R_C+R_E)\,I_C = 6\,V$

dalle caratt. d'uscita si ottiene $I_B \simeq 10.3\,\mu A$

Deve allora essere $V^+\frac{R_4}{R_3+R_4} - (R_3 /\!/ R_4)\,I_B - V_\gamma - R_E(I_C+I_B) = 0$

con la condizione $R_3+R_4 = 100\,k\Omega$ — Risolvendo, si ottiene

$R_4 = 21.6\,k\Omega$

$R_3 = 78.4\,k\Omega$ $\quad R_B = R_1 \| R_2 = 16.92\,k\Omega$ - Nel p.r. $h_{fe} \simeq 278$

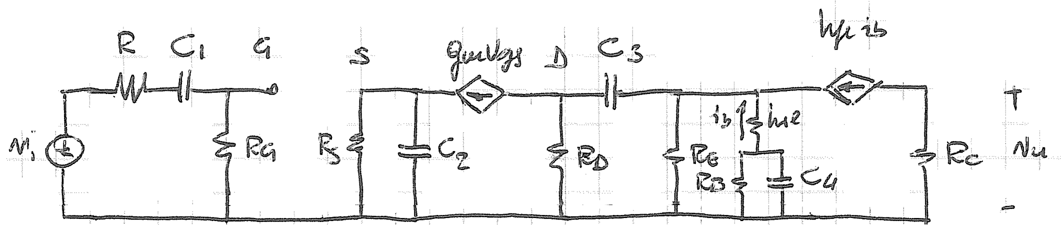
$h_{ie} = r_{bb'} + \frac{V_T}{I_C}\,h_{fe} \simeq 2.9\,k\Omega$

Per il MOSFET:

$V_{GS} = V^+\frac{R_2}{R_1+R_2} - R_S I_D = V^+\frac{R_2}{R_1+R_2} - R_S\frac{k_n}{2}(V_{GS}-V_T)^2$ - Segue $V_{GS} = 2.80\,V$, $I_D = 2.52\,mA$

Inoltre $V_{DS} = V^+ - (R_D+R_S)I_D = 13.42\,V > V_{GS}-V_T$; dunque il MOSFET lavora effettivamente in zona di saturazione. Nel p.r. $g_m = k_n(V_{GS}-V_T) = 3.89\,mS$

Circuito per le variazioni $\quad (R_G = R_1 /\!/ R_2 = 98.55\,k\Omega)$



C_1 (zero nell'origine) e C_2 (zero finito) non interagiscono con gli altri condensatori; per il calcolo delle relative frequenze di polo è possibile impiegare il metodo delle resistenze viste.

$R_{VC_1} = R + R_G = 99.55\,k\Omega$ $\qquad R_{VC_2} = R_S /\!/ 1/g_m = 196\,\Omega$

$f_{PC_1} = \frac{1}{2\pi C_1 R_{VC_1}} \simeq 16.\,Hz$ $\qquad f_{PC_2} = \frac{1}{2\pi C_2 R_{VC_2}} = 81.27\,Hz$

$$f_{ZC_2} = \frac{1}{2\pi C_2 R_S} = 19.41\,Hz$$

C_3 e C_4 interagiscono:

nell'ipotesi $f_{PC_3} \ll f_{ZC_4} < f_{PC_4}$ si utilizzerà il metodo della res. vista con C_4 aperto: $R_{VC_3} = R_D + \left(R_E \parallel \frac{h_{ie}+R_B}{h_{fe}+1} \right) = 1.067\ k\Omega$

$f_{PC_3} = \frac{1}{2\pi C_3 R_{VC_3}} = 2{,}19\ Hz$

con C_3 "chiuso": $R_{VC_4} = R_B \parallel \left[h_{ie} + (R_E \parallel R_D)(h_{fe}+1) \right] = 15.12\ k\Omega$

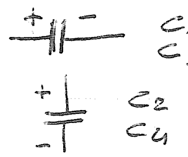
$f_{PC_4} = \frac{1}{2\pi C_4 R_{VC_4}} = 1.052\ kHz$; inoltre $f_{ZC_4} = \frac{1}{2\pi C_4 R_B} = 940{,}6\ Hz$

A centro banda (tutti i condensatori "chiusi")

$$A_{CB} = \frac{v_u}{v_i} = -R_C h_{fe} \cdot \frac{1}{h_{ie}}\, g_m \left(R_D \parallel R_E \parallel \frac{h_{ie}}{h_{fe}+1} \right) \cdot \frac{R_G}{R+R_G} = -11.26 \quad (21.04\ dB)$$

$$A(f) = A_{CB} \frac{f_{ZC_2} f_{ZC_4}}{f_{PC_2} f_{PC_4}} \frac{j\frac{f}{f_{PC_1}}\, j\frac{f}{f_{PC_3}} \left(1+j\frac{f}{f_{ZC_2}}\right)\left(1+j\frac{f}{f_{ZC_4}}\right)}{\left(1+j\frac{f}{f_{PC_1}}\right)\left(1+j\frac{f}{f_{PC_2}}\right)\left(1+j\frac{f}{f_{PC_3}}\right)\left(1+j\frac{f}{f_{PC_4}}\right)}$$

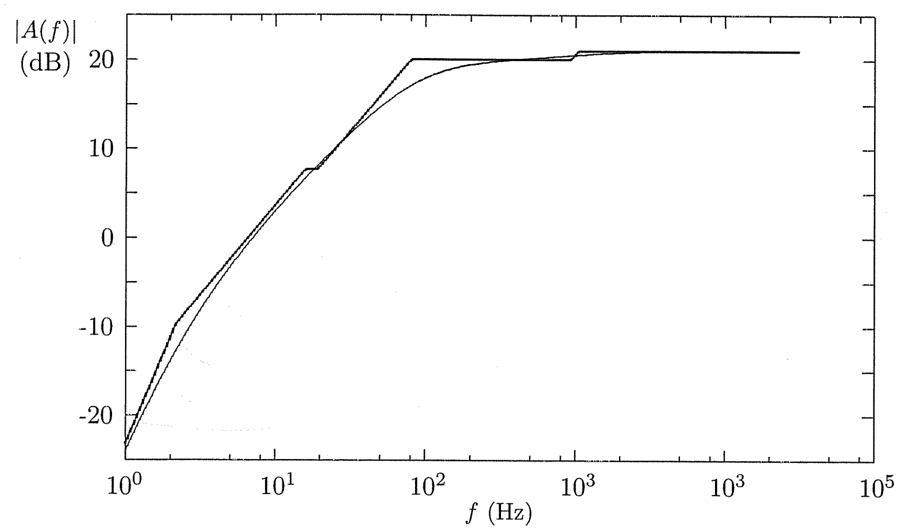
A riposo



$V_{C_1} = -V_G = -V^+ \frac{R_2}{R_1+R_2} = -4.86\ V$ $\qquad V_{C_2} = R_S I_D = 2.07\ V$

$V_{C_3} = V^+ - R_D I_D - R_E (I_C + I_D) = 12.47\ V$ $\qquad V_{C_4} = V^+ \frac{R_4}{R_3+R_4} = 3.89\ V$

Diagramma di Bode (non richiesto)



ESERCIZIO 3

Definite

$$v_d = v_1 - v_2 \qquad \text{e} \qquad v_c = \frac{v_1 + v_2}{2}, \qquad A_1 = \left.\frac{v_u}{v_1}\right|_{v_2=0} \qquad \text{e} \qquad A_2 = \left.\frac{v_u}{v_2}\right|_{v_1=0}$$

segue

$$A_c = \left.\frac{v_u}{v_c}\right|_{v_d=0} = A_1 + A_2 \qquad \text{e} \qquad A_d = \left.\frac{v_u}{v_d}\right|_{v_c=0} = \frac{A_1 - A_2}{2}$$

Per il circuito in questione si ha

$$A_1(s) = \frac{1}{2}\left(1 + \frac{R_4}{R_2 + \dfrac{R_3}{1 + R_3 Cs}}\right) \qquad \text{e} \qquad A_2(s) = -\frac{R_4}{R_2 + \dfrac{R_3}{1 + R_3 Cs}}$$

Così:

$$\begin{aligned}
A_c(s) &= \frac{1}{2}\left(1 + \frac{R_4}{R_2 + \dfrac{R_3}{1 + R_3 Cs}}\right) - \frac{R_4}{R_2 + \dfrac{R_3}{1 + R_3 Cs}} = \frac{1}{2}\left(1 - \frac{R_4}{R_2 + \dfrac{R_3}{1 + R_3 Cs}}\right) \\
&= \frac{1}{2}\left[1 - \frac{R_4(1 + R_3 Cs)}{R_2 + R_3 + R_2 R_3 Cs}\right] \quad = \quad \frac{1}{2}\left[\frac{R_2 + R_3 - R_4 + R_3(R_2 - R_4)Cs}{R_2 + R_3 + R_2 R_3 Cs}\right] \\
&= \frac{1}{2} \cdot \frac{R_2 + R_3 - R_4}{R_2 + R_3} \cdot \frac{1 + \dfrac{R_3(R_2 - R_4)}{R_2 + R_3 - R_4}Cs}{1 + \dfrac{R_2 R_3}{R_2 + R_3}Cs}
\end{aligned}$$

e

$$\begin{aligned}
A_d(s) &= \frac{1}{2}\left[\frac{1}{2}\left(1 + \frac{R_4}{R_2 + \dfrac{R_3}{1 + R_3 Cs}}\right) + \frac{R_4}{R_2 + \dfrac{R_3}{1 + R_3 Cs}}\right] = \frac{1}{4}\left(1 + 3\frac{R_4}{R_2 + \dfrac{R_3}{1 + R_3 Cs}}\right) \\
&= \frac{1}{4}\left[1 + 3\frac{R_4(1 + R_3 Cs)}{R_2 + R_3 + R_2 R_3 Cs}\right] \quad = \quad \frac{1}{4}\left[\frac{R_2 + R_3 + 3R_4 + R_3(R_2 + 3R_4)Cs}{R_2 + R_3 + R_2 R_3 Cs}\right] \\
&= \frac{1}{4} \cdot \frac{R_2 + R_3 + 3R_4}{R_2 + R_3} \cdot \frac{1 + \dfrac{R_3(R_2 + 3R_4)}{R_2 + R_3 + 3R_4}Cs}{1 + \dfrac{R_2 R_3}{R_2 + R_3}Cs}
\end{aligned}$$

Allora

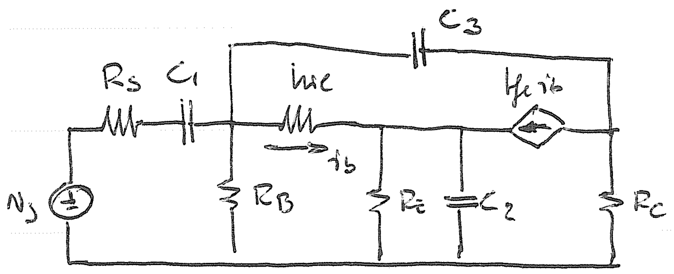
$$\rho(s) = \frac{A_d(s)}{A_c(s)} = \frac{1}{2} \cdot \frac{R_2 + R_3 + 3R_4}{R_2 + R_3 - R_4} \cdot \frac{1 + \dfrac{R_3(R_2 + 3R_4)}{R_2 + R_3 + 3R_4} Cs}{1 + \dfrac{R_3(R_2 - R_4)}{R_2 + R_3 - R_4} Cs}$$

e

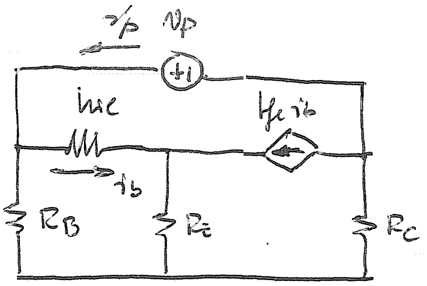
$$\rho(f) = \rho_0 \frac{1 + j\dfrac{f}{f_{z\rho}}}{1 - j\dfrac{f}{f_{p\rho}}}, \qquad \text{con} \qquad \rho_0 = \frac{1}{2} \cdot \frac{R_2 + R_3 + 3R_4}{R_2 + R_3 - R_4} = 9.5 \quad (19.55\,\text{dB}),$$

$$f_{p\rho} = \left| \frac{R_2 + R_3 - R_4}{2\pi C R_3 (R_2 - R_4)} \right| = 19.89\ \text{Hz}, \qquad f_{z\rho} = \frac{R_2 + R_3 + 3R_4}{2\pi C R_3 (R_2 + 3R_4)} = 108\ \text{Hz},$$

ESERCIZIO 4



R_3^0 :



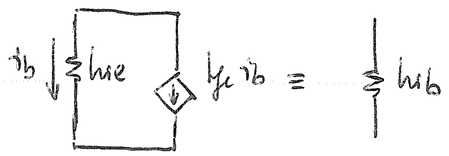
$$i_p = i_b\left[1 + \frac{h_{ie} + R_E(h_{fe}+1)}{R_B}\right]$$

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

$$= i_b\left\{h_{ie} + R_E(h_{fe}+1) + R_C h_{fe} + R_C\left[1 + \frac{h_{ie}+R_E(h_{fe}+1)}{R_B}\right]\right\}$$

$$R_3^0 = \frac{v_p}{i_p} = \frac{h_{ie} + R_E(h_{fe}+1) + R_C\left[h_{fe}+1 + \frac{h_{ie}+R_E(h_{fe}+1)}{R_B}\right]}{1 + \frac{h_{ie}+R_E(h_{fe}+1)}{R_B}} = 48.43\ k\Omega$$

Con C_3 chiuso :



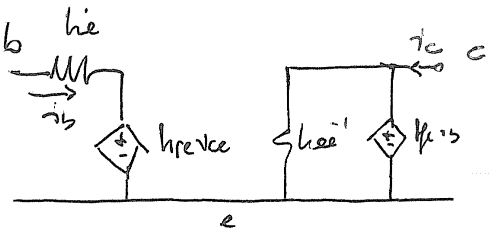
e dunque

$$R_1^3 = R_S + \left[R_B \parallel (h_{ib} + R_E) \parallel R_C\right] = 2.696\ k\Omega$$

$$R_2^3 := R_E \parallel \left[h_{ib} + (R_C \parallel R_B)\right] = 1.195\ k\Omega$$

$$R_1^{23} = R_S + (R_B \parallel h_{ib} \parallel R_C) = 1.508\ k\Omega$$

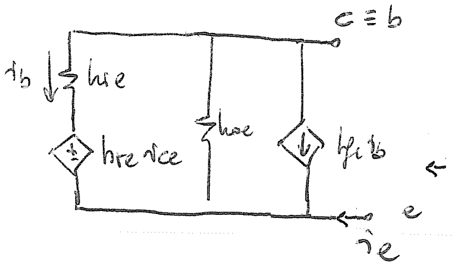
ESERCIZIO 5



$$h_{ib} = \frac{v_{eb}}{i_e}\bigg|_{v_{cb}=0} \qquad h_{fb} = \frac{i_c}{i_e}\bigg|_{v_{cb}=0}$$

$$h_{rb} = \frac{v_{eb}}{v_{cb}}\bigg|_{i_e=0} \qquad h_{ob} = \frac{i_c}{v_{cb}}\bigg|_{i_e=0}$$

* con $v_{cb} = 0$



$$i_e = -i_b(h_{fe}+1) - h_{oe} v_{ce}$$

$$v_{ce} = h_{ie} i_b + h_{re} v_{ce}$$

$$v_{ce} = \frac{h_{ie} i_b}{1-h_{re}}$$

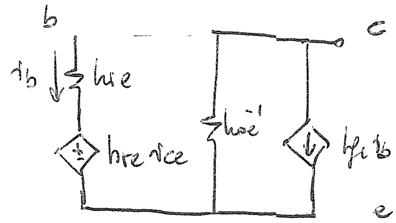
$$\to i_e = -i_b\left(h_{fe}+1+\frac{h_{oe}h_{ie}}{1-h_{re}}\right)$$

$$h_{ib} = \frac{v_{eb}}{i_e}\bigg|_{v_{cb}=0} = \frac{-v_{ce}}{i_e}\bigg|_{v_{cb}=0} = \frac{h_{ie}}{1-h_{re}}\left(h_{fe}+1+\frac{h_{oe}h_{ie}}{1-h_{re}}\right)^{-1}$$

$$= \frac{h_{ie}}{(h_{fe}+1)(1-h_{re})+h_{oe}h_{ie}} = 11.37\ \Omega$$

$$h_{fb} = \frac{i_c}{i_e}\bigg|_{v_{cb}=0} = -\frac{h_{fe}i_b + h_{oe}v_{ce}}{i_b\left(h_{fe}+1+\frac{h_{oe}h_{ie}}{1-h_{re}}\right)} = -\frac{h_{fe}+\frac{h_{oe}h_{ie}}{1-h_{re}}}{h_{fe}+1+\frac{h_{oe}h_{ie}}{1-h_{re}}} = -0.994$$

* con $i_e = 0$ $\quad (i_c = -i_b)$



$$v_{eb} = -h_{ie} i_b - h_{re} v_{ce} = -h_{ie} i_b + h_{re}\frac{(h_{fe}+1)\,i_b}{h_{oe}}$$

$$v_{cb} = -h_{ie} i_b - h_{re} v_{ce} + v_{ce} = -h_{ie} i_b + (h_{re}-1)\frac{(h_{fe}+1)\,i_b}{h_{oe}}$$

$$i_c = h_{fe} i_b + h_{oe} v_{ce} = h_{fe} i_b + h_{oe}\frac{(h_{fe}+1)\,i_b}{h_{o}} = -i_b$$

Così
$$h_{rb} = -\frac{-h_{ie} + h_{re}\frac{(h_{fe}+1)}{h_{oe}}}{h_{ie} + \frac{(1-h_{re})(h_{fe}+1)}{h_{oe}}} = \frac{h_{oe}h_{ie} - h_{re}(h_{fe}+1)}{h_{oe}h_{ie} + (1-h_{re})(h_{fe}+1)} = -932.7\times 10^{-6}$$

$$h_{ob} = \frac{+1}{h_{ie} + (1-h_{re})\frac{h_{fe}+1}{h_{oe}}} = \frac{h_{oe}}{h_{ie}h_{oe} + (1-h_{re})(h_{fe}+1)} = 284.4\times 10^{-9}\ \Omega^{-1}$$