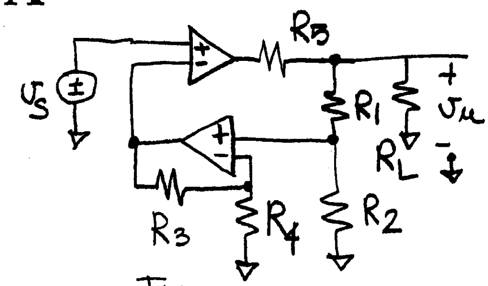
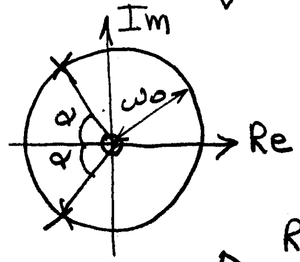
Esame di Elettronica - Corso di Laurea in Ingegneria delle Telecomunicazioni
14 luglio 2004

Parte A FILA A

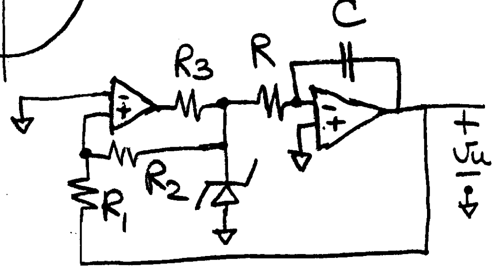
1. Calcolare la funzione di trasferimento e la resistenza di uscita del circuito in reazione mostrato a lato. Si supponga che i due amplificatori operazionali siano amplificatori di tensione ideali, con A_v=1000. Altri dati del problema R_1=1KΩ, R_2=2KΩ, R_3=3KΩ, R_4=4KΩ, R_5=5KΩ, R_L=500Ω.



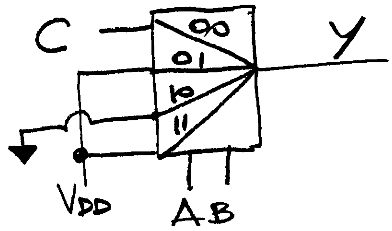
2. Si realizzi il filtro che abbia i poli e gli zeri illustrati in figura. Ricavare la funzione di trasferimento del filtro e quotare tutti i componenti per ottenere le singolarità richieste.
ω_0 = 6.28Krad/s, $\alpha = \pi/3$.



3. Mostrare il funzionamento del circuito mostrato a lato, disegnando e quotando l'andamento delle tensioni all'uscita dei due operazionali. Giustificare il procedimento. [R_1=10KΩ, R_2=10KΩ, R_3=3KΩ, R=1KΩ, C=1μF, Vz=4.7V]



4. Disegnare e quotare la porta complessa CMOS che svolga la stessa funzione logica del circuito mostrato a lato.



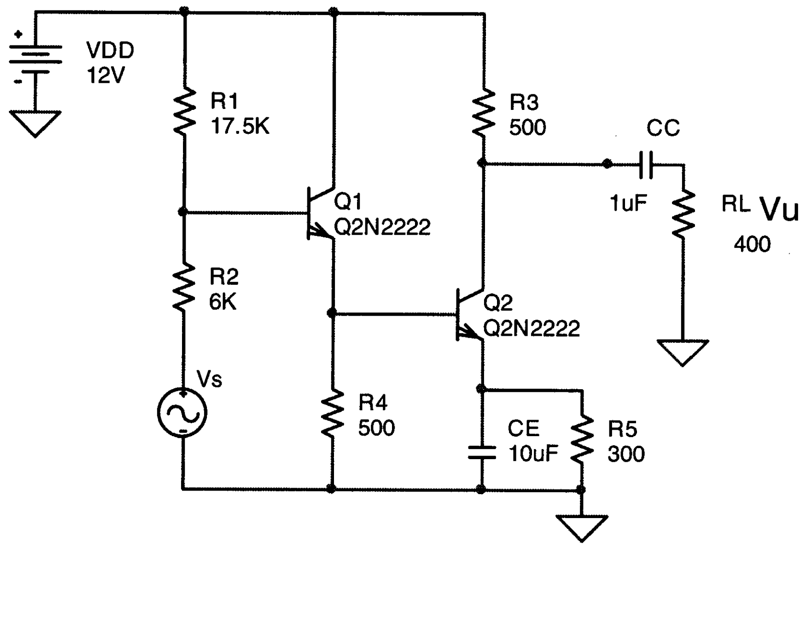
Punteggio totale Parte A: 14

Parte B FILA A

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
- il limite inferiore di banda.

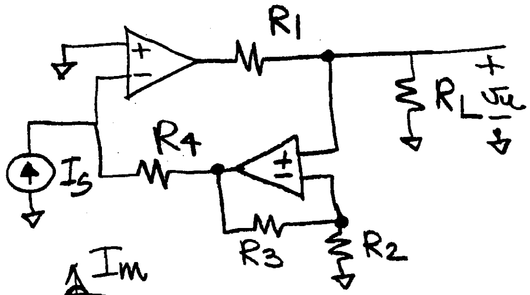
Punteggio totale Parte B: 14/30



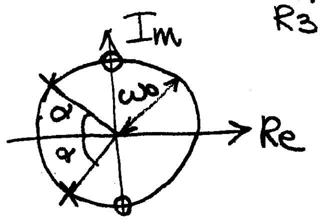
Esame di Elettronica - Corso di Laurea in Ingegneria delle Telecomunicazioni
14 luglio 2004

Parte A FILA B

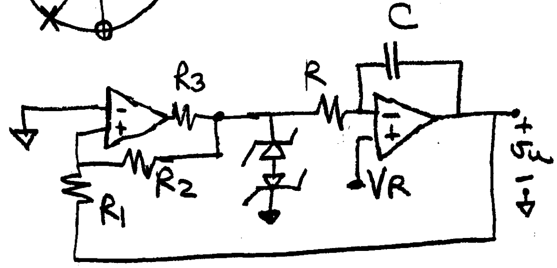
1. Calcolare la funzione di trasferimento e la resistenza di uscita del circuito in reazione mostrato a lato. Si supponga che i due amplificatori operazionali siano amplificatori di tensione ideali, con A_v=1000. Altri dati del problema R_1=1KΩ, R_2=2KΩ, R_3=3KΩ, R_4=4KΩ, R_L=500Ω.



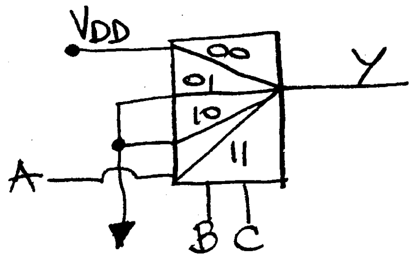
2. Si realizzi il filtro che abbia i poli e gli zeri illustrati in figura. Ricavare la funzione di trasferimento del filtro e quotare tutti i componenti per ottenere le singolarità richieste.
ω_0 = 6.28Krad/s, $\alpha = \pi/4$



3. Mostrare il funzionamento del circuito mostrato a lato, disegnando e quotando l'andamento delle tensioni all'uscita dei due operazionali. Giustificare il procedimento. [R_1=10KΩ, R_2=10KΩ, R_3=3KΩ, R=1KΩ, C=1μF, Vz=4.7V, Vr=3V]



4. Disegnare e quotare la porta complessa CMOS che svolga la stessa funzione logica del circuito mostrato a lato.

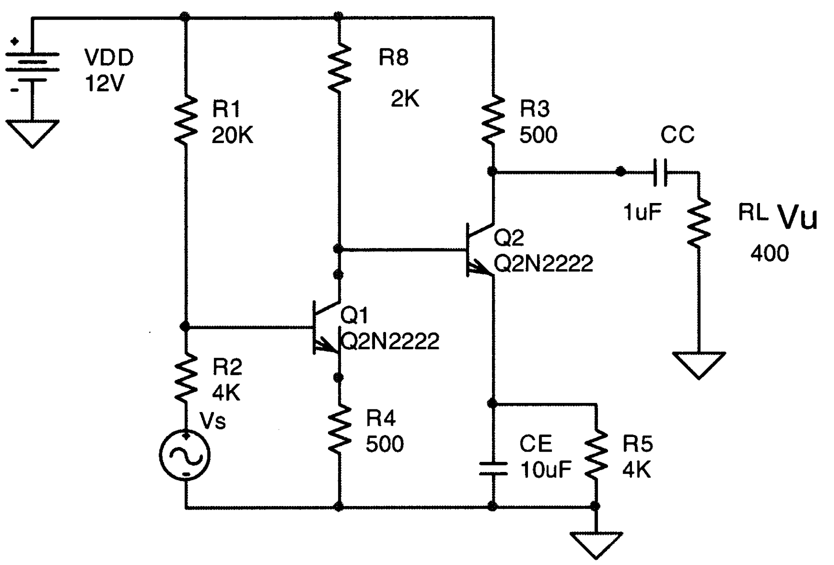


Punteggio totale Parte A: 14

Parte B FILA B

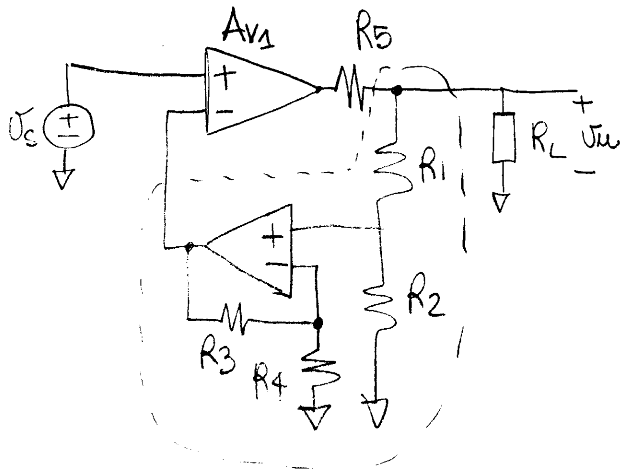
Con riferimento al circuito mostrato a lato, calcolare:

- 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
- il limite inferiore di banda.



Punteggio totale Parte B: 14/30

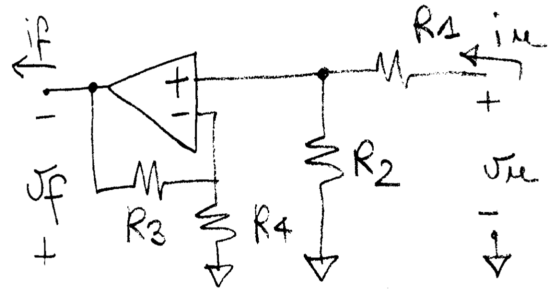
Esercizio 1 - FILA A



$R_1 = 1K\Omega$
$R_2 = 2K\Omega$
$R_3 = 3K\Omega$
$R_4 = 4K\Omega$
$R_5 = 5K\Omega$
$R_L = 500\Omega$
$A_{v_1} = 1000$

Prelievo di tensione e inserzione di tensione

Rete per β



$v_f = \beta v_u + R_{of} i_f$

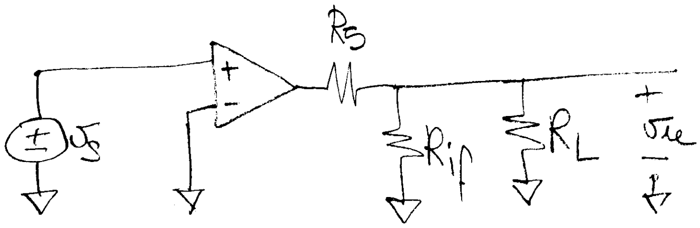
$i_u = \frac{v_u}{R_o\beta} + \cancel{K_1 i_f}$

$$\beta = \left.\frac{v_f}{v_u}\right|_{i_f=0} = \frac{R_2}{R_1+R_2}\left(1+\frac{R_3}{R_4}\right) = \frac{2}{3}\left(1+\frac{3}{4}\right) = \frac{7}{6} \simeq 1.17$$

$$R_{of} = \left.\frac{v_f}{i_f}\right|_{v_u=0} = 0$$

$$R_{if} = \left.\frac{v_u}{i_u}\right|_{i_f=0} = R_1 + R_2 = 3K\Omega$$

Rete per Ae



$$A_e = \frac{v_u}{v_s} = \frac{A_{v1}\, R_L /\!/ R_{if}}{R_L /\!/ R_{if} + R_5} = \frac{428.6 \cdot 10^3}{428.6 + 5000} = 78.9$$

$$A_F = \frac{A_e}{1-\beta A_e} = \underline{\underline{0.846}}$$

②

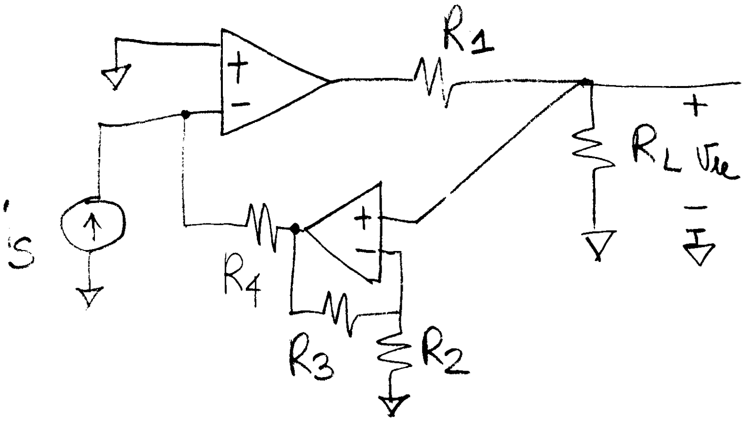
Resistenza di uscita

$$A_{eo} = A_{V1} \frac{R_{if}}{R_{if}+R_5} = 10^3 \cdot \frac{3}{8} = 375$$

↑ R_L rimosso

$$R_{OF} = \frac{(R_{if} // R_5)}{1-\beta A_e} = \frac{1875}{439.75} = 4.26\ \Omega$$

FILA B



$R_1 = 1K\Omega$

$R_2 = 2K\Omega$

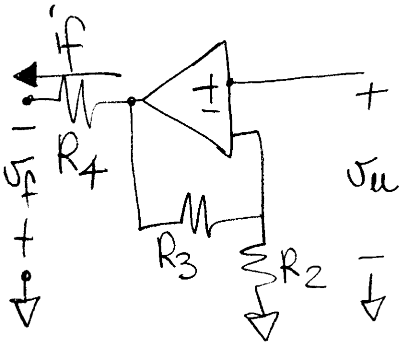
$R_3 = 3K\Omega$

$R_4 = 4K\Omega$

$R_L = 500\ \Omega$

Prelievo di tensione e inserzione di corrente

Rete per β



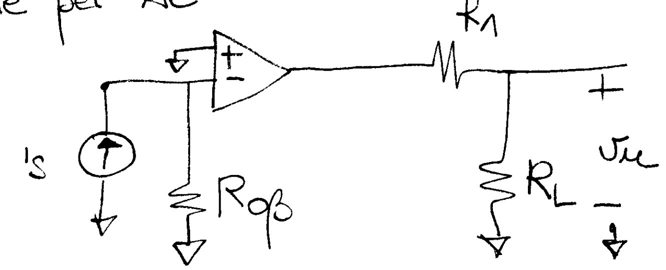
$$i_f = \beta v_u + \frac{v_f}{R_{o\beta}}$$

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

$$\beta = \left.\frac{i_f}{v_u}\right|_{v_f=0} = \left(1+\frac{R_3}{R_2}\right)\frac{1}{R_4} = \frac{5}{8 \cdot 10^3} = 0.625 \cdot 10^{-3}\ \Omega^{-1}$$

$$R_{o\beta} = \left.\frac{v_f}{i_f}\right|_{v_u=0} = R_4 \qquad R_{i\beta} = \frac{v_u}{i_u} \to \infty$$

Rete per Ae



$$A_e = \left.\frac{v_u}{i_s}\right|_{\beta=0} = -R_{o\beta}\, A_{v_1} \frac{R_L}{R_1+R_L} = -4\cdot 10^3 \cdot 10^3 \cdot \frac{500}{1500} = -1.33\cdot 10^6\,\Omega$$

$$A_F = \frac{A_e}{1-\beta A_e} = \frac{-1{,}33\cdot 10^6}{1+0{,}625\cdot 10^{-3}\cdot 1{,}33\cdot 10^6} = \underline{1598\,\Omega}$$

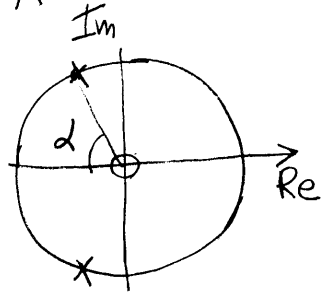
$$A_{e0} = -R_{o\beta} A_{v_1} = -4\cdot 10^6\,\Omega$$

↑ rimosso R_L

$$R_{oF} = \frac{R_1}{(1-\beta A_{e0})} = \frac{1000}{834.3} = \underline{1.199\,\Omega}$$

ESERCIZIO 2

FILA A



$\alpha = \pi/3$

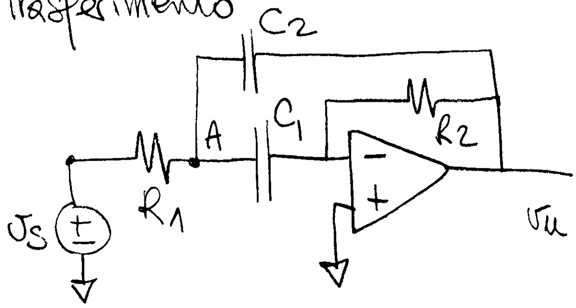
il filtro che vogliamo ottenere è un passabanda

$$H(s) = \frac{H_{CB}\frac{s}{\omega_0 Q}}{\frac{s^2}{\omega_0^2} + \frac{s}{\omega_0 Q} + 1}$$

$$\frac{\omega_0}{Q} = 2\cos\alpha\, \omega_0 \rightarrow \quad Q = \frac{1}{2\cos\alpha} \not> 1$$

$$\omega_0 = 6.28\cdot 10^3 \text{ rad/s}$$

usiamo un filtro passabanda e ricaviamo la funzione di trasferimento



$$v_u = -R_2 C_1 s \; v_A$$

$$v_A\left(\frac{1}{R_1} + C_1 s + C_2 s\right) - \frac{v_S}{R_1} - C_2 s \, v_u = 0$$

$$v_u\left(1 + R_1 C_1 s + R_1 C_2 s\right) + R_2 C_1 s \, v_S + R_1 R_2 C_1 C_2 s^2 \, v_u = 0$$

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

$$\omega_0^2 = \frac{1}{R_1 R_2 C_1 C_2}$$

$$\frac{\omega_0}{Q} = \frac{1}{R_1 (C_1 + C_2)} \rightarrow Q = \frac{\sqrt{R_1 R_2 C_1 C_2}}{R_1 (C_1 + C_2)}$$

poniamo $C_1 = C_2 = C$

$$\omega_0^2 = \frac{1}{R_1 R_2 C^2} \qquad Q = \frac{1}{2}\sqrt{\frac{R_2}{R_1}}$$

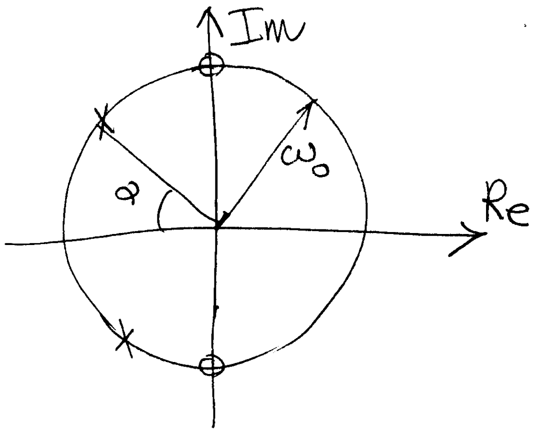
se vogliamo $Q = 1 \rightarrow R_2 = 4R_1$

$$\omega_0^2 = \frac{1}{4 R_1^2 C^2} \rightarrow \omega_0 = \frac{1}{2 R_1 C}$$

poniamo $R_1 = 1 k\Omega \rightarrow C = \frac{1}{2 R_1 \omega_0} = 79.6 \, nF$

$\rightarrow R_2 = 4 k\Omega$

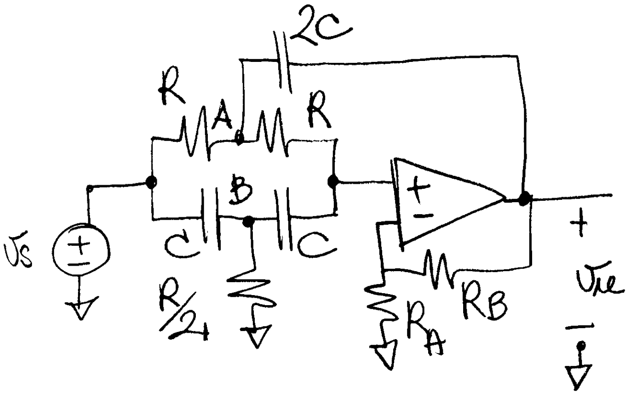
FILA B



2 zeri immaginari puri +
2 poli c.c.

$$H(s) = \frac{\left(\frac{s}{\omega_0}\right)^2 + 1}{\left(\frac{s}{\omega_0}\right)^2 + \frac{s}{Q\omega_0} + 1}$$

$\omega_0 = 6.28 \cdot 10^3$ rad/s, $Q = \frac{1}{2\cos\varphi} = \frac{1}{\sqrt{2}}$



$$A_V = 1 + \frac{R_B}{R_A}$$

equazioni ai nodi

$$v_A\left(\frac{2}{R} + 2Cs\right) - v_S\frac{1}{R} - 2Cs\,v_u - \frac{1}{R}\frac{v_u}{A_V} = 0$$

$$v_B\left(\frac{2}{R} + 2Cs\right) - v_S Cs - \frac{Cs\,v_u}{A_V}$$

$$\frac{v_A + v_B RCs}{RCs + 1} = \frac{v_u}{A_V}$$

$$\left(\frac{2}{R} + 2Cs\right)\frac{v_u}{A_V}(RCs+1) - v_S\left(\frac{1}{R} + RC^2s^2\right) - v_u\left[2Cs + \frac{1}{R}A_V + \frac{RC^2s^2}{A_V}\right] = 0$$

$$v_u\left[2\left(1 + 2RCs + R^2C^2s^2\right) - 2RCsA_V - 4 - R^2C^2s^2\right] = v_S\left(1 + R^2C^2s^2\right)$$

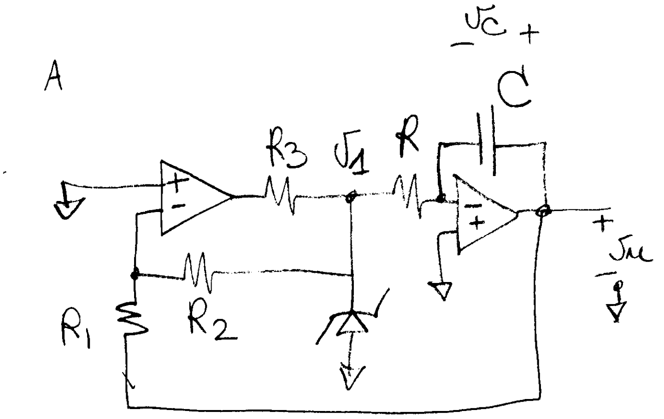
$$\frac{v_u}{v_S} = \frac{1 + R^2C^2s^2}{R^2C^2s^2 + 2(2 - A_V)RCs + 1} \rightarrow \omega_0 = \frac{1}{RC}$$

$$2(2 - A_V) = \frac{1}{Q} = 2\cos\varphi \rightarrow A_V = 2 - \frac{\sqrt{2}}{2} = 1{,}29$$

$R = 1\,k\Omega$, $C = 159\,nF$, $R_A = 10\,k\Omega$, $R_B = 2{,}9\,k\Omega$

ESERCIZIO 3

FILA A



$R_1 = 10\,k\Omega$

$R_2 = 10\,k\Omega$

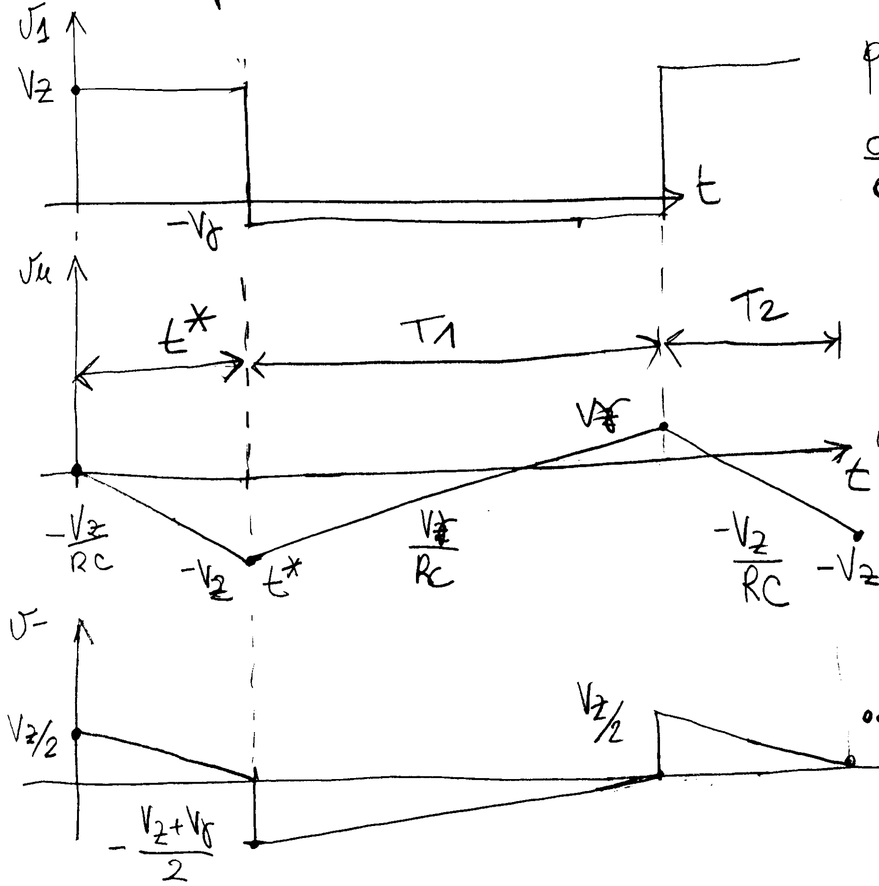
$R_3 = 3\,k\Omega$

$R = 1\,k\Omega$

$C = 1\,\mu F$

$RC = 10^{-3}\,s$

poniamo che per $t=0$ $v_C = v_u = 0$, e $v_1 = V_Z$



per $t>0$

$$\frac{dv_u}{dt} = -\frac{1}{RC} V_Z$$

$$v^- = \frac{v_1 + v_u}{2}$$

quando $v^- = 0$ si ha la commutazione (cioè per $v_u = V_Z$)

se $v_1 = -V_\gamma$

$$\dots \frac{dv_u}{dt} = \frac{V_\gamma}{RC}$$

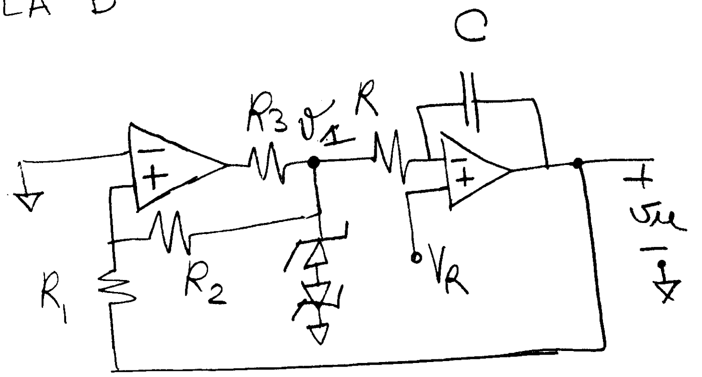
[nuova commutazione per $v_u = V_\gamma$]

$$T_1 = \frac{V_Z + V_\gamma}{V_\gamma / RC} = RC\,\frac{V_Z + V_\gamma}{V_\gamma} = 10^{-3}\,\frac{5.4}{0.7} = 7{,}7\ ms$$

$$T_2 = \frac{V_\gamma + V_Z}{V_Z / RC} = RC\,\frac{V_Z + V_\gamma}{V_Z} = 10^{-3}\,\frac{5.4}{4.7} = 1.15\ ms$$

$$t^* = \frac{V_Z}{V_Z}\,RC = \underline{1\,ms}$$

FILA B



$R_1 = R_2 = 10\,K\Omega$

$R_3 = 3\,K\Omega$

$R = 1\,K\Omega$

$C = 1\,\mu F$

$V_R = 3\,V$

$V_Z = 4.7\,V$

per $t=0$ poniamo che la capacità sia scarica. Abbiamo $v_u = V_R$.

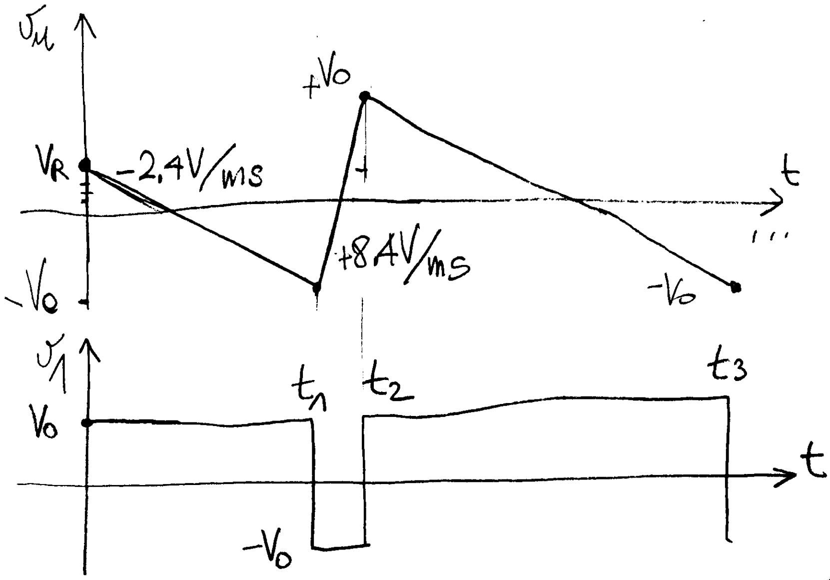
Poniamo che l'uscita del trigger di Schmitt sia alta.

$v_1 = V_\gamma + V_Z = 5.4\,V = V_0$

la corrente che carica la capacità è $\frac{v_1 - V_R}{R} = \frac{V_0 - V_R}{R}$

abbiamo $\frac{dv_u}{dt} = -\frac{V_0 - V_R}{RC} = -2.4\,V/ms$

dato che $R_1 = R_2$ il trigger commuta se $v_u = -v_1$.



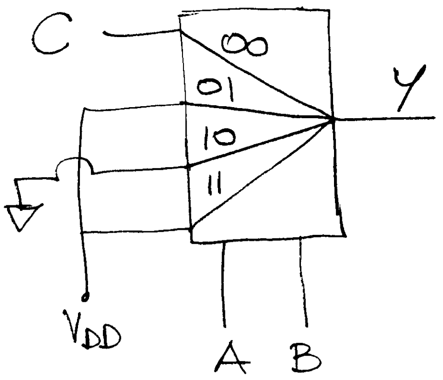
Quando l'uscita del trigger di Schmitt è bassa abbiamo $\frac{dv_u}{dt} = \frac{V_0 + V_R}{RC} = 8.4\,V/ms$

abbiamo

$$t_1 = \frac{V_R + V_0}{(V_0 - V_R)/RC} = \frac{8.4}{2.4} = 3{,}5\ ms$$

$$t_2 - t_1 = \frac{2V_0}{V_0 + V_R} RC = \frac{10.8}{8.4} = 1.29\ ms$$

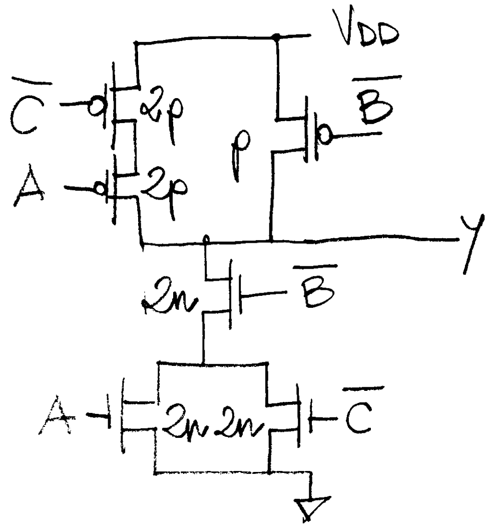
$$t_3 - t_2 = \frac{2V_0}{V_0 - V_R} RC = \frac{10{,}8}{2{,}4} = 4.5\ ms$$



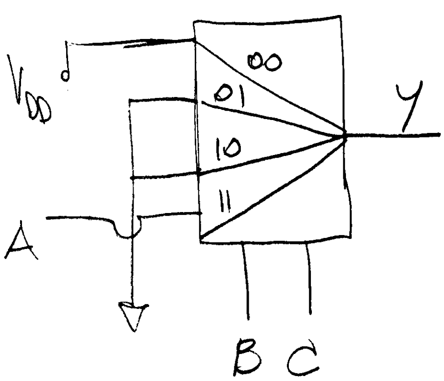
$$Y = C\bar{A}\bar{B} + \bar{A}B + AB =$$
$$= C\bar{A}\bar{B} + B$$

C \ AB	00	01	11	10
0	0	1	1	0
1	1	1	1	0

$$Y = C\bar{A} + B$$

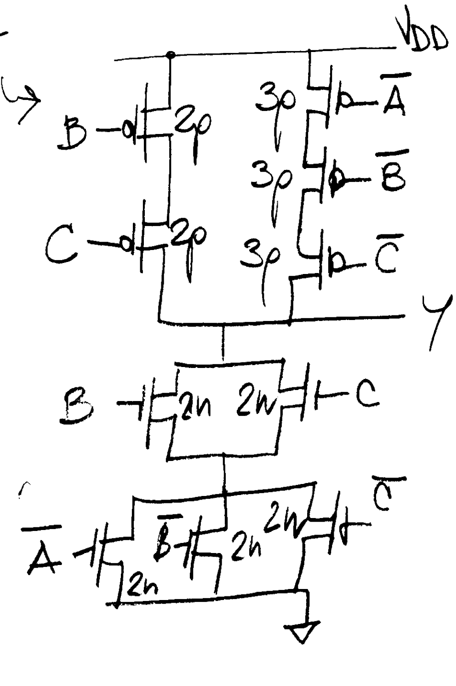


FILA B

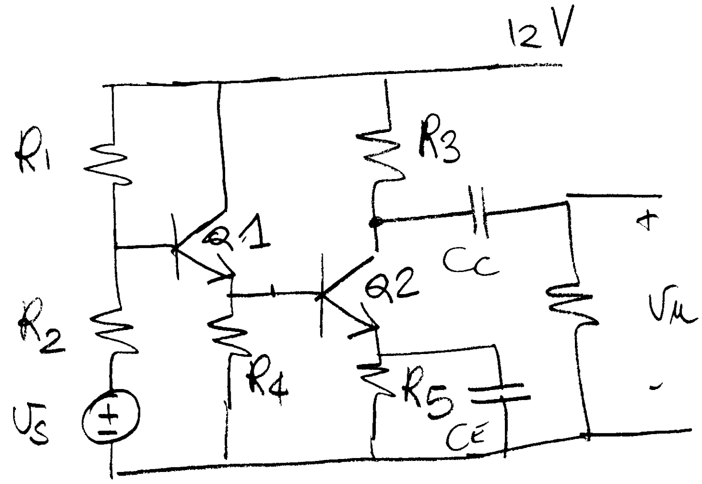


$$Y = \bar{B}\bar{C} + ABC$$

C \ AB	00	01	11	10
0	1	0	0	1
1	0	0	1	0



PARTE B Fila A



$R_1 = 17{,}5\,k\Omega$
$R_2 = 6\,k\Omega$
$V = 12\,V$
$R_4 = 500\,\Omega$
$R_5 = 300\,\Omega$
$R_3 = 500\,\Omega$
$R_L = 400\,\Omega$

$C_C = 1\mu F$
$C_E = 10\mu F$

$$V_{B1} = \frac{R_2}{R_1+R_2} V_{CC} = \frac{6}{6+17{,}5} \cdot 12 = 3{,}06\,V$$ Hp partitore pesante Q1

$$V_{E1} = V_{B1} - V_\gamma = 2{,}36\,V$$

Hp: $I_{R_4} \gg I_{B2}$

$$I_{C_1} \cong I_{R_4} = \frac{V_{E1}}{R_4} = 4.72\,mA$$

$$V_{CE_1} = 12 - 2{,}36 = 9{,}64\,V$$

$$h_{FE_1} = 180$$

$$I_{B_1} = \frac{I_{C1}}{h_{FE_1}} = 26.2\,\mu A \qquad \frac{V_{CC}}{R_1+R_2} = 510.7\,\mu A \gg I_{B1}$$ → Verificata l'Hp per il partitore A

$$V_{E2} = V_{E1} - V_\gamma = 2{,}36 - 0{,}7 = 1{,}66\,V$$

$$I_{E_2} \sim I_{C_2} = \frac{V_{E2}}{R_5} = \frac{1{,}66}{300} = 5{,}53 \cdot 10^{-3}\,A$$

$$h_{FE_2} = 190$$

$$I_{B2} = \frac{I_{C2}}{h_{FE_2}} = \frac{5{,}53 \cdot 10^{-3}}{190} = 29.1\,\mu A \ll I_{R4}$$

$$V_{C2} = V_{CC} - R_3 I_{C_2} = 12 - 500 \cdot 5{,}53 \cdot 10^{-3} = 9{,}235\,V$$

$$V_{CE2} = V_{C2} - V_{E2} = 7{,}575\,V$$

prendiamo $r_{b1} @ 1mA = h_{ie} @ 1mA - h_{fe} @ 1mA \cdot \frac{V_T}{1mA} =$

$$= 5000 - \frac{175 \cdot 26 \cdot 10^{-3}}{10^{-3}} = \underline{\underline{450\Omega}}$$

usiamo $r_b = 450$ anche per i punti di riposo di circa 5 mA

$$g_{m1} = \frac{I_{C1}}{V_T} = \frac{4{,}72 \cdot 10^{-3}}{26 \cdot 10^{-3}} = 0{,}181 \ A/V$$

$$r_{\pi 1} = \frac{h_{fe1}}{g_{m1}} = \frac{175}{0{,}181} = 966{,}9\ \Omega$$

$$h_{ie1} = r_b + r_{\pi 1} = 450 + 966{,}9 = \underline{1416{,}9\ \Omega}$$

$$V_A = \frac{1mA}{h_{oe}@1mA} = \frac{10^{-3}}{20 \cdot 10^{-6}} = 50\ V$$

$\frac{1}{h_{oe1}} = \frac{V_A}{I_{C1}} = \frac{50}{4{,}72 \cdot 10^{-3}} = 10{,}6\ K\Omega \gg R_4$ quindi è trascurabile

$$g_{m2} = \frac{I_{C2}}{V_T} = \frac{5{,}53 \cdot 10^{-3}}{26\ 10^{-3}} = 0{,}213\ \Omega^{-1}$$

$$r_{\pi 2} = \frac{h_{fe2}}{g_{m2}} = \frac{175}{0{,}213} = 821{,}6\ \Omega$$

$$h_{ie2} = r_{\pi 2} + r_b = 821{,}6 + 450 = 1271{,}6\ \Omega$$

$$\frac{1}{h_{oe2}} = \frac{V_A}{I_{C2}} = \frac{50}{5{,}53 \cdot 10^{-3}} = 9041{,}6\ \Omega$$

$$V_{CB1} = V_{CE1} - V_\gamma = 8{,}94V \rightarrow C_{\mu 1} = 4pF$$

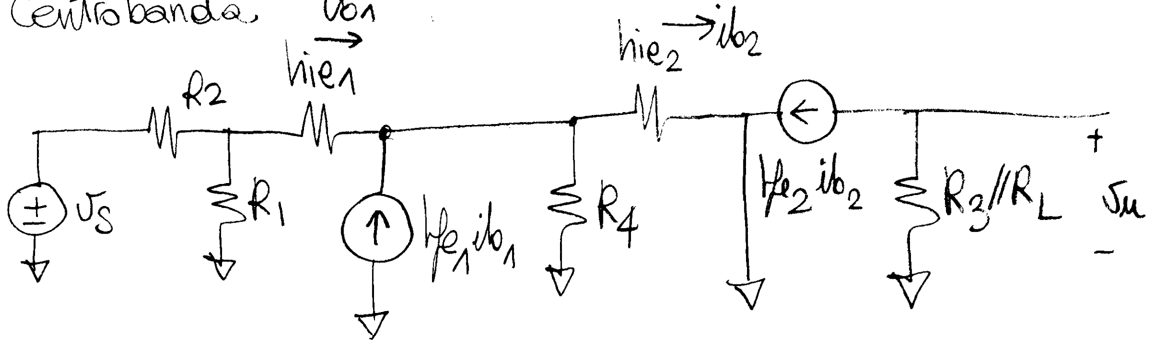
$$V_{CB2} = V_{CE2} - V_\gamma = 6{,}875V \rightarrow C_{\mu 2} = 4{,}3pF$$

$f_{T1} = f_{T2} = 230$ MHz $\rightarrow$ $C_{\pi 1} = \frac{g_{m1}}{2\pi f_{T1}} - C_{\mu 1} = 125{,}3 - 4 = 121{,}3\,pF$

$$f_{T1} = \frac{g_{m1}}{2\pi (C_{\pi 1} + C_{\mu 1})}$$

$$C_{\pi 2} = \frac{g_{m2}}{2\pi f_{T2}} - C_{\mu 2} = 147{,}5 - 4{,}3 = 143{,}2\,pF$$

Centrobanda



$$\frac{v_u}{v_S} = -\frac{R_1}{R_1+R_2} \cdot \frac{(R_4 // h_{ie2})(h_{fe1}+1)}{R_2 // R_1 + h_{ie1} + R_4 // h_{ie2}(h_{fe}+1)} \cdot \frac{h_{fe2}\, R_3 // R_L}{h_{ie2}}$$

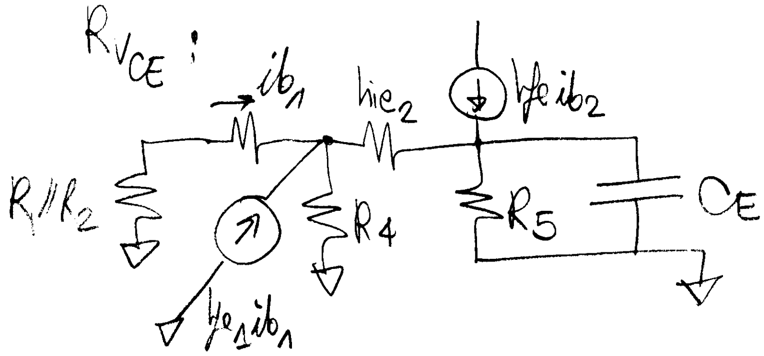
$$= -\frac{17{,}5}{17.5+6} \cdot \frac{358.9\,(176)}{4468 + 1416{,}9 + 358.9\,(176)} \cdot \frac{176 \cdot 222}{1271.6} =$$

$$\frac{v_u}{v_S} = -0{,}7447 \cdot 0{,}915 \cdot 30.73 = -20.93$$

limite inferiore di banda

$$R_{V_{Cc}} = R_3 + R_L = 900\,\Omega$$

$R_{V_{CE}}$:



$$R_{V_{CE}} = R_5 // \frac{\left[h_{ie2} + R_4 // \left[\frac{h_{ie1} + R_1 // R_2}{h_{fe1}+1} \right] \right]}{h_{fe2}+1} =$$

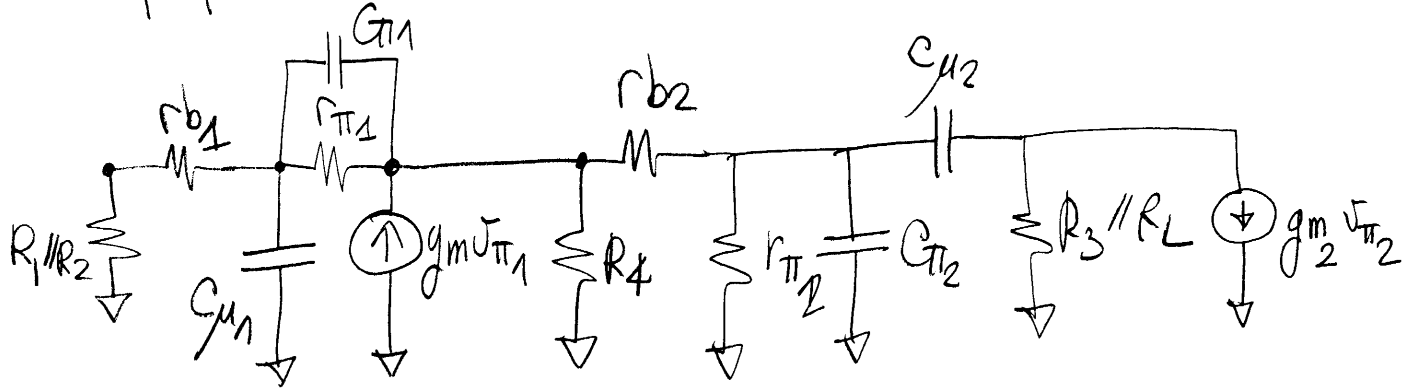
$$= 300 // \left[\frac{1271{,}6 + 500 // 33.4}{176} \right] =$$

$$= 300 // 7{,}4 = \underline{7{,}22\,\Omega}$$

$$f_L = \frac{1}{2\pi} \left[\frac{1}{R_{V_{Cc}} C_c} + \frac{1}{R_{V_{CE}} C_E} \right] =$$

$$= \frac{1}{6{,}28} \left[\frac{1}{900 \cdot 10^{-6}} + \frac{1}{7{,}22 \cdot 10^{-6} \cdot 10} \right] = \underline{\underline{2382\ Hz}}$$

Alte frequenze



$$Rv_{\pi_2} = + r_{\pi_2} // \left[rb_2 + R_4 // \left[\frac{r_{\pi_1} + rb_1 + R_1//R_2}{1 + g_m r_{\pi_1}} \right] \right] =$$

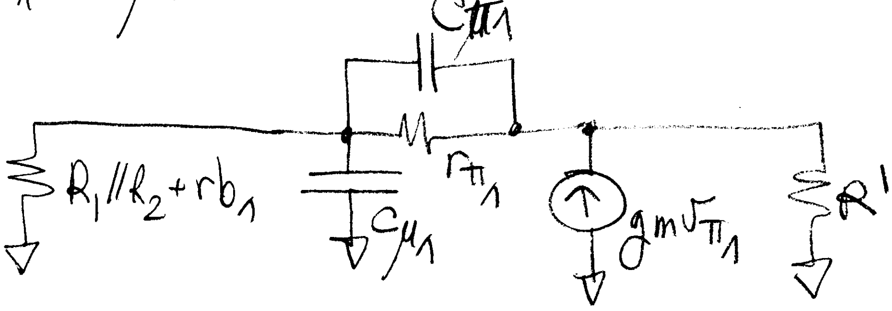
$$= 821.6 // \left[450 + 500 // 33.4 \right] =$$

$$= 821.6 // 481{,}34 = 303.5\ \Omega$$

$$Rv_{\mu_2} = Rv_{\pi_2} \left(1 + g_{m_2} (R_3 // R_L) \right) + R_3 // R_L =$$

$$303.5 \left(1 + 47.3 \right) + 222 = 14.88\ K\Omega$$

Rv_{π_1} e Rv_{μ_1}



$$R' = R_4 // \left[rb_2 + r_{\pi_2} \right] = 500 // 1271.6 = 358.9\ \Omega$$

$$Rv_{\pi_1} = r_{\pi_1} // \left[\frac{R' + R_1//R_2 + rb_1}{1 + g_{m_1} R'} \right] =$$

$$= 966.9 // \left[\frac{358.9 + 4468 + 450}{65{,}96} \right] = 966{,}9 // 80 = 73{,}9\ \Omega$$

$$R_{V\mu_1} = (R_1 // R_2 + r_{b_1}) // \left[r_{\pi_1} + (1 + g_{m_1} r_{\pi_1}) R' \right] =$$

$$= (4468 + 450) // (966{,}9 + 176 \cdot 358{,}9) = \underline{4567{,}7\ \Omega}$$

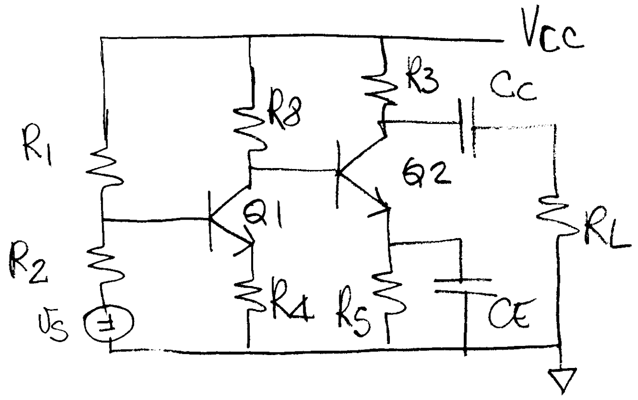
$$f_H = \frac{1}{2\pi} \left[\frac{1}{R_{V\mu_1} C_{\mu_1} + R_{V\pi_1} C_{\pi_1} + R_{V\mu_2} C_{\mu_2} + R_{V\pi_2} C_{\pi_2}} \right] =$$

$$\frac{1}{2\pi} \left[4567{,}7 \cdot 4 \cdot 10^{-12} + 73{,}9 \cdot 121{,}3 \cdot 10^{-12} + 14880 \cdot 4{,}3 \cdot 10^{-12} + 303{,}5 \cdot 143{,}2 \cdot 10^{-12} \right]^{-1} =$$

$$= \underline{1{,}182\ \text{MHz}}$$

Parte 2 - Fila B

$V_{CC} = 12V$ (14)



$R_1 = 20K\Omega$

$R_2 = 4K\Omega$

$R_3 = 500\Omega$

$R_4 = 500\Omega$

$R_8 = 2K\Omega$

$R_5 = 4K\Omega$

$R_L = 400\Omega$

$C_C = 1\mu F$

$C_E = 10\mu F$

Hp partitore pesante Q_1

$V_{B1} = \frac{R_2}{R_1+R_2} V_{CC} = \frac{4}{24} \cdot 12 = 2V$

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

$I_{E1} = V_{E1}/R_4 = 1{,}3/500 = 2.6\,mA \sim I_{C1}$

Hp $I_{B2} \ll I_{C1}$

$V_{C1} = V_{CC} - R_8 I_{C1} = 12 - 2 \cdot 2{,}6 = 6{,}8\,V$

$V_{CE1} = V_{C1} - V_{E1} = 6{,}8 - 1{,}3 = 5{,}5V$

$h_{FE1} = 160$

$I_{B1} = \frac{I_{C1}}{h_{FE1}} = \frac{2{,}6}{160} = 16.25\,\mu A \ll \frac{V_{CC}}{R_1+R_2} = 500\mu A$

$V_{E2} = V_{C1} - V_\gamma = 6.8 - 0{,}7 = 6{,}1\,V$

$I_{E2} = \frac{V_{E2}}{R_5} = \frac{6{,}1}{4} = 1{,}52\,mA \sim I_{C2}$

$V_{C2} = V_{CC} - R_3 I_{C2} = 12 - 0.5 \cdot 1{,}52 = 11.24V$

$V_{CE2} = V_{C2} - V_{E2} = 5.13\,V$

$h_{FE2} = 150$

$I_{B2} = \frac{I_{C2}}{h_{FE2}} = \frac{1{,}52}{150} = 10.13\,\mu A \ll I_{C1} = 2{,}6\,mA$

$r_{b1} = 450\,\Omega$

$r_{\pi 1} = 1750\,\Omega$

$g_{m1} = 0{,}1\,\Omega^{-1}$

$h_{ie1} = 2200\,\Omega$

$r_{o1} = 19{,}2\,k\Omega$

$C_{\mu 1} = 4{,}5\ pF$

$C_{\pi 1} = 100\ pF$

$C_{\mu 2} = 4{,}7\ pF$

$C_{\pi 2} = 71\,pF$

$r_{b2} = 450\,\Omega$

$r_{\pi 2} = 3033\,\Omega$

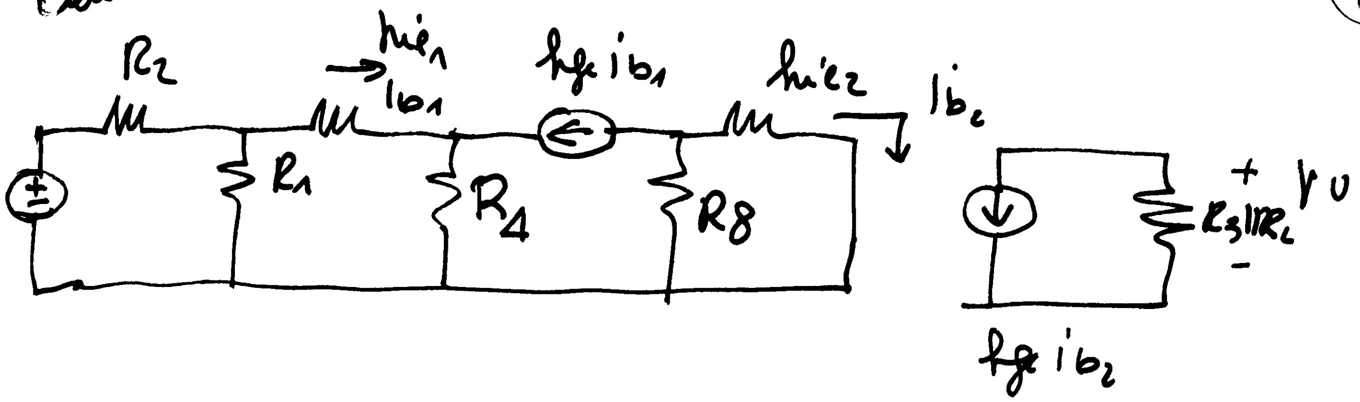
$g_{m2} =$ [redacted] $0{,}0576\,\Omega^{-1}$

$h_{ie2} = 3483\,\Omega$

$f_{T1} = 150\,MHz$

$f_{T2} = 125\ MHz$

Centrobanda



$$i_{b2} = -\frac{h_{fe1} R_8}{R_8 + h_{ie2}} i_{b1}$$

$$i_{b1} = V_s \cdot \frac{R_1}{R_1 + R_2} \cdot \frac{1}{R_4(1 + h_{fe}) + h_{ie1} + R_1 \| R_2}$$

$$V_U = -h_{fe2} (R_3 \| R_L) \, i_1$$

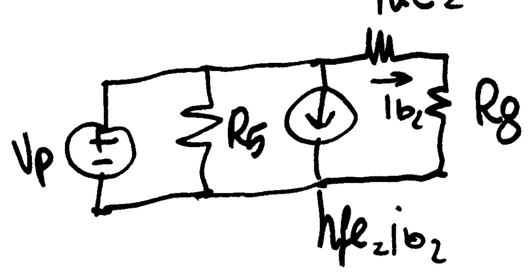
$$A_{CB} = h_{fe1} h_{fe2} \cdot \frac{R_8}{R_1 + h_{ie}} \cdot \frac{R_1}{R_1 + R_L} \cdot \frac{R_3 \| R_L}{R_4 (1 + h_{fe1}) + h_{ie1} + R_1 \| R_L}$$

$$= +22$$

Limite inferiore di banda

$$R_{VCC} = R_3 + R_L = 900\,\Omega$$

R_{VCE} :

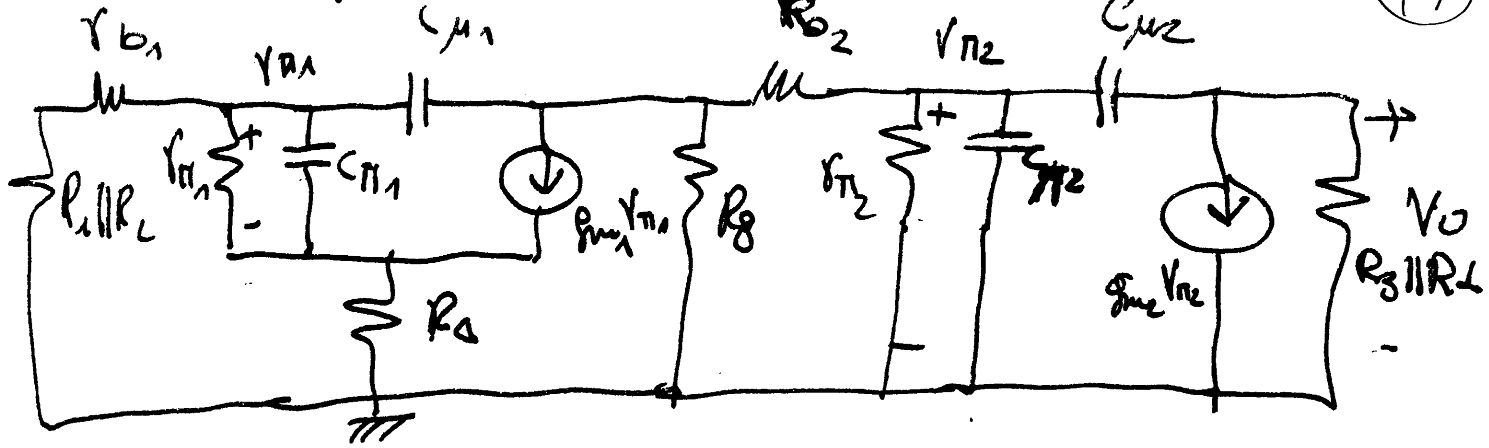


$$R_{VCE} = R_5 \| \left(\frac{h_{ie2} + R_8}{1 + h_{fe2}} \right)$$

$$= 31\,\Omega$$

$$f_L = 687\ Hz$$

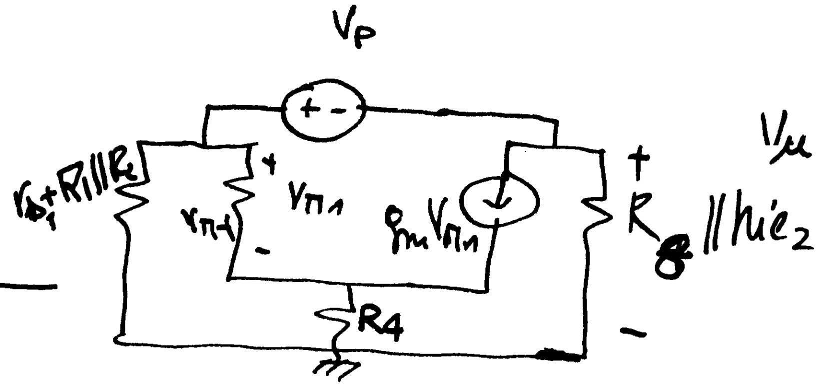
Alte frequenze



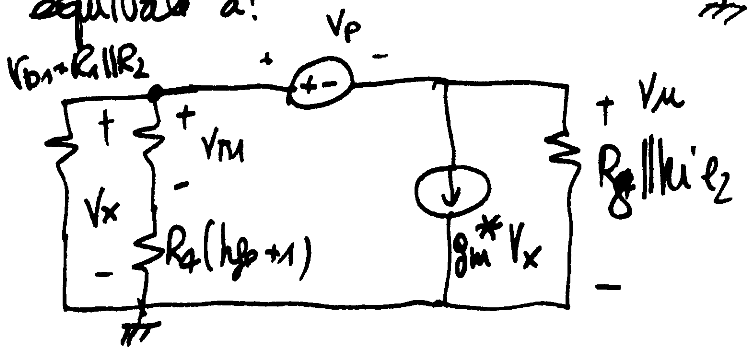
Rvcπ1 :

$$R_{VC\pi 1} = r_{\pi 1} \,\Big\|\, \left[\frac{R_4 + r_b + R_1 \| R_2}{1 + g_{m1} R_4}\right] = 80\,\Omega$$

Rvcμ1:



equivale a:



dove $g_m^* = \dfrac{g_m}{1 + \dfrac{R_4(h_{fe}+1)}{r_{\pi 1}}} = \dfrac{h_{fe1}}{r_{\pi 1} + R_4(h_{fe}+1)}$

A questo punto si applica:

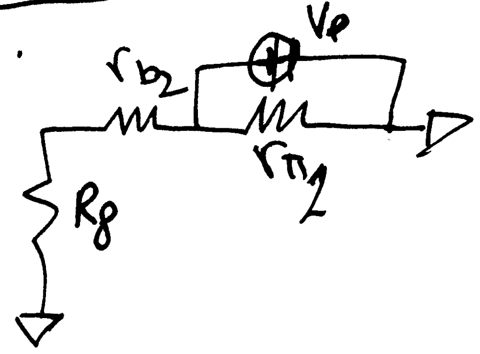
$$R_V = R_{in} + R_{out} + g_m^* R_{in} R_{out} = R_{in} + R_{out} + A_V R_{in}$$

con: $R_{in} = (R_1 \| R_2 + r_{b1}) \| (R_4(h_{fe}+1) + r_{\pi 1})$; $R_{out} = R_8 \| h_{ie2}$; $A_V = g_m^* R$...

Quindi:

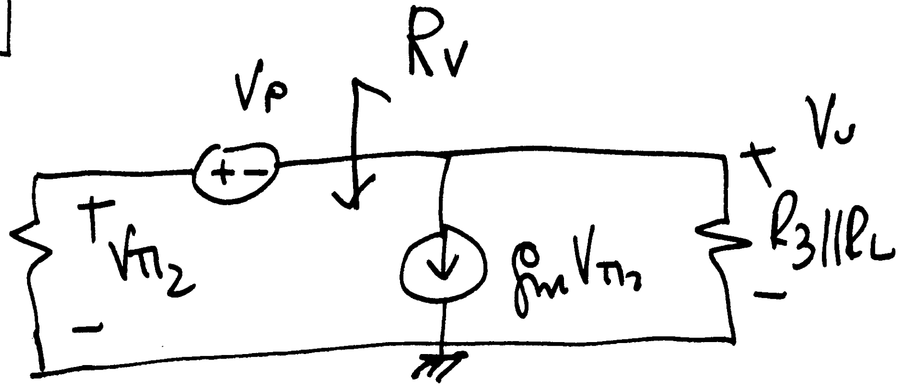
$R_{VC\mu 1} = 13{,}8\,K\Omega$

$R_{V\pi 2}$



$R_{V\pi 2} = r_{\pi 2} \,\|\, (r_{b2} + R_8)$
$= 1355\,\Omega$

$R_{V\mu 2}$



Si applica:

$R_V = R_{in} + R_{OUT} + g_m R_{in} R_{OUT}$

con $R_{in} = R_{V\pi 2}$

$R_{OUT} = R_3 \| R_L$

$g_m = g_{m2}$

$R_{V\mu 2} = R_{VC\pi 2}\,(1 + g_{m2}(R_3 \| R_L)) + R_3 \| R_L = 18{,}9\,K\Omega$