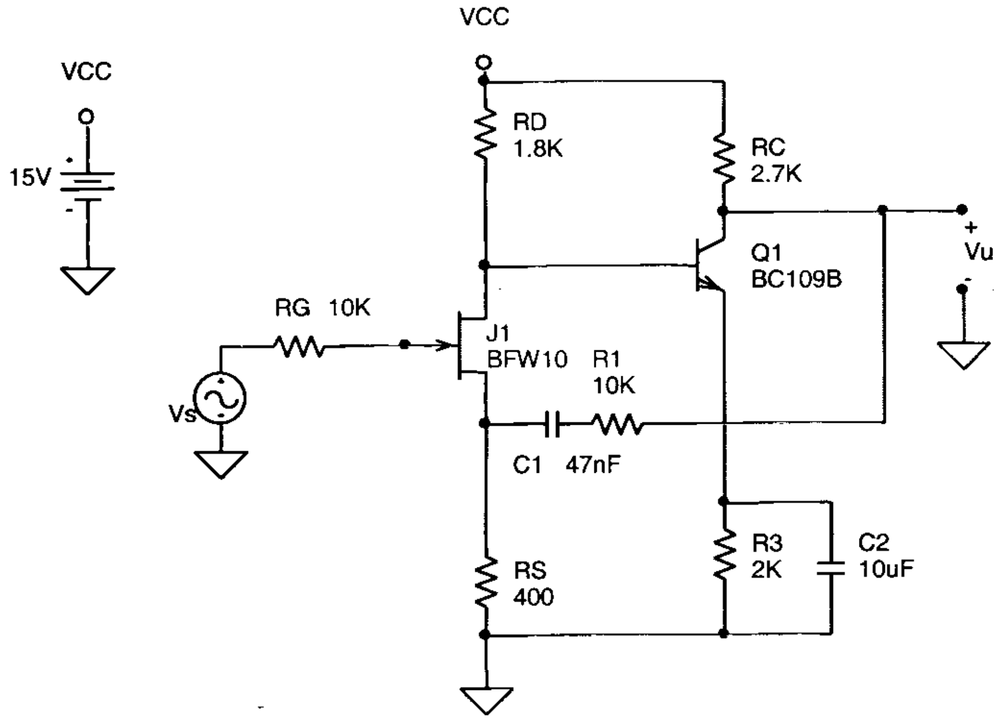
Elettronica II

Corso di Laurea in Ingegneria Elettronica
11 gennaio 2001

Esercizio A



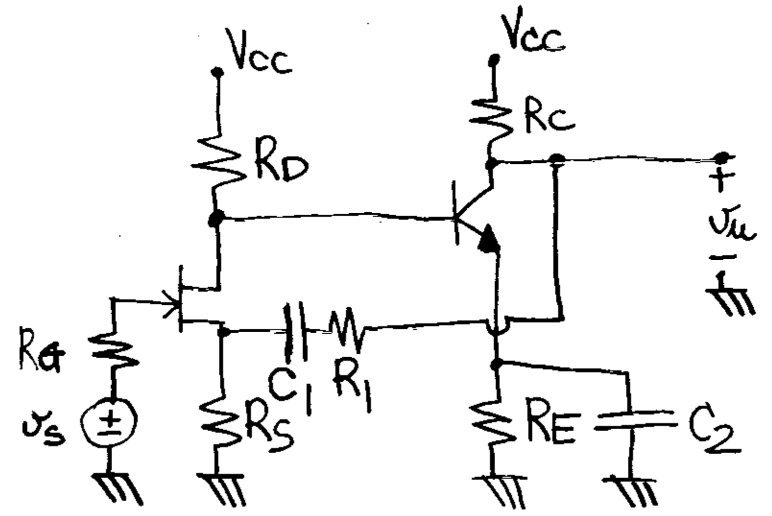
Le tensioni di alimentazione sono Vcc= 15 V. J1 è un BFW10 resistivo, con rd infinita, Q1 è un BC109B resistivo con hoe =0, hre = 0.

Con riferimento al circuito di figura:

1. calcolare il punto di riposo dei due transistori.
2. determinare la funzione di trasferimento Vu/Vs e tracciarne i diagrammi di Bode.
3. calcolare la cifra di rumore a 100 Hz considerando solo il contributo di rumore di J1 indipendente dalla frequenza.

Esercizio B

Disegnare e discutere lo schema circuitale di un sistema elettronico in grado di generare due onde triangolari alla frequenza di 2 KHz sfasate di un quarto di periodo.

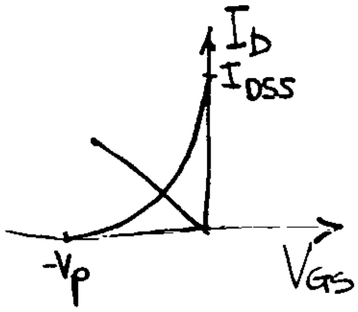


$R_D = 1{,}8\ K\Omega$
$R_S = 400\ \Omega$
$R_E = 2K\Omega$
$R_C = 2{,}7\ K\Omega$
$R_1 = 10000\ \Omega$
R_G
$C_1 = 47nF$
$C_2 = 10\mu F$

1) Punto di Riposo

sulla transcaratteristica

$$V_{GS} = -R_S I_D$$



troviamo
$I_D = 5mA$
$V_{GS} = -2V$

$V_D = V_{CC} - R_D I_D = 15 - 1.8 \cdot 5 = 6V$

$V_{DS} = V_D - V_S = 4V$

$V_B = V_D = 6V \rightarrow V_E = 5{,}3V$

$I_E \sim I_C = \frac{V_E}{R_E} = \frac{5{,}3}{2} = 2{,}65\ mA$

$V_C = V_{CC} - R_C I_E = 15 - 2{,}7 \cdot 2{,}65 = 7.845V$

$V_{CE} = V_C - V_E = 2.545\ V$

parametri per il piccolo segnale $\quad h_{fe} = 300$

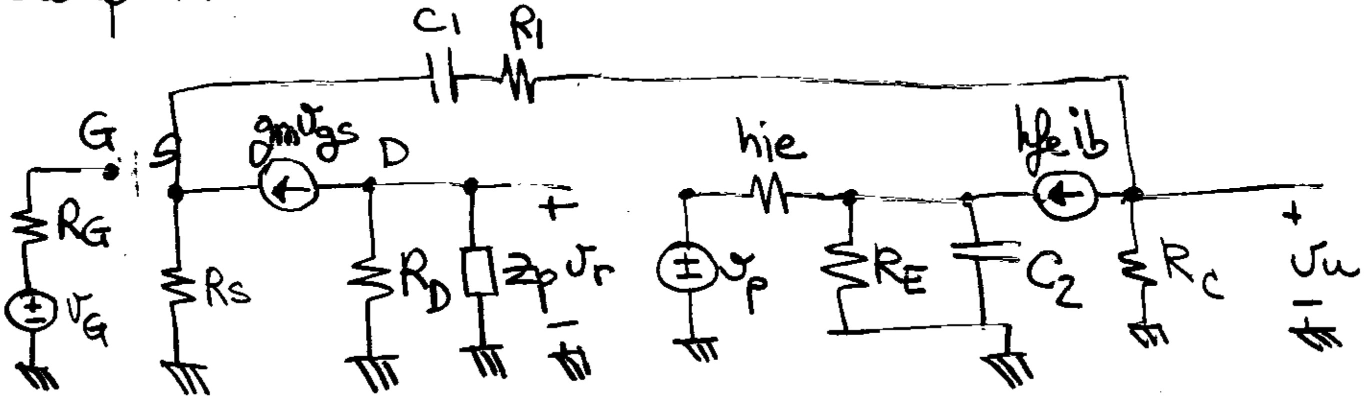
$r_{b'e} = h_{fe}\frac{V_T}{I_C} = 2943\ \Omega \quad h_{ie} = r_{b'e} + \underset{\uparrow\ 900\Omega}{r_{bb'}} = 3840\ \Omega$

per il JFET: dalle caratteristiche abbiamo

$g_m = 2{,}78 \cdot 10^{-3}\ \Omega^{-1}$

2) fdt

Scomponiamo tra la base del BJT e massa



$$Z_p = h_{ie} + \frac{R_E(h_{fe}+1)}{R_E C_2 s + 1} = \frac{h_{ie} + R_E(h_{fe}+1) + R_E C_2 s\, h_{ie}}{1 + R_E C_2 s} =$$

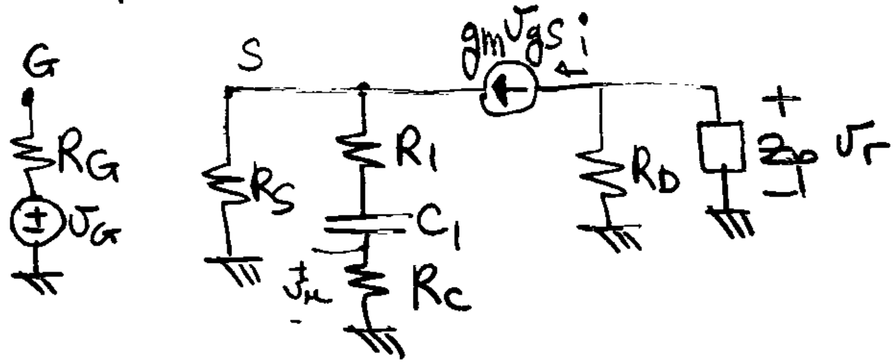
$$Z_p = Z_{p0} \frac{(1 - s/s_{z1})}{(1 - s/s_{p1})}$$

dove $Z_{p0} = h_{ie} + R_E(h_{fe}+1) = 3840 + 2000 \cdot 301 = 605.84\,K\Omega$

$$s_{p1} = -\frac{1}{R_E C_2} = -50 \text{ rad/s}$$

$$s_{z1} = -\frac{h_{ie} + R_E(h_{fe}+1)}{R_E C_2 h_{ie}} = -7889 \text{ rad/s}$$

rete per α



$$k_0 = \left.\frac{i}{v_g}\right|_0 = g_m \frac{1}{1 + g_m R_S} = 1{,}316 \cdot 10^{-3}\,\Omega^{-1}$$

$$k_\infty = g_m \frac{1}{1 + g_m [R_S // (R_1 + R_C)]} = 1{,}33 \cdot 10^{-3}\,\Omega^{-1}$$

poniamo $K_0 \sim K_\infty = K_0 = 1{,}316 \cdot 10^{-3} \Omega^{-1}$

$$\alpha = \frac{v_r}{v_G} = -\frac{i}{v_G} R_D // Z_p = -K_0 \frac{R_D\left(hie + R_E(hfe+1) + R_E hie C_2 s\right)}{R_D(1+R_E C_2 s) + hie + R_E hfe + R_E hie C_2 s}$$

$$\alpha = \frac{K_0 R_D \left(hie + R_E(hfe+1) + hie R_E C_2 s\right)}{R_D + hie + (R_E(hfe+1))s \left[R_D R_E C_2 + R_E hie C_2\right]}$$

$$\alpha = \alpha_0 \frac{\left(1 - s/s_{z1}\right)}{\left(1 - s/s_{p2}\right)} \qquad \alpha_0 = \frac{K_0 R_D \left(hie + R_E(hfe+1)\right)}{R_D + hie + R_E(hfe+1)} = -2.36$$

$$s_{p2} = -5387 \text{ rad/s}$$

calcoliamo γ

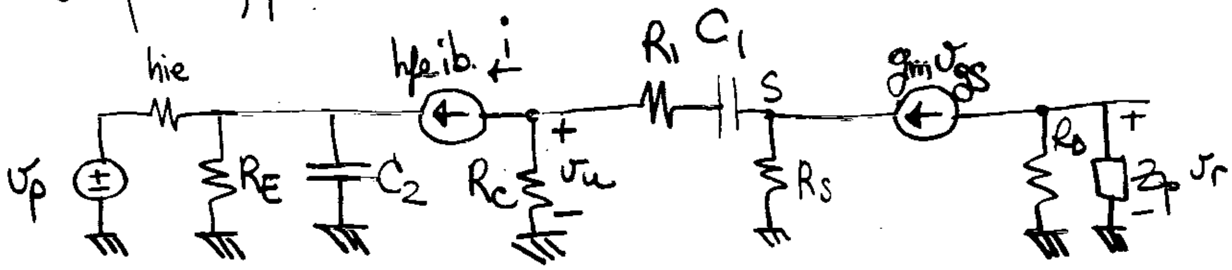
$$\gamma_\infty = \frac{v_u}{v_G}\bigg|_\infty = \frac{i}{v_G}\bigg|_\infty \cdot \frac{R_S R_C}{R_S + R_1 + R_C} = K_\infty \frac{R_S R_C}{R_S + R_1 + R_C} = 1{,}33 \cdot 10^{-3} \cdot 0{,}03 \cdot 2700$$

$$\boxed{\gamma_\infty = 0.11}$$

$$\gamma = \gamma_\infty \frac{s}{s - s_{p3}} \qquad s_{p3} = \frac{-1}{\left(R_C + R_1 + R_S // \frac{1}{gm}\right) C_1}$$

$$= \frac{-1}{12889 \cdot 47 \cdot 10^{-9}} = -1650 \text{ rad/s}$$

rete per A, βA



$$\left.\frac{i}{v_p}\right|_0 = \frac{h_{fe}}{h_{ie}+(h_{fe}+1)R_E} = \frac{300}{605840} = 0.495\cdot 10^{-3}\,\Omega^{-1} = \xi_0$$

$$\left.\frac{i}{v_p}\right|_\infty = \frac{h_{fe}}{h_{ie}} = \frac{300}{3840} = 78.1\cdot 10^{-3}\,\Omega^{-1} = \xi_\infty$$

$$s_{p4} = -\frac{1}{R_E /\!/ \left(\frac{h_{ie}}{h_{fe}+1}\right) C_2} = -\frac{1}{12.67\cdot 10^{-5}} = -7889 \text{ rad/s} = s_{z1}$$

$$s_{z4} = -\frac{1}{R_E C_2} = -50 \text{ rad/s} = s_{p1} \quad \Rightarrow \xi = \frac{i}{v_p} = \xi_0 \frac{(1-s/s_{z4})}{(1-s/s_{p4})}$$

$$\frac{v_u}{i} = -R_C /\!/ \left[R_1 + \frac{1}{g_m} /\!/ R_S + \frac{1}{C_1 s}\right] = \frac{-R_C\left[R_1+\frac{1}{g_m}/\!/R_S+\frac{1}{C_1 s}\right]}{R_C+R_1+\frac{1}{g_m}/\!/R_S+\frac{1}{C_1 s}} =$$

$$= \frac{-R_C\left[\left(R_1+\frac{1}{g_m}/\!/R_S\right)C_1 s + 1\right]}{\left(R_C+R_1+\frac{1}{g_m}/\!/R_S\right)C_1 s + 1} = \underbrace{\left.\frac{v_u}{i}\right|_0}_{-R_C} \frac{1-s/s_{z3}}{1-s/s_{p3}}$$

$$s_{z3} = -\frac{1}{\left(R_1+\frac{1}{g_m}/\!/R_S\right)C_1} = -\frac{1}{10189\cdot 47\cdot 10^{-9}} = -2088 \text{ rad/s}$$

$$A = -\xi_0 \frac{(1-s/s_{z4})}{(1-s/s_{p4})} R_C \frac{(1-s/s_{z3})}{(1-s/s_{p3})} \qquad A_0 = -\xi_0 R_C = -1{,}3365$$

$$\left.\frac{v_r}{i}\right|_0 = 0$$

$$\left.\frac{v_r}{i}\right|_\infty = \underbrace{-\frac{R_C}{R_C + R_1 + R_S /\!/ \frac{1}{g_m}} \cdot \frac{R_S}{R_S + \frac{1}{g_m}}}\cdot R_D /\!/ Z_p = -\chi \, R_D /\!/ Z_p$$

$\chi \to 0.11$

$$\frac{v_r}{i} = -\chi \, R_D /\!/ Z_p \frac{s}{s - s_{p3}}$$

$$\beta A = -\xi_0 \frac{(1 - s/s_{z4})}{\cancel{(1 - s/s_{p4})}} \chi \frac{\cancel{(1 - s/s_{z1})}}{(1 - s/s_{p2})} \left(\frac{\alpha_0}{K_0}\right) \frac{s}{s - s_{p3}}$$

$$A' = \frac{\alpha A}{1 - \beta A} = \frac{-\alpha_0 \frac{\cancel{(1 - s/s_{z1})}}{(1 - s/s_{p2})} \xi_0 R_C \frac{(1 - s/s_{z4})(1 - s/s_{z3})}{\cancel{(1 - s/s_{p4})}(1 - s/s_{p3})}}{1 + \xi_0 \chi \frac{\alpha_0}{K_0} \frac{(1 - s/s_{z4})\cancel{(1 - s/s_{z1})}}{\cancel{(1 - s/s_{p4})}(1 - s/s_{p2})} \frac{s}{s - s_{p3}}}$$

$$\simeq \frac{-\alpha_0 \xi_0 R_C \left(1 - \frac{s}{s_{z4}}\right)\left(1 - \frac{s}{s_{z3}}\right)}{\left(1 - \frac{s}{s_{p3}}\right)\left(1 - \frac{s}{s_{p2}}\right) + \xi_0 \chi \frac{\alpha_0}{K_0}\left(1 - \frac{s}{s_{z4}}\right)\left(-\frac{s}{s_{p3}}\right)}$$

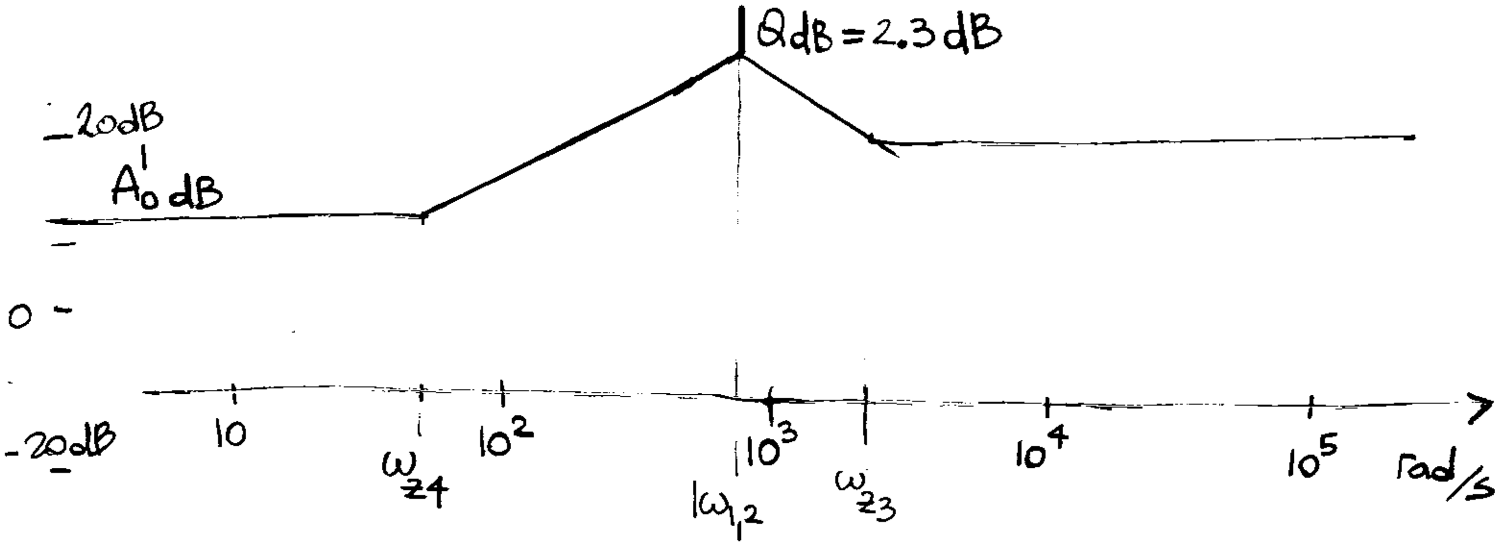
denominatore

$$s^2\left[\frac{1}{s_{p3} s_{p2}} + \xi_0 \chi \frac{\alpha_0}{K_0} \frac{1}{s_{z4} s_{p3}}\right] + s\left[-\frac{1}{s_{p3}} - \frac{1}{s_{p2}} - \frac{\xi_0 \chi \alpha_0}{K_0} \frac{1}{s_{p3}}\right] + 1$$

$$s^2 \underbrace{\left[1.125 \cdot 10^{-7} + 9.76 \cdot 10^{-2} \cdot 1.21 \cdot 10^{-5}\right]}_{1.3 \cdot 10^{-6}} + s \underbrace{\left[6.06 \cdot 10^{-4} + 1.856 \cdot 10^{-4} + 5.913 \cdot 10^{-5}\right]}_{6.508 \cdot 10^{-4}} + 1$$

$s_{1,2} = -3282 \pm i\,813$ $\quad |s_{1,2}| = 877$ rad/s $\quad Q = 1.34$

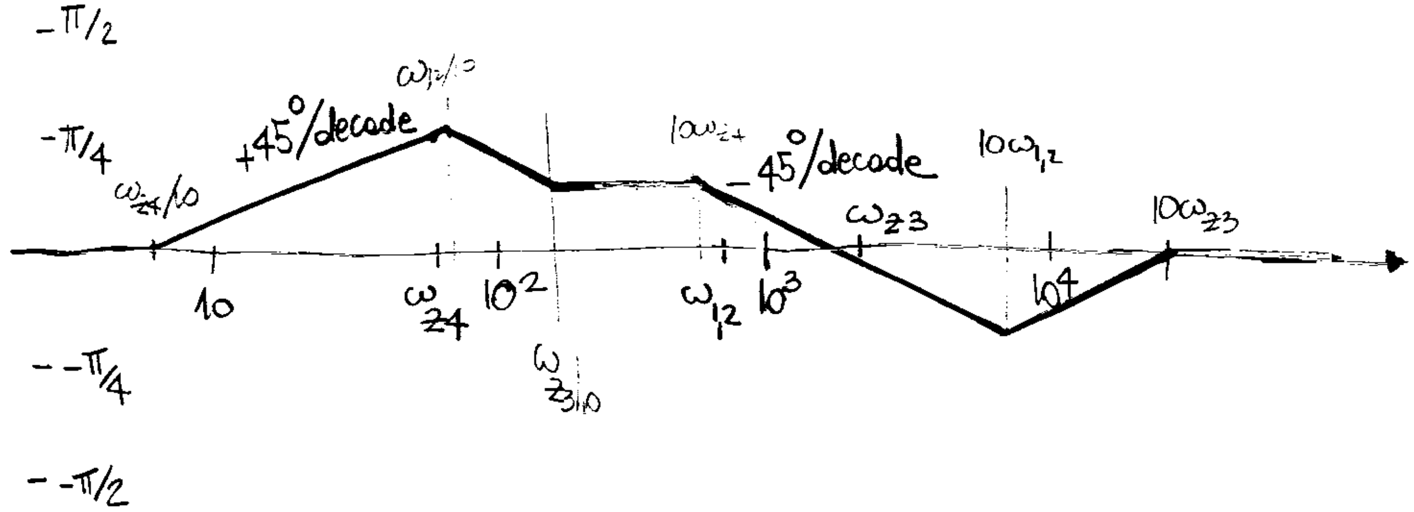
$$A'_0 = g_0 \xi_0 R_C = 2{,}358 \cdot 0.495 \cdot 10^{-3} \cdot 2700 = 3.15$$



$\gamma < A'$ in tutti i casi

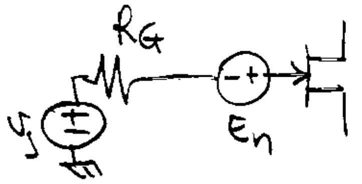
$$A_f = A' = A'_0 \frac{\left(1 - \frac{s}{s_{z4}}\right)\left(1 - \frac{s}{s_{z3}}\right)}{\left(1 - \frac{s}{s_1}\right)\left(1 - \frac{s}{s_2}\right)}$$

$$\angle A_f \sim \angle A'$$



A3)

il generatore di tensione equivalente all'ingresso del JFET tiene conto del rumore "termico" del canale

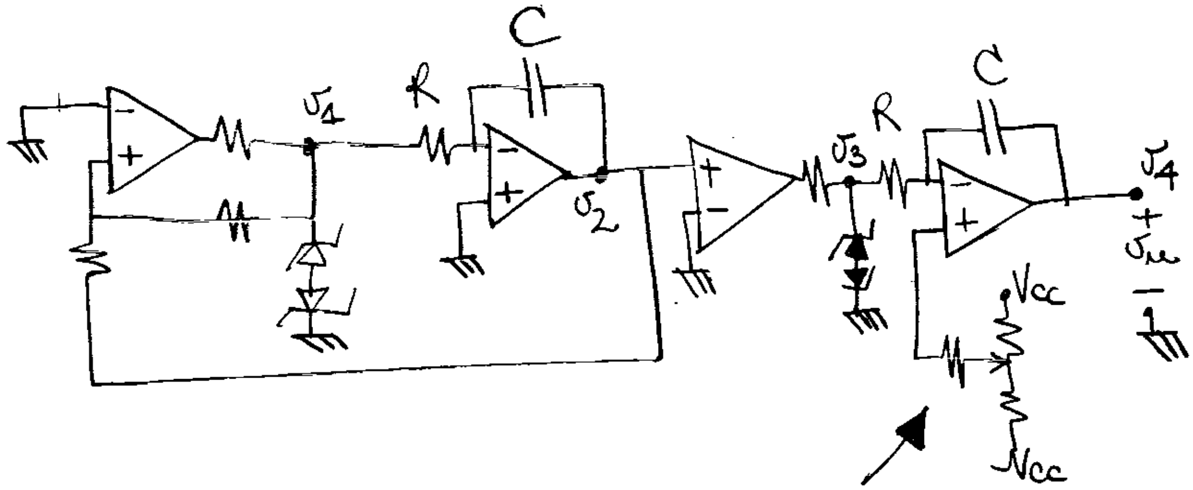


$$S_{E_N} = 4KT\,\frac{2}{3}g_m\left(\frac{1}{g_m}\right)^2 = 4KT\,\frac{2}{3g_m}$$

E_N è in serie a R_G e a v_s, quindi

$$F = 1 + \frac{4KT\frac{2}{3g_m}}{4KTR_G} = 1 + \frac{2}{3g_mR_G} = 1.024$$

(B) Una possibile soluzione è la seguente:



Serve a compensare le correnti di offset