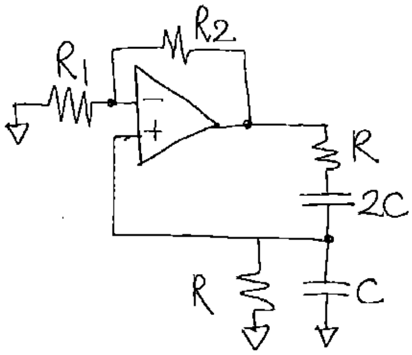
Prova scritta di Elettronica – Corso di Laurea in Ingegneria delle Telecomunicazioni

1 Febbraio 2012

1. Si consideri un amplificatore con amplificazione di tensione in continua A_{VO}=5000, R_{in} = 130 KΩ, R_{out} = 2 KΩ, un polo a frequenza f_p = 300 Hz. Inoltre sia R_s = 2 KΩ la resistenza del generatore di segnale e R_L = 200 Ω la resistenza del carico. Si reazioni il circuito in modo da ottenere una resistenza di ingresso maggiore di 2 MΩ e una resistenza di uscita di 1 MΩ. (con una tolleranza del 5%)

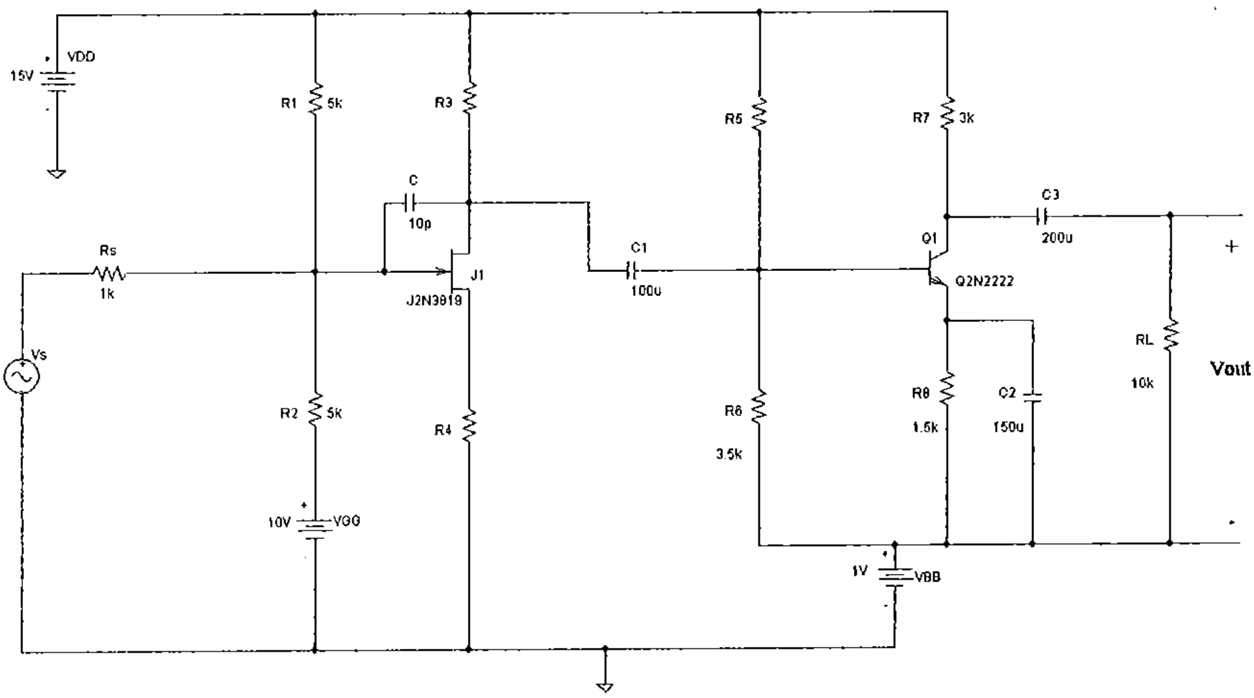
2. Sia dato l'oscillatore a lato. Verificare il criterio di Barkhausen all'innesco e calcolare l'eventuale frequenza di oscillazione. Sia R=1 KΩ, C = 50 nF, R_1=10 KΩ, R_2=15 KΩ.



3. Dato l'amplificatore disegnato in figura, calcolare:

- I valori delle resistenze R_3, R_4, R_5 sapendo che: $I_{DS} = 1.8mA$, $V_{DS} = 6.9V$ e che $I_C = 2.7mA$ *(Punteggio 5/30)*
- l'amplificazione Vu/Vs a centrobanda *(Punteggio 4/30)*
- il limite superiore di banda e il limite inferiore di banda *(Punteggio 8/30)*

NOTE: J1 è un 2N3819 con rd → ∞, Q1 un QN2222 con $h_{oe} = 0$.

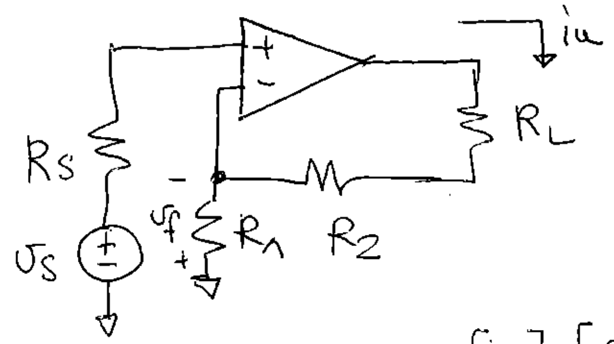


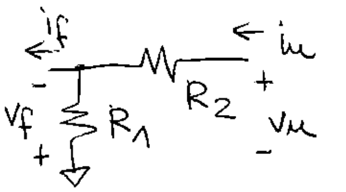
Es. 1.

$R_{in} = 130\,k\Omega \rightarrow R_{IF} > 2\,M\Omega$

$R_{out} = 2\,k\Omega \rightarrow R_{OF} = 1\,M\Omega$

È necessaria una reazione con inserzione di tensione e prelievo di corrente

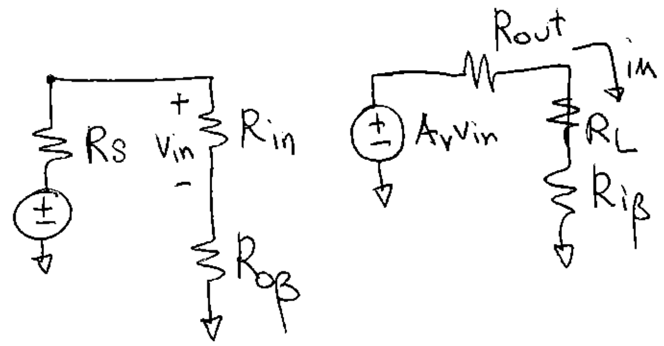




$$\begin{bmatrix} v_f \\ v_u \end{bmatrix} = \begin{bmatrix} \beta & R_{o\beta} \\ R_{i\beta} & K \end{bmatrix} \begin{bmatrix} i_u \\ i_f \end{bmatrix}$$

$$\beta = \frac{v_f}{i_u}\Big|_{i_f=0} = -R_1 \; ; \quad R_{o\beta} = \frac{v_f}{i_f}\Big|_{i_u=0} = R_1 \; ; \quad R_{i\beta} = \frac{v_u}{i_u}\Big|_{i_f=0} = R_1 + R_2$$

A_e



$$A_e = \frac{i_u}{v_s}\Big|_{\beta=0} = \frac{R_{in}}{R_{in}+R_S+R_{o\beta}} \cdot A_v \frac{1}{R_{out}+R_{i\beta}+R_L}$$

$$A_e = \frac{R_{in}}{R_{in}+R_S+R_1} A_v \frac{1}{R_{out}+R_1+R_2+R_L}$$

$$R_{OF} = \left(R_{out}+R_{i\beta}\right)\left(1-\beta A_e\Big|_{R_L=0}\right) = \left(\underset{\uparrow\, 2k\Omega}{R_{out}} + \overset{R_1+R_2}{R_{i\beta}}\right)\left[1 + \frac{R_{in}}{R_{in}+R_S+R_{o\beta}} \overset{5000}{A_v} \frac{R_1}{R_{out}+R_{i\beta}}\right]$$

Per avere $R_{OF} = 1\,M\Omega$ dobbiamo avere $|\beta A_e| \gg 1$, possiamo quindi ~~di~~ trascurare 1 rispetto a βA_e:

$$R_{OF} = \frac{A_V R_{in} R_1}{R_{in} + R_S + R_1} \rightarrow R_1 = \frac{R_{in} + R_S}{\frac{A_V R_{in}}{R_{OF}} - 1} \cong \underline{203\,\Omega}$$

$$R_{IF} = (R_{in} + R_{o\beta})\left(1 - \beta A e\big|_{R_S=0}\right) =$$

$$= (R_{in} + R_{o\beta})\left(1 + \frac{R_1 R_{in} A_V}{(R_{in} + R_{o\beta})(R_{out} + R_{i\beta})}\right)$$

di nuovo trascuriamo 1, scegliamo $R_{IF} = 5\,M\Omega$, e calcoliamo R_2

$$R_{IF} \cong \frac{R_1 R_{in} A_V}{R_{out} + R_1 + R_2} \rightarrow R_2 = \frac{R_1 R_{in} A_V}{R_{IF}} - R_{out} - R_1$$

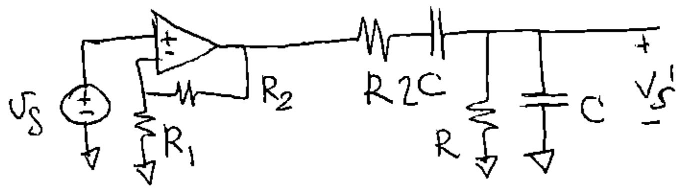
$$= 24187$$

Sostituendo otteniamo:

$R_{OF} = 1{,}026\ M\Omega$

$R_{IF} = 5{,}14\ M\Omega$

2) ~~Apriamo il giro~~ Apriamo l'anello di reazione:



$$\frac{V_S'}{V_S} = \frac{\frac{R}{1+RCs}}{\frac{R}{1+RCs} + R + \frac{1}{2Cs}} \cdot \left(1 + \frac{R_2}{R_1}\right) =$$

$$\beta A = \frac{V_S'}{V_S} = \frac{2RCs}{2RCs + 2RCs(1+RCs) + (1+RCs)}\left(1 + \frac{R_2}{R_1}\right) =$$

$$\beta A = \frac{2RCs}{2R^2C^2s^2 + 5RCs + 1}\left(1 + \frac{R_2}{R_1}\right)$$

la fase è nulla se $1 - 2R^2C^2\omega_0^2 \rightarrow \omega_0 = \frac{1}{\sqrt{2}RC} = \frac{1}{1{,}41 \cdot 1000 \cdot 50 \cdot 10^{-9}} =$

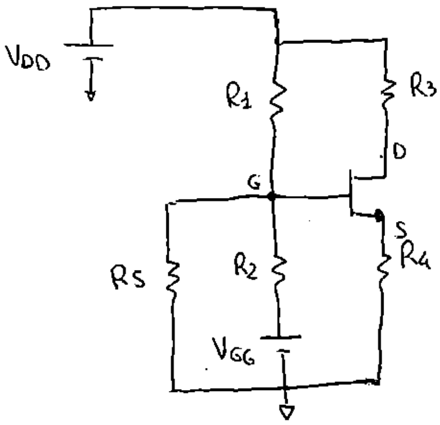
$$\omega_0 = 14{,}18\ \text{Krad/s}$$

$\beta A(\omega_0) = \frac{2}{5}\left(1 + \frac{15}{10}\right) = 1$ ← al limite dell'innesco NON si può dire se l'oscillazione si innesca.

LA CAPACITA' C HA UN VALORE DELL'ORDINE DEI pF, QUINDI COMPARABILE CON LE CAPACITA' INTRINSECHE DEL JFET E DEL BJT. L'UNICO EFFETTO CHE HA E' DI FINIRE IN PARALLELO A C_{GD}, QUINDI E' COME SE AVESSIMO UN JFET CON UNA

$$C'_{GD} = C_{GD} + C$$

PUNTO DI RIPOSO JFET



HP. JFET IN SATURAZIONE

PRINCIPIO DI SOVRAPPOSIZIONE DEGLI EFFETTI

$$V_G = V_{GG} \cdot \frac{R_1 // R_S}{R_1 // R_S + R_2} + V_{DD} \cdot \frac{R_2 // R_S}{R_2 // R_S + R_1} \cong 3.5V$$

$$V_{GS} = V_G - V_S$$

$$V_{GS} = V_G - R_4 \cdot I_{DS}$$

$$I_{DS} = \frac{V_G - V_{GS}}{R_4}$$

DALLE CARATTERISTICHE VEDO CHE PER $T = 25°C$ PER $I_{DS} = 1.8\,mA$ RISULTA $V_{GS} \cong -1.9\,V$

$$\boxed{R_4 = 3k\Omega}$$

$$R_4 = \frac{V_G - V_{GS}}{I_{DS}} \cong 3\,k\Omega$$

$$V_{DS} = V_{DD} - (R_3 + R_4) I_{DS}$$

$$R_3 + R_4 = \frac{V_{DD} - V_{DS}}{I_{DS}} \cong 4.5\,k\Omega$$

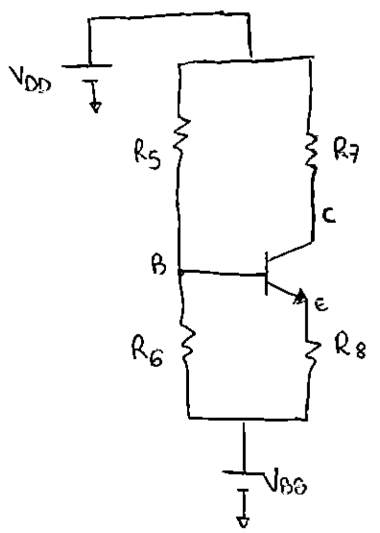
$$\boxed{R_3 = 1.5\,k\Omega}$$

$$R_3 = 4.5\,k\Omega - R_4 \cong 1.5\,k\Omega$$

VERIFICA HP. JFET IN SATURAZIONE

$$\begin{cases} V_{GS} > V_P & -1.9V > -3V \quad ok! \\ V_{DS} > V_{GS} - V_P & 6.9V > (-1.9+3)V \quad ok! \end{cases}$$

PUNTO DI RIPOSO BJT



HP. PARTITORE PESANTE.

PRINCIPIO DI SOVRAPPOSIZIONE DEGLI EFFETTI

$$V_B = V_{BB} \cdot \frac{R_5}{R_5+R_6} + V_{DD} \cdot \frac{R_6}{R_5+R_6} \quad (*)$$

$$V_{BE} = V_B - V_E = V_\gamma \cong 0.7V$$

$$I_C \cong I_E = \frac{V_E - V_{BB}}{R_8}$$

$$V_E = V_{BB} + R_8 \cdot I_C \cong 5.05V$$

$$V_B = V_E + V_{BE} = 5.05V + 0.7V = 5.75V$$

Da (*) si ha:

$$V_B \cdot (R_5+R_6) = V_{BB} \cdot R_5 + V_{DD} \cdot R_6$$

$$(V_B - V_{BB})\, R_S = (V_{DD} - V_B)\, R_G$$

$\boxed{R_S = 7\,K\Omega}$

$$R_S = \frac{(V_{DD} - V_B)}{(V_B - V_{BB})} \cdot R_G = \frac{15 - 5.75}{5.75 - 1} \cdot 3.5\,k\Omega \cong 7\,k\Omega$$

$V_C = V_{DD} - R_7 \cdot I_C \cong 6.9V$

$V_{CE} = V_C - V_E \cong 1.85V$

VERIFICA HP. PARTITORE PESANTE

$h_{FE} \cong 160$

$$I_B = \frac{I_C}{h_{FE}} \cong 16.9\,\mu A$$

$$I_{RS} = \frac{V_{DD} - V_B}{R_S} \cong 1.33\,mA \qquad I_{RG} = \frac{V_B - V_{BB}}{R_G} \cong 1.33\,mA$$

$I_B << I_{RS}, I_{RG}$

PARAMETRI DI PICCOLO SEGNALE

- JFET

$g_m \cong 2.7\,mS$ (letta per $V_{GS} \cong -1.9V$)

$C_{iss} \cong 2\,pF$ (letta sulla curva $V_{DS} = 10V$)

$C_{rss} \cong 0.9\,pF$

$C_{GD} = C_{rss} = 0.9\,pF \longrightarrow C_{GD}' = C_{GD} + C = 10.9\,pF$

$C_{GS} = C_{iss} - C_{rss} = 1.1\,pF$

- BJT

$$h_{fe} = \frac{50+300}{2} = 175$$

$$h_{ie} \,@\, 1mA = \frac{2+8}{2} = 5\,K\Omega$$

$$r_{b'e} \,@\, 1mA = \frac{V_T \cdot h_{fe}}{I_C @ 1mA} = 4.55\,K\Omega$$

$r_{bb'} = h_{ie} - r_{b'e} = 450\,\Omega$

$r_{b'e} = \dfrac{V_T \cdot h_{fe}}{I_C} \cong 1.69\ K\Omega$

$h_{ie} = r_{b'e} + r_{bb'} = 2.14\,K\Omega$

$V_{CB} = V_{CE} - V_{BE} = 1.15V$

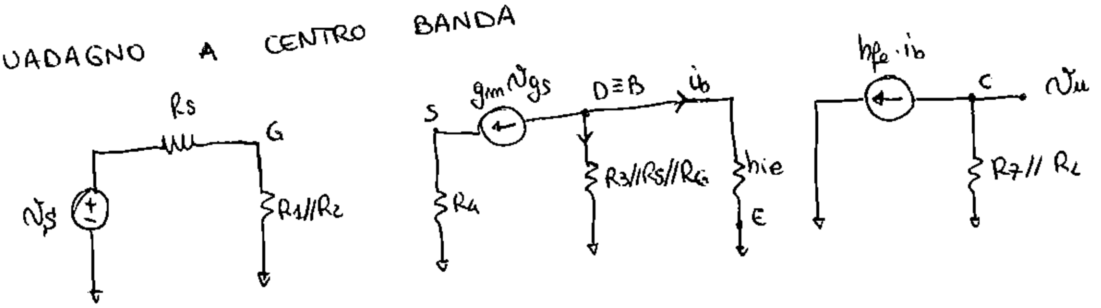
$f_T \cong 160MHz$

$g_{m_{BJT}} = \dfrac{I_C}{V_T} \cong 103.85\,mS$

$C_{b'c} \cong 7pF$

$C_{b'e} = \dfrac{g_{mBJT}}{2\pi f_T} - C_{b'c} \cong 96.3\ pF$

GUADAGNO A CENTRO BANDA



$v_u = - R_L // R_7\ h_{fe} \cdot i_b$

$i_b = -g_m v_{gs} - \dfrac{v_B}{R_3//R_5//R_6} = -g_m v_{gs} - \dfrac{h_{ie} \cdot i_b}{R_3//R_5//R_6}$

$i_b \left(1 + \dfrac{h_{ie}}{R_3//R_5//R_6} \right) = -g_m v_{gs}$

$i_b = \dfrac{-g_m v_{gs} (R_3//R_5//R_6)}{h_{ie} + (R_3//R_5//R_6)}$

$v_{gs} = v_g - v_s$

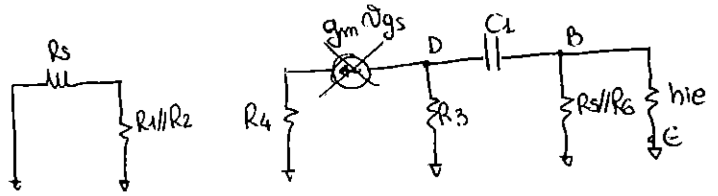
$$v_{gs} = v_s \frac{R_1 /\!/ R_2}{R_1 /\!/ R_2 + R_s} - R_4 g_m v_{gs}$$

$$v_{gs} = \frac{\frac{R_1 /\!/ R_2}{R_1 /\!/ R_2 + R_s}}{1 + R_4 g_m} \cdot v_s = \frac{R_1 /\!/ R_2}{R_1 /\!/ R_2 + R_s} \cdot \frac{1}{1 + R_4 g_m} \cdot v_s$$

$$i_b = - \frac{g_m (R_3 /\!/ R_5 /\!/ R_6)}{h_{ie} + (R_3 /\!/ R_5 /\!/ R_6)} \cdot \frac{R_1 /\!/ R_2}{R_1 /\!/ R_2 + R_s} \cdot \frac{1}{1 + R_4 g_m} \cdot v_s$$

$$A_{CB} = \frac{v_u}{v_s} = (R_L /\!/ R_7) h_{fe} \cdot \frac{g_m (R_3 /\!/ R_5 /\!/ R_6)}{h_{ie} + (R_3 /\!/ R_5 /\!/ R_6)} \cdot \frac{R_1 /\!/ R_2}{R_1 /\!/ R_2 + R_s} \cdot \frac{1}{1 + R_4 g_m} \cong 26$$

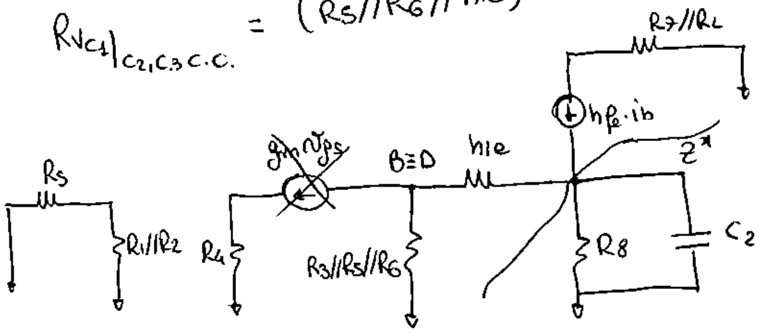
LIMITE INFERIORE DI BANDA

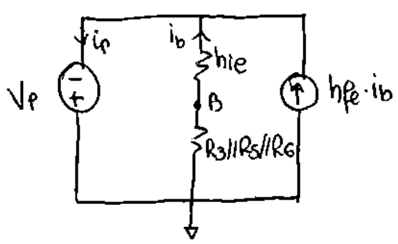


$v_g = 0$

$v_s = 0$

$$R_{VC1}\big|_{C_2, C_3\, c.c.} = (R_5 /\!/ R_6 /\!/ h_{ie}) + R_3 \cong 2.62\,K\Omega$$



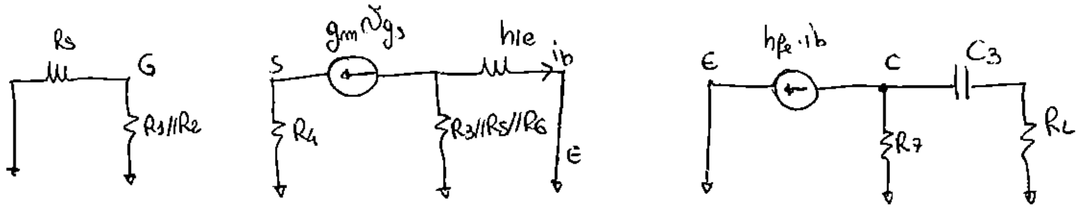


$$i_p = i_b + h_{fe} \cdot i_b = (1 + h_{fe}) \cdot i_b$$

$$V_p = (h_{ie} + R_3 /\!/ R_5 /\!/ R_6) \cdot i_b$$

$$Z^* = \frac{V_p}{i_p} = \frac{h_{ie} + R_3 /\!/ R_5 /\!/ R_6}{1 + h_{fe}} \cong 17.35\,\Omega$$

$$R_{V_{C2}}\Big|_{C_1, C_3\ c.c.} = R_8 // Z^* \cong 17.15\,\Omega$$



$v_g = 0$

$v_s = 0$

$i_b = 0$

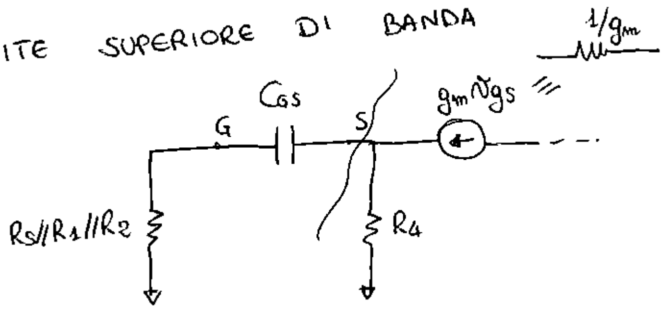
$h_{fe} \cdot i_b = 0$

$$R_{V_{C3}}\Big|_{C_1, C_2\ c.c.} = R_7 + R_L = 13\,k\Omega$$

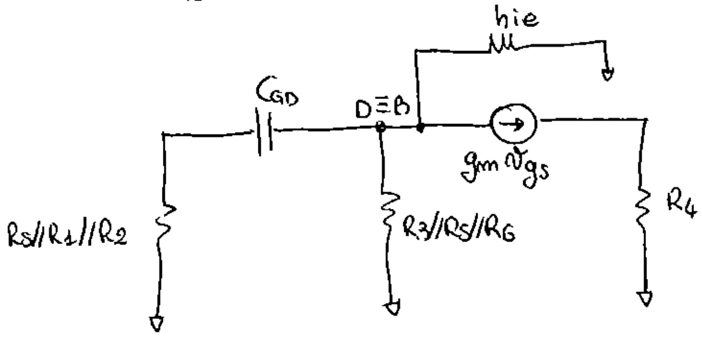
$$f_L = \frac{1}{2\pi}\left[\frac{1}{C_1 \cdot R_{VC1}} + \frac{1}{C_2 \cdot R_{VC2}} + \frac{1}{C_3 \cdot R_{VC3}}\right] =$$

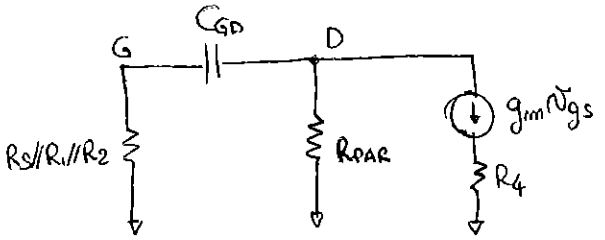
$$= \frac{1}{2\pi}\left[\frac{1}{100\times10^{-6}\times 2.62\times10^{3}} + \frac{1}{200\times10^{-6}\times 17.15} + \frac{1}{200\times10^{-6}\times 13\times10^{3}}\right] \cong 47\,Hz$$

LIMITE SUPERIORE DI BANDA



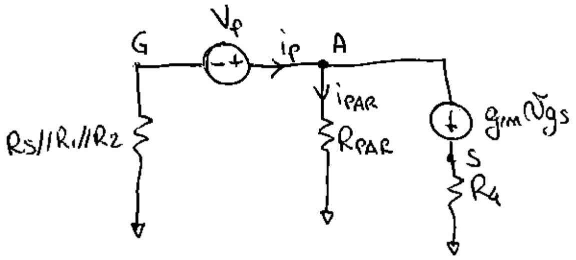
$$R_{V_{GS}} = (R_S // R_1 // R_2) + \left(R_4 // \frac{1}{g_m}\right) \cong 330\,\Omega$$





$R_{PAR} = R_3 // R_5 // R_6 // h_{ie} \cong 640\,\Omega$

$R_S // R_1 // R_2 \cong 714\,\Omega$



$$V_p = R_{PAR} \cdot i_{PAR} + (R_S // R_1 // R_2) \cdot i_p$$

$$i_p = i_{PAR} + g_m v_{gs}$$

$$v_{gs} = v_g - v_s = -(R_S // R_1 // R_2) \cdot i_p - R_4 g_m v_{gs}$$

$$v_{gs} = \frac{-(R_S // R_1 // R_2)}{1 + R_4 g_m} \cdot i_p$$

$$i_p = i_{PAR} - \frac{g_m (R_S // R_1 // R_2)}{1 + R_4 g_m} \cdot i_p$$

$$i_{PAR} = \frac{V_A}{R_{PAR}} = \frac{V_p - (R_S // R_1 // R_2) i_p}{R_{PAR}}$$

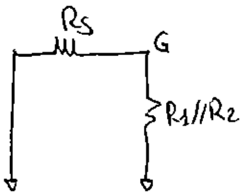
$$i_p = \frac{V_p}{R_{PAR}} - \frac{(R_S // R_1 // R_2)}{R_{PAR}} \cdot i_p - \frac{g_m (R_S // R_1 // R_2)}{1 + R_4 g_m} \cdot i_p$$

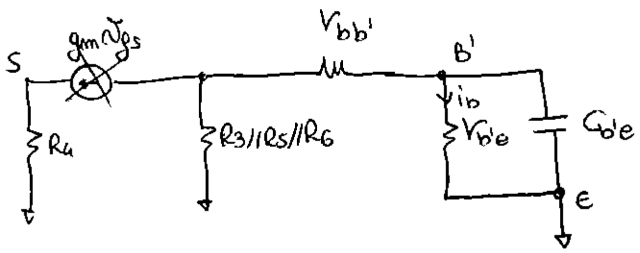
$$\left[1 + \frac{(R_S // R_1 // R_2)}{R_{PAR}} + \frac{g_m (R_S // R_1 // R_2)}{1 + R_4 g_m} \right] i_p = \frac{V_p}{R_{PAR}}$$

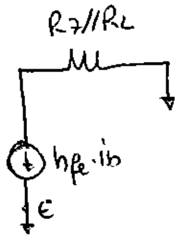
$$R_{V_{CGD}} = \frac{v_p}{i_p} = R_{PAR}\left[1 + \frac{(R_S//R_1//R_2)}{R_{PAR}} + \frac{g_m(R_S//R_1//R_2)}{1+R_4 g_m}\right] =$$

$$= R_{PAR} + (R_S//R_1//R_2) + \frac{g_m(R_S//R_1//R_2)\cdot R_{PAR}}{1+R_4 g_m} =$$

$$= 640 + 714 + \frac{2.7\times10^{-3}\times 714\times 640}{1+3\times 2.7} \cong 1.5\ K\Omega$$

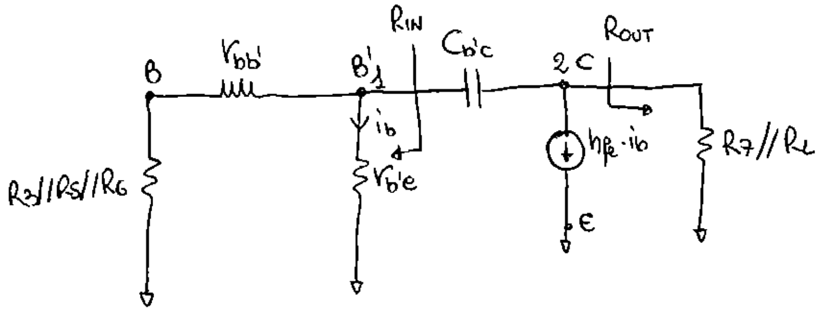






$v_g = 0 \qquad v_s = 0$

$$R_{V_{Cb'e}} = r_{b'e} // (R_3//R_5//R_6 + r_{bb'}) \cong 754\ \Omega$$



$R_{IN} = R_{V_{Cb'e}} \cong 754\ \Omega$

$R_{OUT} = R_7 // R_L \cong 2.31\ K\Omega$

$$A_V = \frac{V_2}{V_1}$$

$V_1 = r_{b'e} \cdot i_b$

$V_2 = -(R_7//R_L)\cdot h_{fe}\cdot i_b$

$$A_V = \frac{V_2}{V_1} = -\frac{(R_7 // R_L) h_{fe}}{r_{b'e}} \cong -239.2$$

$$R_{V_{C_{b'c}}} = R_{IN}\left(1+|A_V|\right) + R_{OUT} \cong 0.754\left(1+239.2\right)+2.31 \cong 183.4\ K\Omega$$

$$f_H = \frac{1}{2\pi\left[C_{GS}\cdot R_{V_{C_{GS}}} + \underset{\substack{\| \\ C_{GD}+C}}{C'_{GD}} \cdot R_{V_{C_{GD}}} + C_{b'e}\cdot R_{V_{C_{b'e}}} + C_{b'c}\cdot R_{V_{C_{b'c}}}\right]} =$$

$$= \frac{1}{2\pi\left[1.1\times 0.33 + 10.9\times 1.5 + 96.3\times 0.754 + 7\times 183.4\right]\times 10^{-9}} \cong 116\ KHz$$