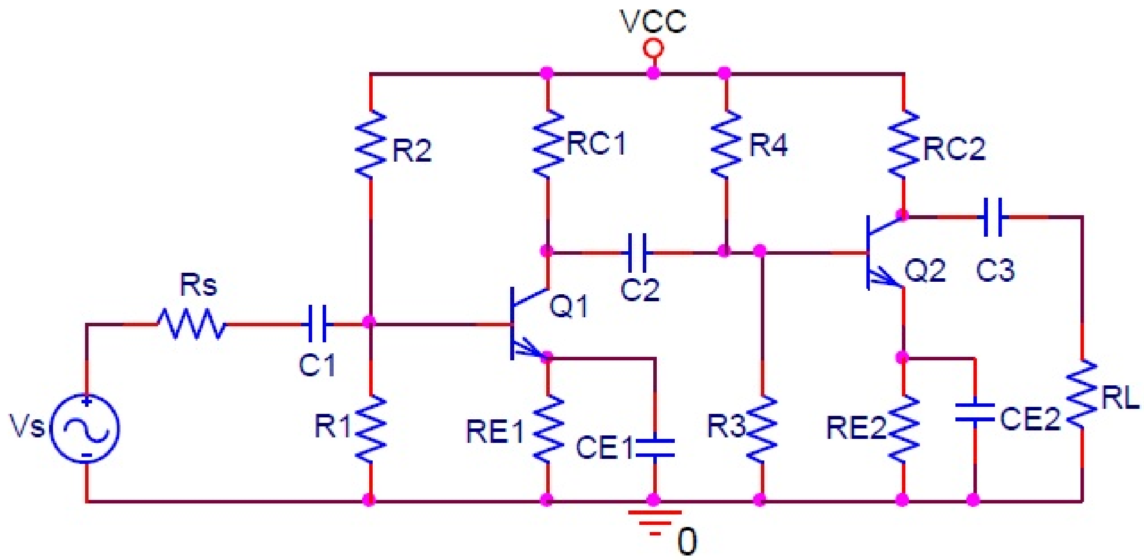
Realizar el análisis del siguiente amplificador:



$R_s = 50\Omega, \quad V_{CC} = 10v$

$R_1 = 1K\Omega, \quad \beta_1 = \beta_2 = 100$

$R_2 = 2.3K\Omega, \quad C_1 = 1\mu F$

$R_{E1} = 100\Omega, \quad C_2 = 2\mu F$

$R_{C1} = 200\Omega, \quad C_3 = 10\mu F$

$R_3 = 10K\Omega, \quad C_{E1} = 5\mu F$

$R_4 = 90K\Omega. \quad C_{E2} = 10\mu F$

$R_{E2} = 500\Omega, \quad C_o = despreciable$

$R_{C2} = 5K\Omega, \quad C_{bc} = 10pF$

$R_L = 5K\Omega, \quad F_T = 500MHz, \quad \omega_T = 2\pi f_T.$

Análisis de frecuencias medias

Análisis D.C

Etapa 1

$R_{B_1} = R_1 \| R_2 \approxeq 696\,\Omega$

$V_{BB_1} = \dfrac{V_{cc} R_1}{R_1 + R_2} = 3.03(V)$

Etapa 2

$R_{B_2} = R_3 \| R_4 = 9K\Omega$

$V_{BB_2} = \dfrac{V_{cc} R_3}{R_3 + R_4} = 1(V)$

L.V.K en la malla de entrada:

$$V_{BB_1} = \frac{I_{CQ_1}}{\beta} R_{B_1} + V_{BE} + I_{CQ_1} R_{E_1}$$

$$\Rightarrow I_{CQ_1} = \frac{V_{BB_1} - V_{BE}}{\frac{R_{B_1}}{\beta} + R_{E_1}} = 21.7\,mA$$

L.V.K en la malla de salida:

$$V_{CC} = I_C R_{C_1} + V_{CE_1} + I_C R_{E_1}$$

$$\Rightarrow V_{CEQ_1} = V_{CC} - I_{CQ_1} (R_{C_1} + R_{E_1})$$

$$\Rightarrow V_{CEQ_1} = 3.49\,(V)$$

$$V_{CEmax_1} = V_{CC} = 10\,(V)$$

$$I_{Cmax_1} = \frac{V_{CC}}{R_{C_1} + R_{E_1}} = 33.3\,mA$$

L.V.K en la malla de entrada:

$$\Rightarrow I_{CQ_2} = \frac{V_{BB_2} - V_{BE}}{\frac{R_{B_2}}{\beta} + R_{E_2}} = 508.5\,\mu A$$

L.V.K en malla de salida:

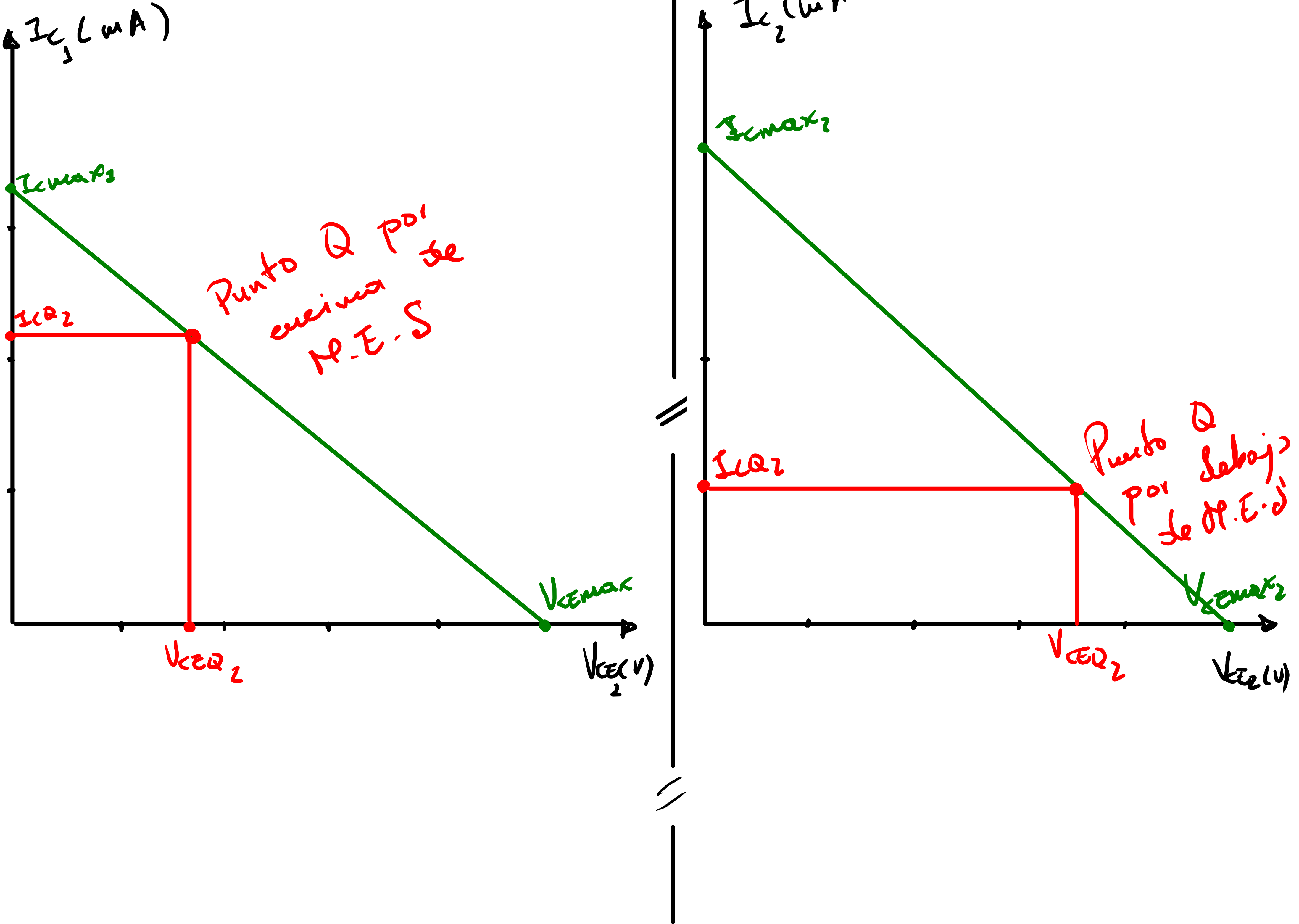
$$\Rightarrow V_{CEQ_2} = V_{CC} - I_{CQ_2} (R_{C_2} + R_{E_2})$$

$$\Rightarrow V_{CEQ_2} = 7.2\,(V)$$

$$V_{CEmax_2} = V_{CC} = 10\,(V)$$

$$I_{Cmax_2} = \frac{V_{CC}}{R_{C_2} + R_{E_2}} = 1.8\,mA$$

La Recta DC :



Ic1 (mA)
Icmax1
ICQ2
Punto Q por encima de M.E.S
VCEQ2
Vcemax
VCE2(V)
Ic2 (mA)
Icmax2
ICQ2
Punto Q por debajo de M.E.S
VCEQ2
Vcemax2
VCE2(V)

Análisis A.C

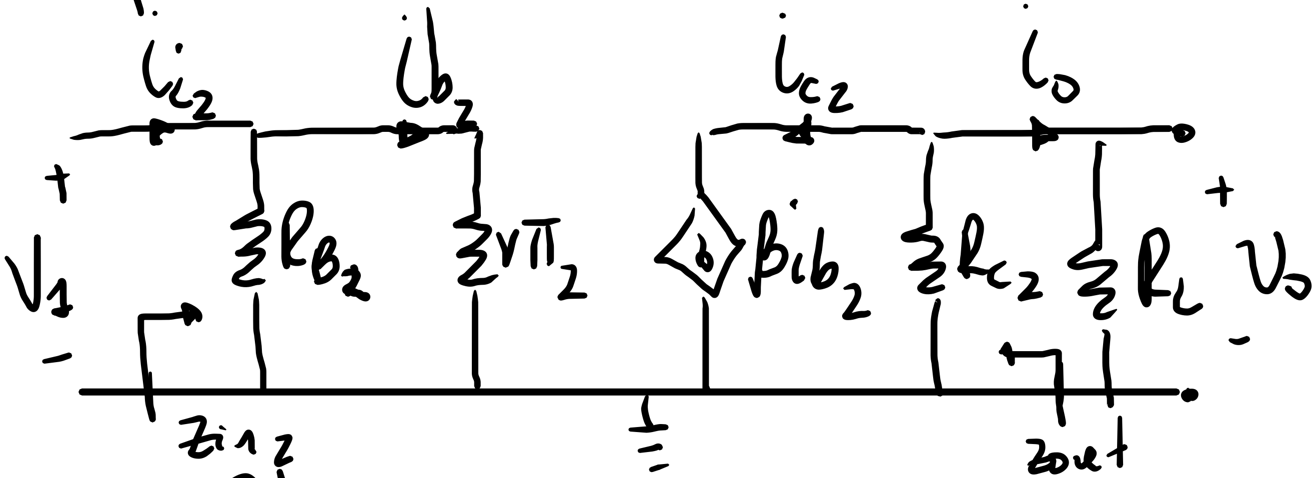
Etapa 2

$$r\pi_2 = \frac{\beta\, 26\,mV}{I_{CQ_2}} = 5.1\,K\Omega$$

$R_{B_2} = 9K\Omega$

$R_{C_2} = 5K\Omega$

$R_L = 5K\Omega$



$$A_{v_2} = \frac{V_o}{V_1} \qquad V_o = -\beta i_{b_2} R_{C_2} \| R_L \;;\; V_1 = i_{b_2} r\pi_2$$

$$A_{v_2} = \frac{-\beta R_{C_2} \| R_L\, \cancel{i_{b_2}}}{\cancel{i_{b_2}}\, r\pi_2} = -49.02$$

$$A_{i_2} = \frac{i_o}{i_{i_2}} \;;\quad i_o = \frac{-\beta i_{b_2} R_{C_2}}{R_{C_2} + R_L} \;;\quad i_{b_2} = \frac{i_{i_2} R_{B_2}}{R_{B_2} + r\pi_2}$$

Reemplazo i_{b_2} en $i_o \Rightarrow i_o = \frac{-\beta R_{C_2}}{R_{C_2} + R_L} \cdot \frac{i_{i_2} R_{B_2}}{R_{B_2} + r\pi_2}$

$$\Rightarrow \frac{i_o}{i_{i_2}} = A_{i_2} = \frac{-\beta R_{C_2} R_{B_2}}{(R_{C_2} + R_L)(R_{B_2} + r\pi_2)} = -32.1$$

$Zin_2 = R_L' = R_{B2} \parallel r\pi_2 = 5.1K \parallel 9K = 3.26K\Omega$

$Zout = R_{C2} = 5K\Omega$

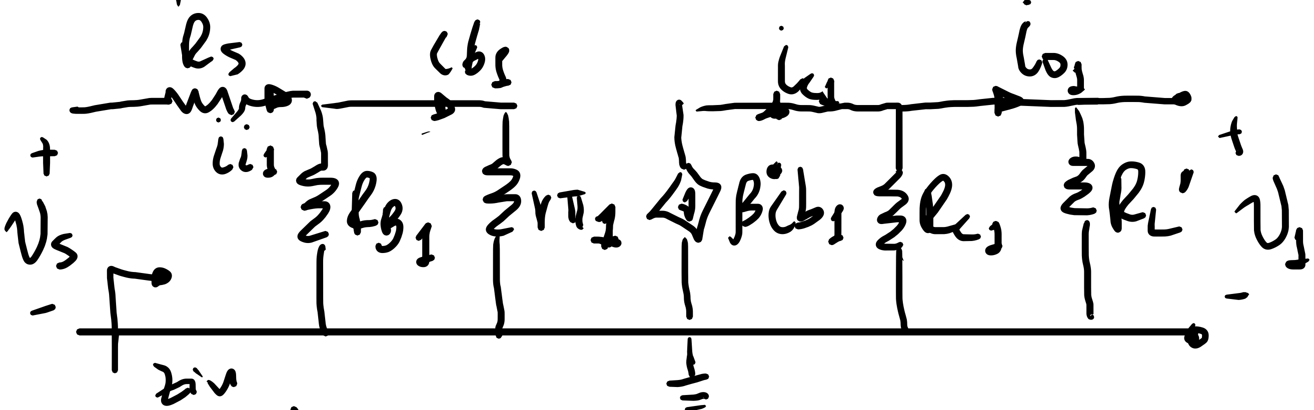
$r\pi_1 = \frac{\beta 26mV}{I_{CQ1}} = 119.8\Omega$

$R_{B1} = 696.6$

$R_{C1} = 200$ $R_S = 50$

$R_L' = 3.26K\Omega$

Etapa 1.



$Av_1 = \frac{V_1}{V_S}$; $V_1 = -\beta i b_1 \, R_{C1} \parallel R_L'$; $V_S = i_{i1} R_S + i b_1 r\pi_1$

Pero $ib_1 = \frac{i_{i1} R_{B1}}{R_{B1} + r\pi_1} \Rightarrow i_{i1} = \frac{ib_1 (R_{B1} + r\pi_1)}{R_{B1}}$

$\Rightarrow V_S = \frac{ib_1 (R_{B1} + r\pi_1) R_S}{R_{B1}} + ib_1 r\pi_1$

$\Rightarrow Av_1 = -\frac{\beta R_{C1} \parallel R_L' \cancel{ib_1}}{\left[\frac{(R_{B1} + r\pi_1) R_S}{R_{B1}} + r\pi_1\right] \cancel{ib_1}} = -105.6$

$$Ai_2 = \frac{\dot{i}_{o1}}{\dot{i}_{i1}} \quad ; \quad \dot{i}_{o1} = -\frac{\beta i_{b1} R_{c1}}{R_{c1} + R_L'} \quad ; \quad i_{b1} = \frac{\dot{i}_{i1} R_{B1}}{R_{B1} + r\pi_1}$$

Reemplazando: $\dot{i}_{o1} = -\frac{\beta R_{c1}}{R_{c1} + R_L'} \cdot \frac{\dot{i}_{i1} R_{B1}}{R_{B1} + r\pi_1}$

$$\Rightarrow \frac{\dot{i}_{o1}}{\dot{i}_{i1}} = Ai_1 = \frac{-\beta R_{c1} R_{B1}}{(R_{c1} + R_L')(R_{B1} + r\pi_1)} = -4.93$$

$$Zin_1 = [R_{B1} \parallel r\pi_1] + R_S = 152.22\,\Omega.$$

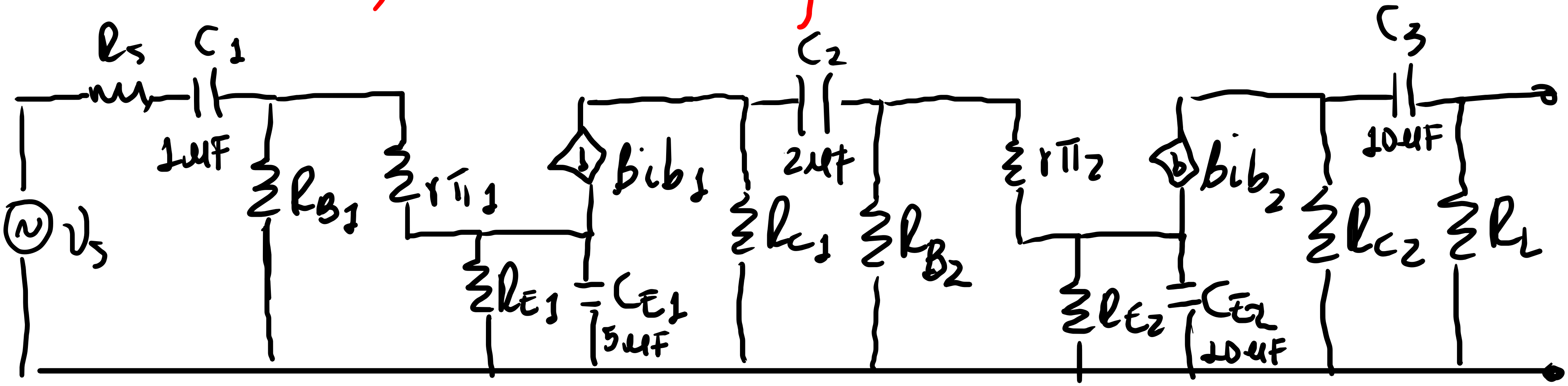
$$Av_T = Av_1 * Av_2 = \overset{Av_2}{-49.02} * (\overset{Av_1}{-105.6}) = 5176.5$$

$$Ai_T = Ai_1 * Ai_2 = \overset{Ai_2}{-32.1} * (\overset{Ai_1}{-4.93}) = 158.25$$

$$Zin = 152.22\,\Omega$$

$$Zout = 5k\,\Omega$$

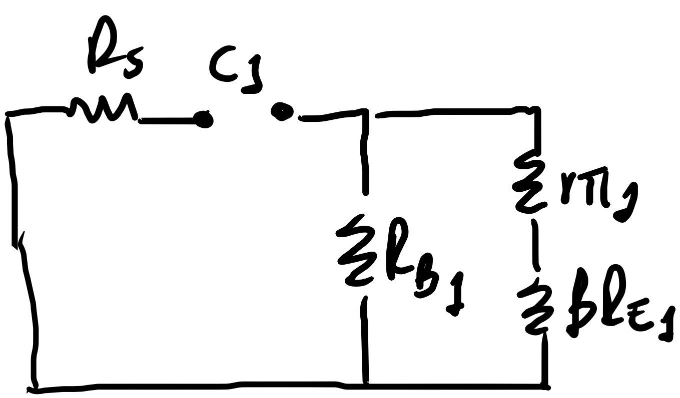
Análisis de frecuencias bajas



Para C_1:

⇒ Cero en el origen

⇒ Polo en $\omega_{p1} = \frac{1}{\tau_1}$; $\tau_1 = R_{eq1} C_1$



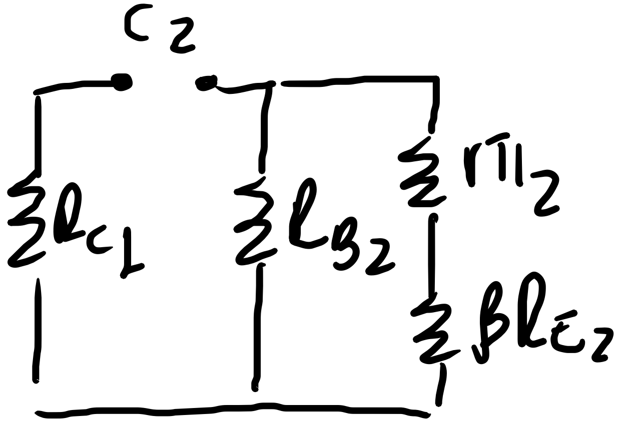
$$R_{eq1} = \left[(r\pi_1 + \beta R_{E1}) \parallel R_{B1} \right] + R_s = 702\,\Omega$$

$$\Rightarrow \omega_{p1} = \frac{1}{702 * 1uF} = 1.42\ \mathrm{Krad/s}$$

Para C_2:

$\Rightarrow$ Cero en el origen

$\Rightarrow$ Polo en $\omega_{p2} = \dfrac{1}{\tau_2}$; $\tau_2 = R_{eq_2} C_2$



$$R_{eq_2} = \left[(r\pi_2 + \beta R_{E_2}) \,||\, R_{B_2} \right] + R_{C_1} = 7.94 K\Omega$$

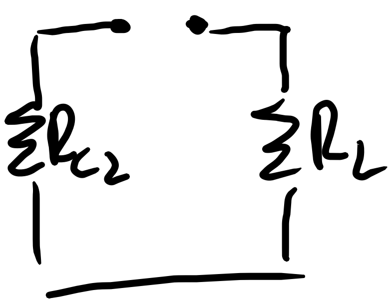
$$\Rightarrow \omega_{p2} = \frac{1}{7.94K * 2\mu F} = 62.97 \text{ rad/s}$$

Para C_3:

$\Rightarrow$ Cero en el origen

$\Rightarrow$ Polo en $\omega_{p3} = \dfrac{1}{\tau_3}$; $\tau_3 = R_{eq_3} C_3$

$$R_{eq_3} = R_{C_2} + R_L = 10 K\Omega$$

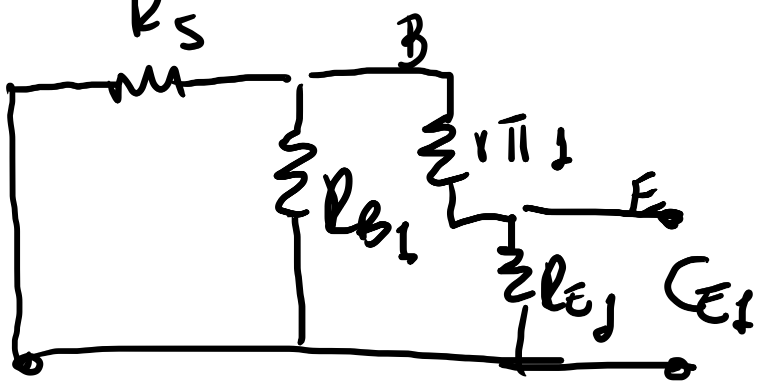


$$\Rightarrow \omega_{p3} = \frac{1}{10K\Omega * 10\mu F} = 10 \text{ rad/s}$$

Para C_{E1}

⇒ Cero en $\omega_{z1} = \frac{1}{R_{E1}C_{E1}} = \frac{1}{100 * 5\mu F} = 2K\,rad/s$

⇒ Polo en $\omega_{p4} = \frac{1}{R_{eq4}C_{E1}}$



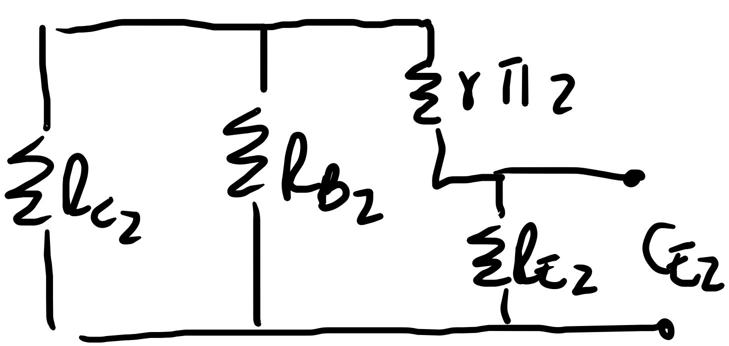
$R_{eq4} = \frac{[(R_S \,||\, R_{B1}) + r_{\pi 1}]}{\beta} \,||\, R_{E1} = 1.64\Omega$

⇒ $\omega_{p4} = \frac{1}{1.64\Omega * 5\mu F} = 121.9\,Krad/s$

Para C_{E2}

⇒ Cero en $\omega_{z2} = 1/R_{E2}C_{E2} = 1/500 \times 10\mu F = 200\,rad/s$

⇒ Polo en $\omega_{p5} = 1/R_{eq5}C_{E2}$



$R_{eq2} = \frac{(R_{C1} \,||\, R_{B2}) + r_{\pi 2}}{\beta} \,||\, R_{E2}$

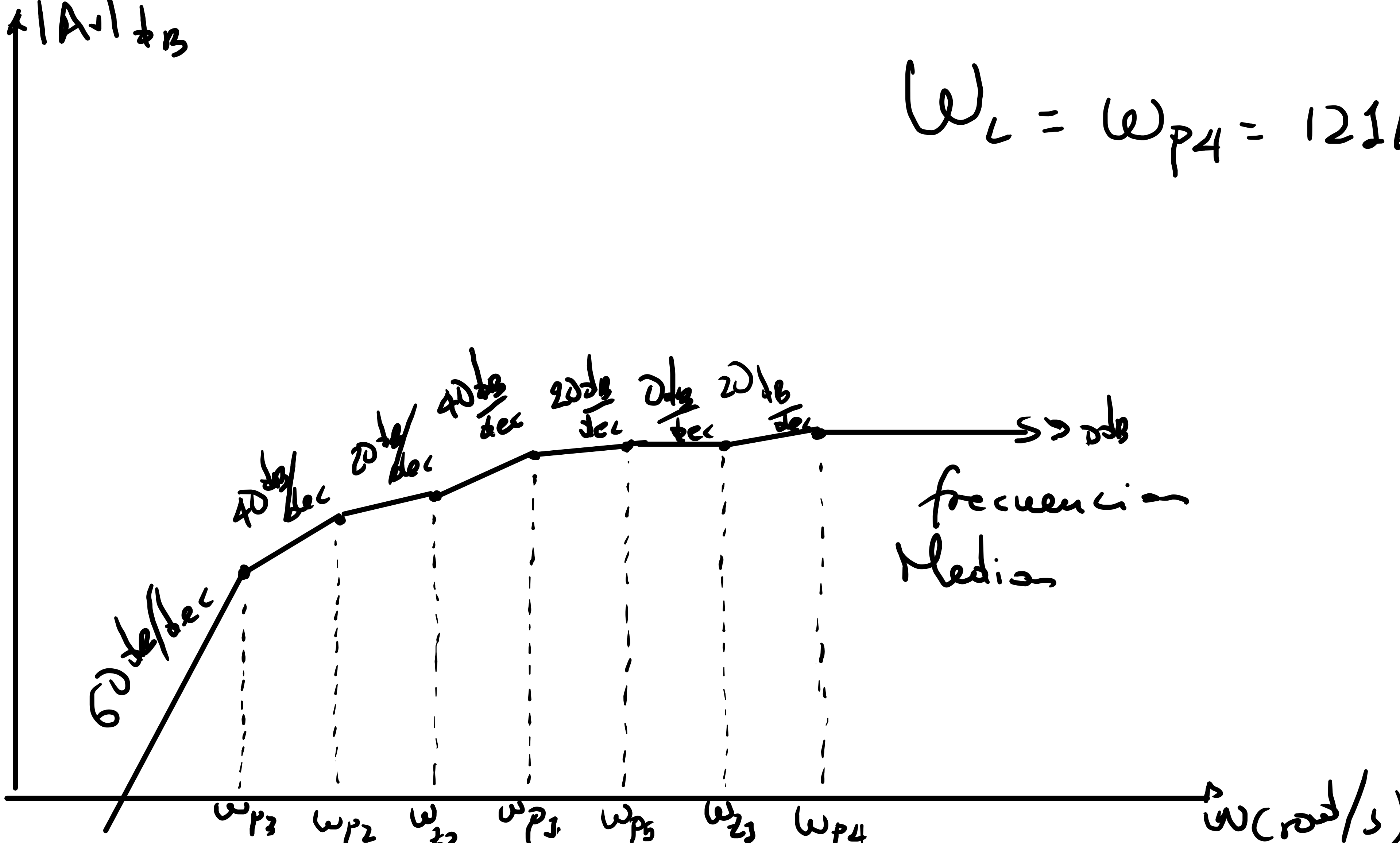
$R_{eq2} = 48.7$

⇒ $\omega_{p5} = \frac{1}{48.7 * 10\mu F} = 2\,Krad/s$

$$\omega_{p3} < \omega_{p2} < \omega_{z2} < \omega_{p1} < \omega_{p5} < \omega_{z1} < \omega_{p4}$$
$$10 \quad 62.97 \quad 200 \quad 1.42K \quad 2K \quad 2K \quad 121K$$

La gráfica de la respuesta en frecuencia:

$$\omega_L = \omega_{p4} = 121\,\mathrm{Krad/s}$$



Análisis para frecuencias altas

Hallamos C_{be_1} y C_{be_2} ; $\omega_T = 2\pi(500MHz)$; $I_{CQ_1} = 21.7mA$

$C_{bc_1} = C_{bc_2} = 10pF$ $\qquad I_{CQ_2} = 508.5\mu A$

$$C_{be_1} = \frac{g_{m_1}}{\omega_T} \; ; \; g_{m_1} = \frac{1}{r_{e_1}} = \frac{I_{CQ_1}}{26mV} = 0.834$$

$A_{v_1} = -105.6$

$A_{v_2} = -49.02$

$$\Rightarrow C_{be_1} = \frac{0.834}{2\pi \times 500MHz} = 265.5pF$$

$$C_{be_2} = \frac{g_{m_2}}{\omega_T} \; ; \; g_{m_2} = \frac{1}{r_{e_2}} = \frac{I_{CQ_2}}{26mV} = 0.0195$$

$$C_{be_2} = \frac{0.0195}{2\pi \times 500MHz} = 6.2pF$$

Aplicamos el teorema de Miller:

Para C_{bc_1} y C_{bc_2}:

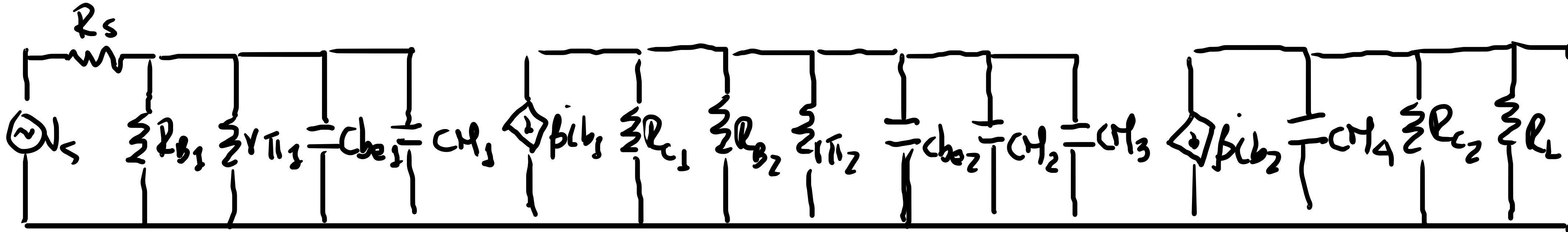
$$C_{M_1} = C_{bc_1}(1 - A_{V_1}) = 10pF(1 + 105.6) = 1.07nF$$

$$C_{M_2} = C_{bc_1}(1 - 1/A_{V_1}) = 10pF\left(1 + \frac{1}{105.6}\right) = 10.9pF$$

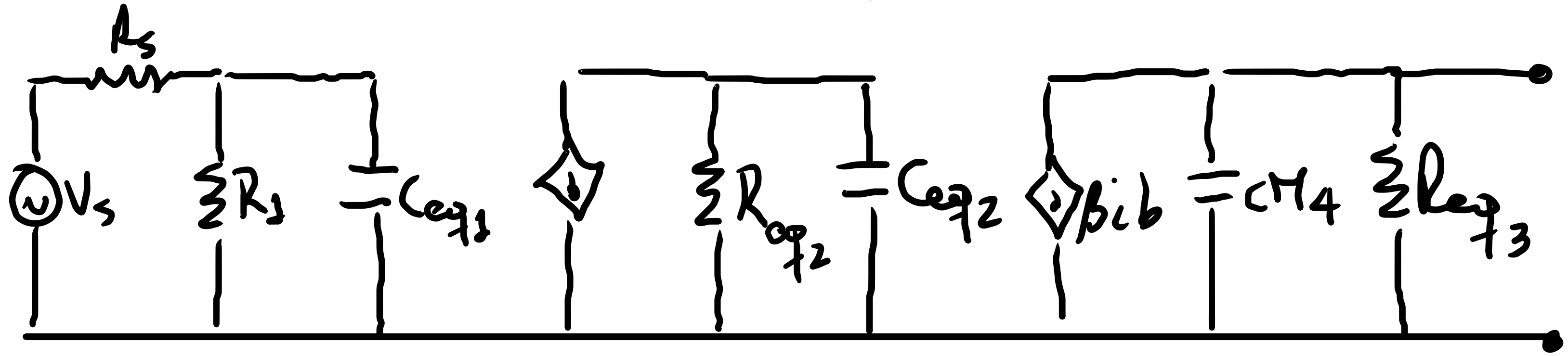
$$C_{M_3} = C_{bc_2}(1 - A_{V_2}) = 10pF(1 + 49.02) = 500.2pF$$

$$C_{M_4} = C_{bc_2}(1 + 1/A_{V_2}) = 10pF(1 + 1/49.02) = 10.2pF$$

El modelo equivalente para frecuencias altas queda:



Reduciendo el circuito, se obtiene:



Polo en C_{eq1}: $\frac{1}{\tau_1} = \frac{1}{R_{eq1} C_{eq1}}$; $C_{eq1} = C_{be1} + C_{M1} =$

$C_{eq1} = 0.265 + 1.07\ nF = 1.335\ nF$

$W_{p1} = \frac{1}{33.57 * 1.335\ nF} = 22.3\ Mrad/s.$

$R_{eq1} = R_S \| R_1 = \left(\frac{1}{R_S} + \frac{1}{R_{B1}} + \frac{1}{r_{\pi1}}\right)^{-1}$

$R_{eq1} = 33.57\ \Omega$

Rlo en C_{eq_2} $\Rightarrow$ $\omega_{p_2} = \dfrac{1}{R_{eq_2} C_{eq_2}}$; $C_{eq_2} = C_{be_2} + C_{M_2} + C_{M_3} = 517.3\,pF$

$6.2\,pF + 10.2\,pF + 500.2\,pF$

$\omega_{p_2} = \dfrac{1}{188.4 * 517.3\,pF} = 10.26\ Mrad/s.$

$R_{eq_2} = R_{C_1} \| R_{B_2} \| r_{\pi_2}$

$= \left(\dfrac{1}{200} + \dfrac{1}{9k} + \dfrac{1}{5.1k}\right)^{-1} = 188.4\,\Omega$

Para $C_{eq_3} = C_{M4} = 10.2\,pF$

$\omega_{p_3} = \dfrac{1}{C_{eq_3} R_{eq_3}}$; $R_{eq_3} = R_{C_2} \| R_L = 2.5\,k\Omega$

$\omega_{p_3} = \dfrac{1}{10.2\,pF * 2.5\,k\Omega} = 39.2\ Mrad/s.$

En resumen $\underset{10.26M}{\omega_{p_2}} < \underset{22.3M}{\omega_{p_1}} < \underset{39.2\,M}{\omega_{p_3}}$

$\omega_H = \omega_{p_2} = 10.26\,Mrad/s$

La gráfica para frecuencia altas queda: