UNIVERSIDAD TECNOLÓGICA NACIONAL
FACULTAD REGIONAL BUENOS AIRES

Trabajo practico N°2

APROXIMACION DE FUNCIONES TRANSFERENCIA

Grupo 3 – 08/06

Teoría de los circuitos II

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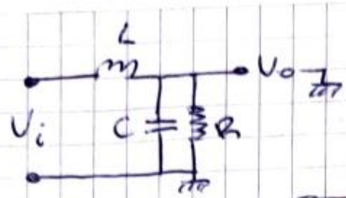
Ejercicio 1)



$Z_1 = sL \qquad Z_2 = \frac{1}{\frac{1}{R}+sC} \qquad R_1 = 1k\Omega$

$$\frac{V_o}{V_i} = \frac{Z_2}{Z_1+Z_2} = \frac{\frac{1}{\frac{1}{R}+sC}}{sL+\frac{1}{\frac{1}{R}+sC}} = \frac{1}{\cancel{\frac{1}{R}+sC}} \cdot \frac{\cancel{\frac{1}{R}+sC}}{s^2CL+s\frac{L}{R}+1}$$

$$\frac{V_o}{V_i} = \frac{1}{s^2CL+s\frac{L}{R}+1} = \frac{1/LC}{s^2+\frac{1}{RC}s+1/LC} = \frac{\omega_0^2}{s^2+s\frac{\omega_0}{Q}+\omega_0^2}$$

Butterworth: $\frac{V_o}{V_i} = \frac{1}{s^2+s\sqrt{2}+1}$

$\frac{1}{RC} = \sqrt{2}$, si $R=1 \Rightarrow C = 0{,}707$

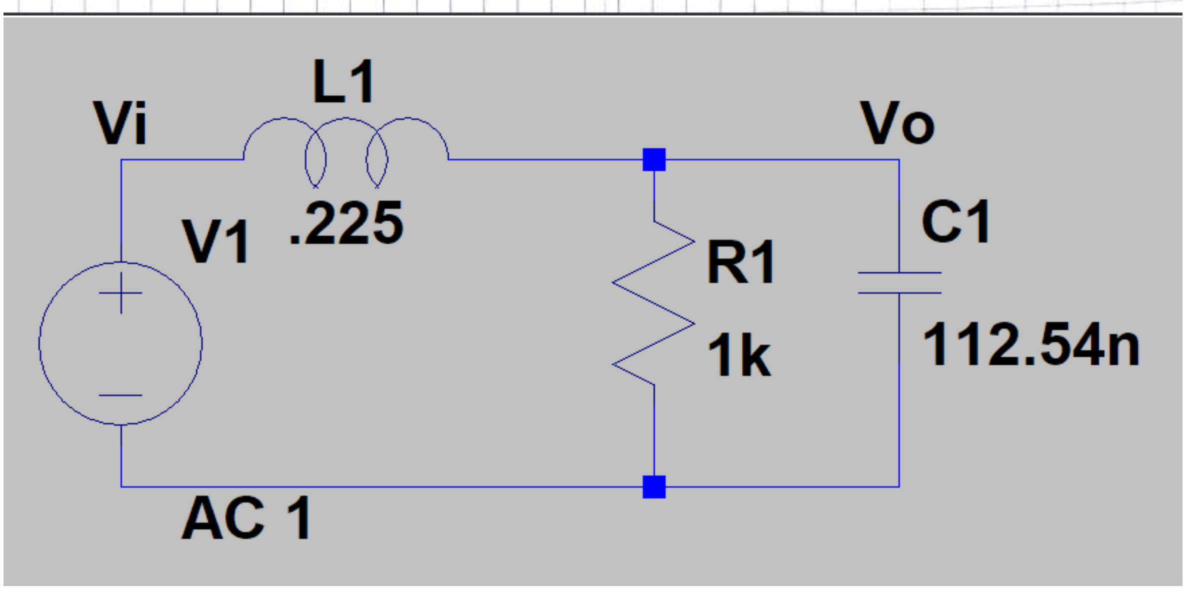
$\omega_0^2 = 1 = \frac{1}{LC} \Rightarrow C = \frac{1}{L} \Rightarrow L = 1{,}414$

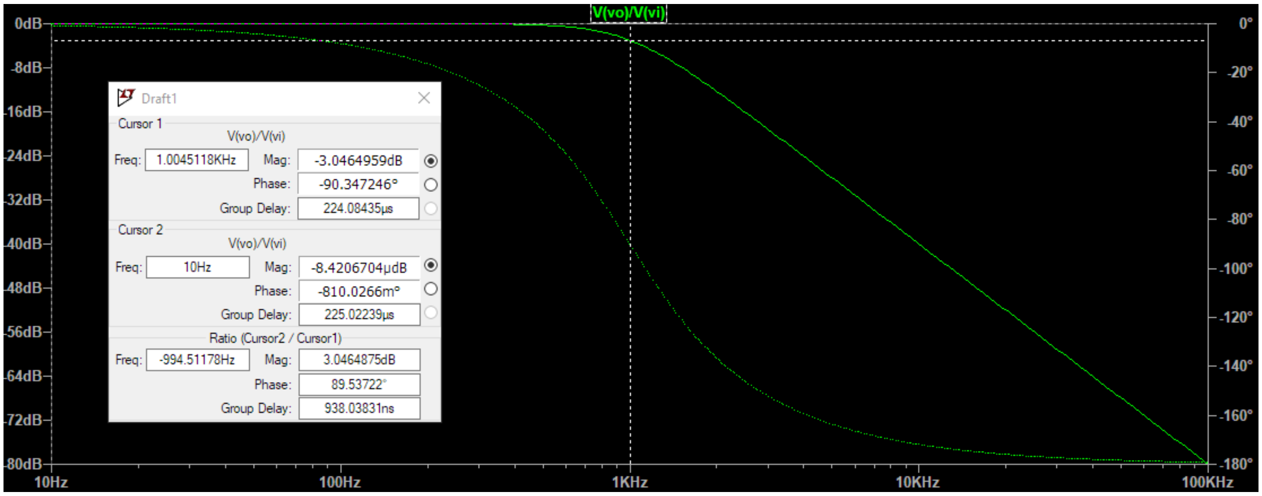
Desnormalizo: $\Omega_Z = 1k\Omega \qquad \Omega_\omega = 2\pi\, 1000 \frac{1}{rad}$

$\underline{R} = 1 \cdot \Omega_Z = \underline{1k\Omega}$

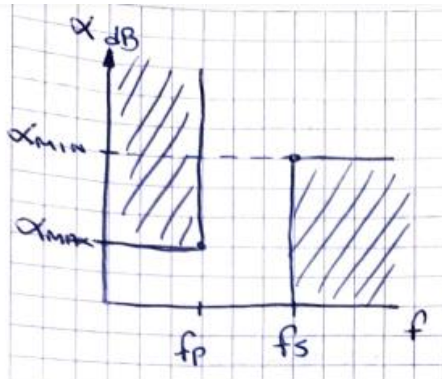
$\underline{L} = 1{,}414 \cdot \Omega_Z \frac{1}{\Omega_\omega} = \underline{0{,}225\ Hy}$

$\underline{C} = 0{,}707 \cdot \frac{1}{\Omega_Z} \cdot \frac{1}{\Omega_\omega} = \underline{112{,}54\ nf}$




V(vo)/V(vi)
0dB
-8dB
-16dB
-24dB
-32dB
-40dB
-48dB
-56dB
-64dB
-72dB
-80dB
0°
-20°
-40°
-60°
-80°
-100°
-120°
-140°
-160°
-180°
10Hz
100Hz
1KHz
10KHz
100KHz
Draft1
Cursor 1
V(vo)/V(vi)
Freq: 1.0045118KHz
Mag: -3.0464959dB
Phase: -90.347246°
Group Delay: 224.08435µs
Cursor 2
V(vo)/V(vi)
Freq: 10Hz
Mag: -8.4206704µdB
Phase: -810.0266m°
Group Delay: 225.02239µs
Ratio (Cursor2 / Cursor1)
Freq: -994.51178Hz
Mag: 3.0464875dB
Phase: 89.53722°
Group Delay: 938.03831ns

Ejercicio 2)



$\alpha_{MIN} = 20dB \quad \alpha_{MAX} = 0,5dB$

$f_p = 1000\,Hz \quad f_s = 2000\,Hz$

Normalizo con $\Omega_w = \omega_p$:

$\omega_p = 1 \;, \quad \omega_s = 2$

Cálculo ξ^2: $\quad |T(\omega)|^2 = \dfrac{1}{1+\xi^2\omega^{2N}}$

En ω_p: $\quad \alpha_{max} = 10 \log(1+\xi^2)$

$\xi^2 = 10^{\frac{\alpha_{MAX}}{10}} - 1 = 0,122$

En ω_s: $\quad \alpha_{MIN} = 10 \log(1+\xi^2 \omega_s^{2N})$

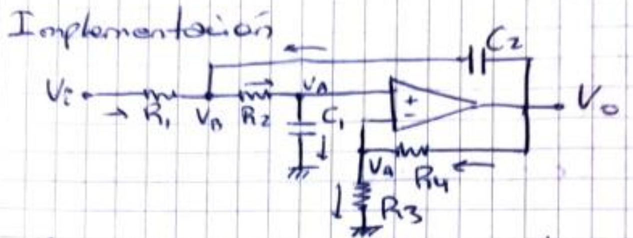
Itero N
- $\to N=2: \quad \alpha = 4,7\,dB < \alpha_{MIN}$
- $\to N=3: \quad \alpha = 9,45\,dB < \alpha_{MIN}$
- $\to N=4: \quad \alpha = 15,08\,dB < \alpha_{MIN}$
- $\to N=5: \quad \alpha = 21\,dB > \alpha_{MIN}$ ✓ $\boxed{N=5}$

Polos cada $\frac{\pi}{N}$ =
- $\to$ 1 polo sobre el eje σ
- $\to$ 2 pares de polos complejos conjugados

$$P \begin{cases} P_1 = \cos(\pi) + j\,\mathrm{sen}(\pi) = -1 \\ P_{2-3} = \cos\left(\frac{4}{5}\pi\right) \pm j\,\mathrm{sen}\left(\frac{4}{5}\pi\right) = -0,81 \pm j\,0,58 \\ P_{4-5} = \cos\left(\frac{3}{5}\pi\right) \pm j\,\mathrm{sen}\left(\frac{3}{5}\pi\right) = -0,31 \pm j\,0,95 \end{cases}$$

$$Q \begin{cases} Q_1 = \dfrac{1}{2\cos(\pi)} = 0,5 \\ Q_{2-3} = \dfrac{1}{2\cos\left(\frac{4}{5}\pi\right)} = 0,617 \\ Q_{4-5} = \dfrac{1}{2\cos\left(\frac{3}{5}\pi\right)} = 1,613 \end{cases}$$

Implementación



$$V_A = V_o \frac{R_3}{R_3+R_4} \quad ① \qquad V_A = \frac{V_o}{A}, \qquad A = \frac{R_3+R_4}{R_4}$$

$I_{C_1} = I_{R_2}$: $\quad V_A sC_1 = \frac{V_B - V_A}{R_2} \Rightarrow V_B = V_A(sC_1R_2+1)$

$$V_B = V_o \cdot \frac{sC_1R_2+1}{A} \quad ②$$

$$\frac{V_B - V_1}{R_1} + \frac{V_B - V_A}{R_2} + \frac{V_B - V_o}{1/sC_1} = 0$$

$$\frac{(sC_1R_2+1)V_o}{R_1A} - \frac{V_1}{R_1} + \frac{(sC_1R_2+1)V_o}{R_2A} - \frac{V_o}{AR_2} + \frac{(sC_1R_2+1)V_o}{\frac{A}{sC_2}} - \frac{V_o}{1/sC_2} = 0$$

$$\frac{V_1}{R_1} = V_o\left[\frac{sC_1R_2+1}{R_1A} + \frac{sC_1R_2+1}{R_2A} - \frac{1}{R_2A} + \frac{sC_1R_2+1}{\frac{A}{sC_2}} - sC_2\right]$$

$$\frac{V_1}{R_1} = \frac{V_o}{A}\left[\frac{sC_1R_2}{R_1} + \frac{1}{R_1} + sC_1\frac{\cancel{R_2}}{\cancel{R_2}} + \frac{\cancel{1}}{R_2} - \frac{\cancel{1}}{R_2} + s^2C_1C_2R_2 + sC_2 - sC_2A\right]$$

$$\frac{V_1}{\cancel{R_1}} = \frac{V_o}{A}\left[\frac{s^2C_1C_2R_2 + sC_1R_2 + sC_1R_1 + sC_2R_1 + sC_2R_1A + 1}{\cancel{R_1}}\right]$$

$$\frac{V_o}{V_1} = \frac{A}{s^2C_1C_2R_2 + s\left(C_1R_1 + C_1R_2 + C_2R_1(1+A)\right) + 1}$$

$$\frac{V_o}{V_1} = A\frac{1/R_1R_2C_1C_2}{s^2 + s\left(\frac{1}{R_1C_2} + \frac{1}{R_2C_2} + \frac{1-A}{R_2C_1}\right) + \frac{1}{R_1R_2C_1C_2}} = A\frac{\omega_o^2}{s^2 + s\frac{\omega_o}{Q} + \omega_o^2}$$

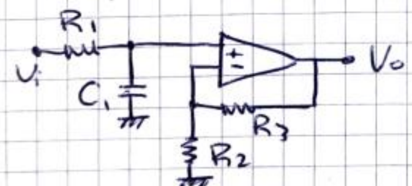
$$\omega_0^2 = \frac{1}{R_1R_2C_1C_2}$$

$$\frac{\omega_0}{Q} = \frac{1}{R_1C_2} + \frac{1}{R_2C_2} + \frac{1-A}{R_2C_1} = \frac{R_1+R_2}{R_1R_2C_2} + \frac{1-A}{R_2C_1}$$

$$\frac{\omega_0}{Q} = \frac{C_1(R_1+R_2) + R_1C_2(1-A)}{R_1R_2C_1C_2} = \left[C_1(R_1+R_2) + R_1C_2(1-A)\right]\omega_0^2$$

$$(C_1R_1 + C_1R_2 + R_1C_2 - AR_1C_2)\cdot\omega_0 = \frac{1}{Q}$$

Primer etapa: $\omega_{01} = 1$, $Q = 0,5$, $A = 10$ (20dB)



$$T_1(s) = A\cdot\frac{\omega_{01}}{s+\omega_{01}}, \quad \omega_{01} = \frac{1}{R_1C_1}$$

$$A = 1 + \frac{R_3}{R_2}$$

* Adoptamos $R_1 = 1$, $C_1 = 1$, $R_2 = 1$, $R_3 = 9$

Segundo etapa: , $Q_2 = 0,617$, $A = 1$, $\omega_{02} = 1$

Sallen-Key: $\omega_{02}^2 = \quad = \frac{1}{R_5R_6C_2C_3} = 1$

$$\frac{\omega_{02}}{Q_2} = 1,614 = \frac{1}{R_5C_3} + \frac{1}{R_6C_3} + \cancel{\frac{1-A}{R_6C_2}}^{\,0} = \frac{R_5+R_6}{R_5R_6C_3} = (R_5+R_6)\,\omega_{02}^2C_2$$

$$\Rightarrow \frac{1}{\omega_{02}Q_2} = (R_5+R_6)C_2 = 1,627,$$

Adopto $\boxed{R_5 = 1}$, $\boxed{R_6 = 1}$ $\Rightarrow \boxed{C_2 = 0,8136}$

$\Rightarrow \boxed{C_3 = 1,2209}$

Tercera etapa:

$Q_3 = 1{,}613$, $A = 1$

$\omega_{03} = 1$

$$\omega_{03}^2 = \frac{1}{R_7 R_8 C_4 C_5} = 1$$

$$\frac{\omega_{03}}{Q_3} = 0{,}6195 = \frac{1}{R_7 C_5} + \frac{1}{R_8 C_5} = \frac{R_8 + R_7}{R_8 R_7 C_5} = (R_8 + R_7)\,\omega_{03}^2\, C_4$$

$$\frac{1}{\omega_{03} Q_3} = 1{,}612 = (R_8 + R_7) C_4$$

Adopto: $\boxed{R_8 = 1}$, $\boxed{R_7 = 1}$ $\Rightarrow$ $\boxed{C_4 = 0{,}806}$

$\Rightarrow$ $\boxed{C_5 = 1{,}24}$

Desnormalización $\Omega_z = 1k$; $\Omega_w = \frac{1}{2\pi\, 1000} \cdot \xi^{1/N} = \frac{1}{7754}$

El cálculo de Q fue para radio unitario

$R_1 = R_2 = R_4 = R_5 = R_6 = R_7 = R_8 = 1 k\Omega$

$R_3 = 9 k\Omega$

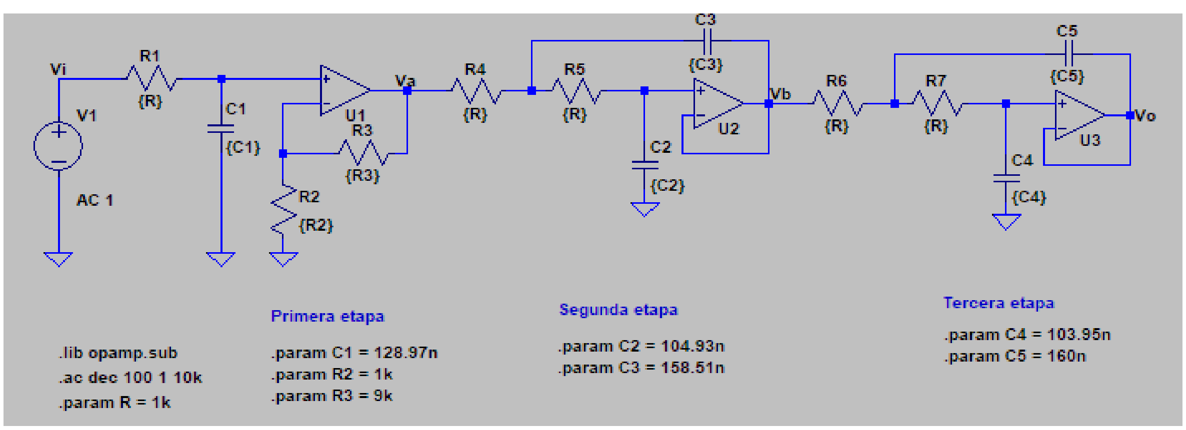
$$C_1 = \frac{1}{\Omega_z} \cdot \Omega_w = 128{,}97\ nf$$

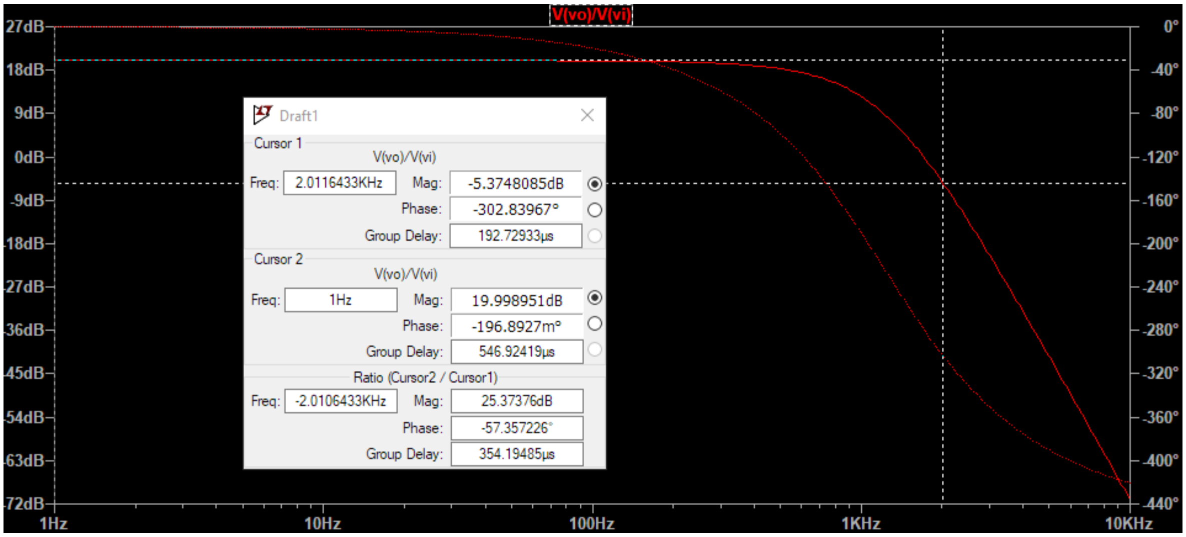
$$C_2 = \frac{0{,}8136}{\Omega_z} \cdot \Omega_w = 104{,}93\ nf$$

$$C_3 = \frac{1{,}2291}{\Omega_z} \cdot \Omega_w = 158{,}51\ nf$$

$$C_4 = \frac{0{,}806}{\Omega_z}\, \Omega_w = 103{,}95\ nf$$

$$C_5 = \frac{1{,}2405}{\Omega_z} \cdot \Omega_w = 160\ nf$$





Ganancia de 20 dB sobre la banda de paso y 25 dB en la frecuencia de corte.

③ Un filtro pasa-bajos Chebyshev se diseña para obtener una atenuación de 48dB para frecuencias mayores a 9,6 KHZ, con una atenuación máxima de 0,4dB desde continua hasta 3,2KHZ.

a) Determinar el orden del filtro y el parámetro ε.

b) Graficar la respuesta en módulo del filtro.

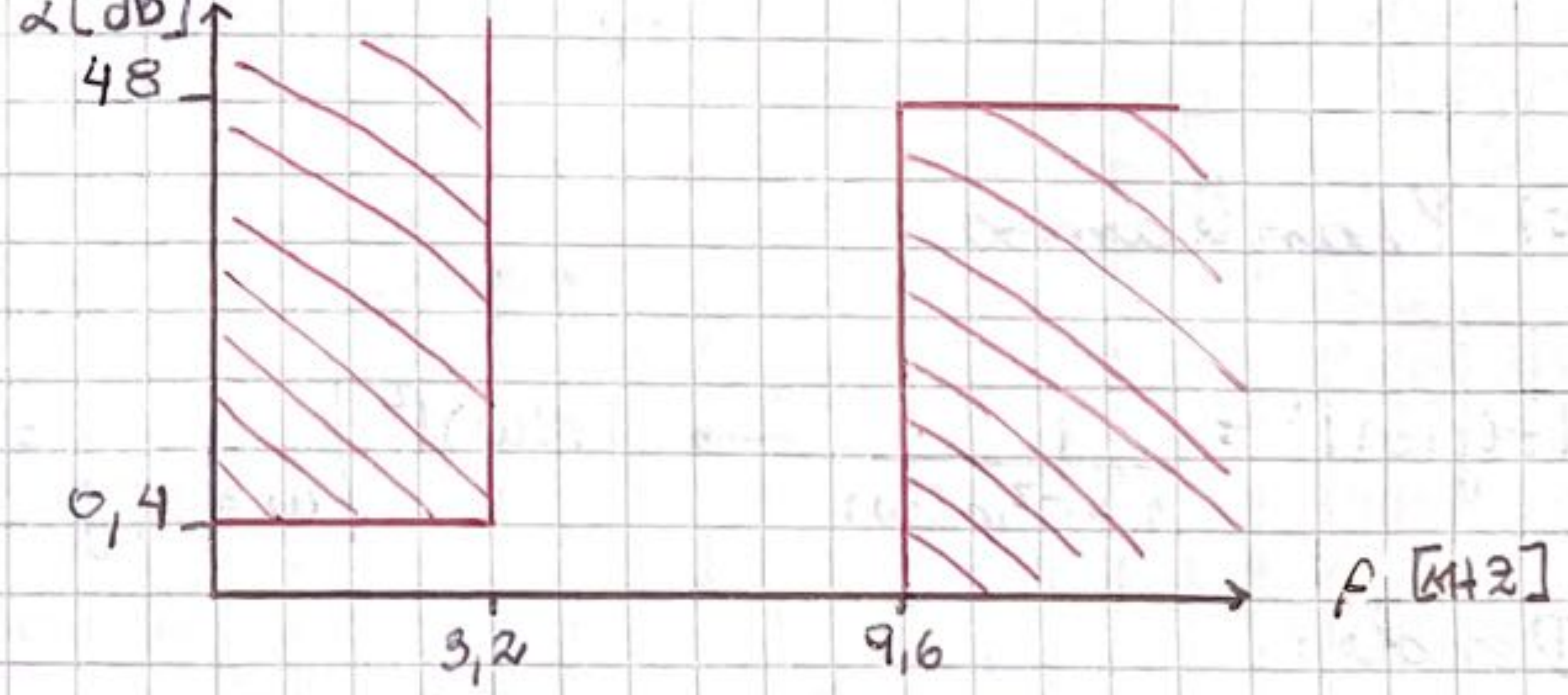
c) Determinar la ubicación de polos y ceros.

d) Sintetizar el circuito utilizando estructuras Kerwin-Huelsman-Newcomb (KHN, también conocido como Variable de estado) y simular verificando las condiciones de diseño.

Resolución:

a) Armamos la plantilla de nuestro pasa-bajos.

$$\begin{cases} \alpha_{MAX} = 0{,}4\,dB \\ \alpha_{MIN} = 48\,dB \\ \omega_p = 2\pi \cdot 3{,}2\,KHZ \\ \omega_s = 2\pi \cdot 9{,}6\,KHZ \end{cases}$$



Luego, calculamos: $\varepsilon^2 = 10^{\alpha_{MAX}/10} - 1 = 10^{0,4/10} - 1 = 0{,}0965$

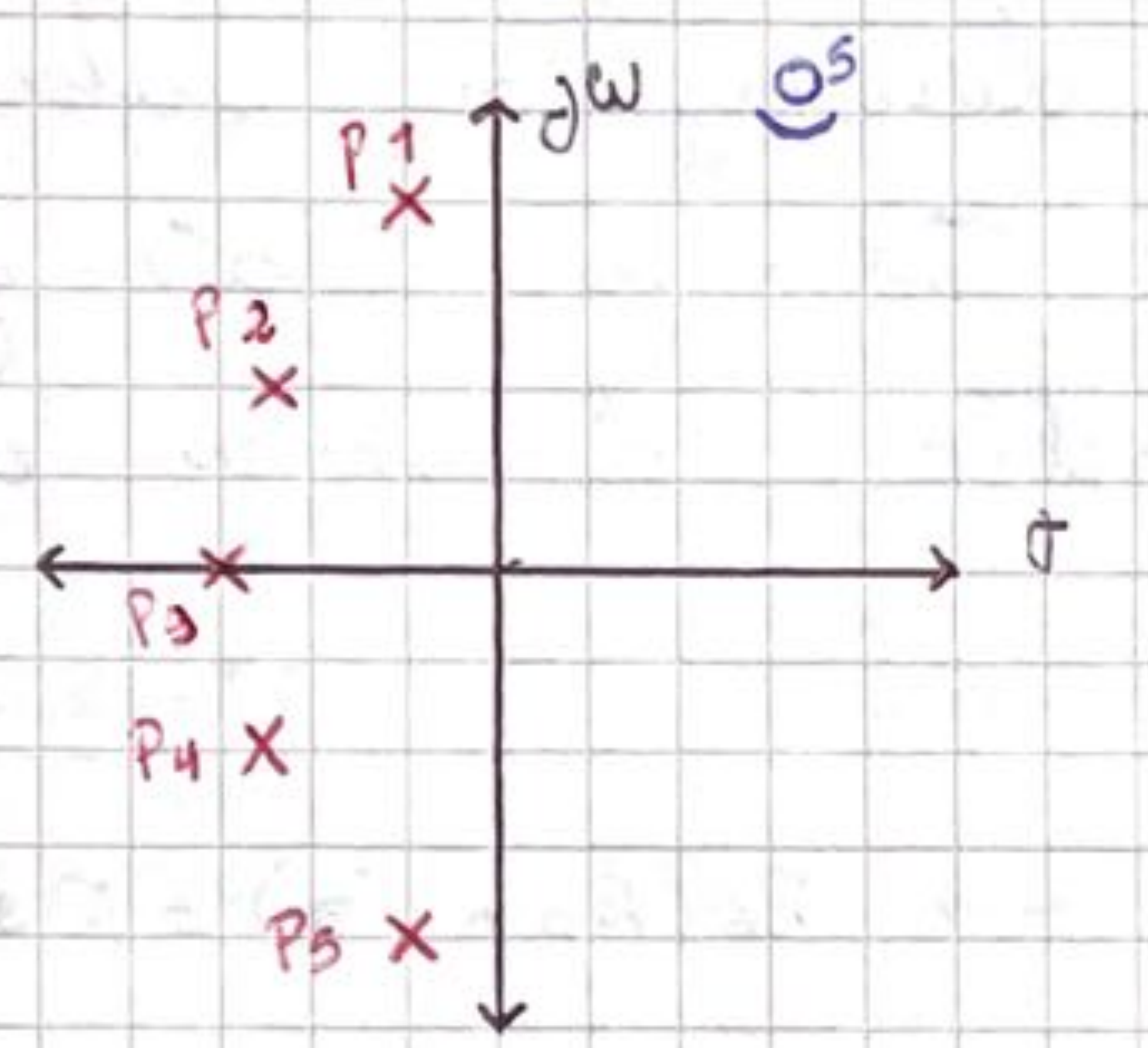
$\boxed{\varepsilon = 0{,}3106}$ $\longrightarrow$

NOTA

* Despejamos P_1, P_2 y P_3, ya que $P_4 = P_2^*$ y $P_5 = P_1^*$.

- $P_1 = \sigma_1 + \omega_1 = -0,119 - j\,1,02 = 1,027\,e^{j\,1,45}$
- $P_2 = \sigma_2 + \omega_2 = -0,3124 - j\,0,63 = 0,703\,e^{j\,1,11}$
- $P_3 = \sigma_3 + \omega_3 = -0,386 = 0,386\,e^{j\pi}$

Como es un filtro pasa-bajos, los 5 ceros se ubican en el infinito. Entonces:



d) Armamos nuestra transferencia a partir de los polos indicados y lo planteamos como una cascada de un pasa-bajos de orden 1 con dos pasa-bajos de orden 2.

$$T(s) = \underbrace{\frac{0,386}{s+0,386}}_{I} + \underbrace{\frac{1,053}{s^2+s\,0,238+1,053}}_{II} + \underbrace{\frac{0,494}{s^2+s\,0,625+0,494}}_{III}$$

Sabemos que:

(I) $\left\{ \omega_{o_1}^2 = 0,386 \right.$

(II) $\left\{ \begin{array}{l} \omega_{o_2}^2 = 1,053 \\ Q_2 = 4,312 \end{array} \right.$

(III) $\left\{ \begin{array}{l} \omega_{o_3}^2 = 0,494 \\ Q_3 = 1,125 \end{array} \right.$

Luego, normalizamos con: $\omega_p = \Delta\omega = 2\pi \cdot 3,2\, kHz$. Así:

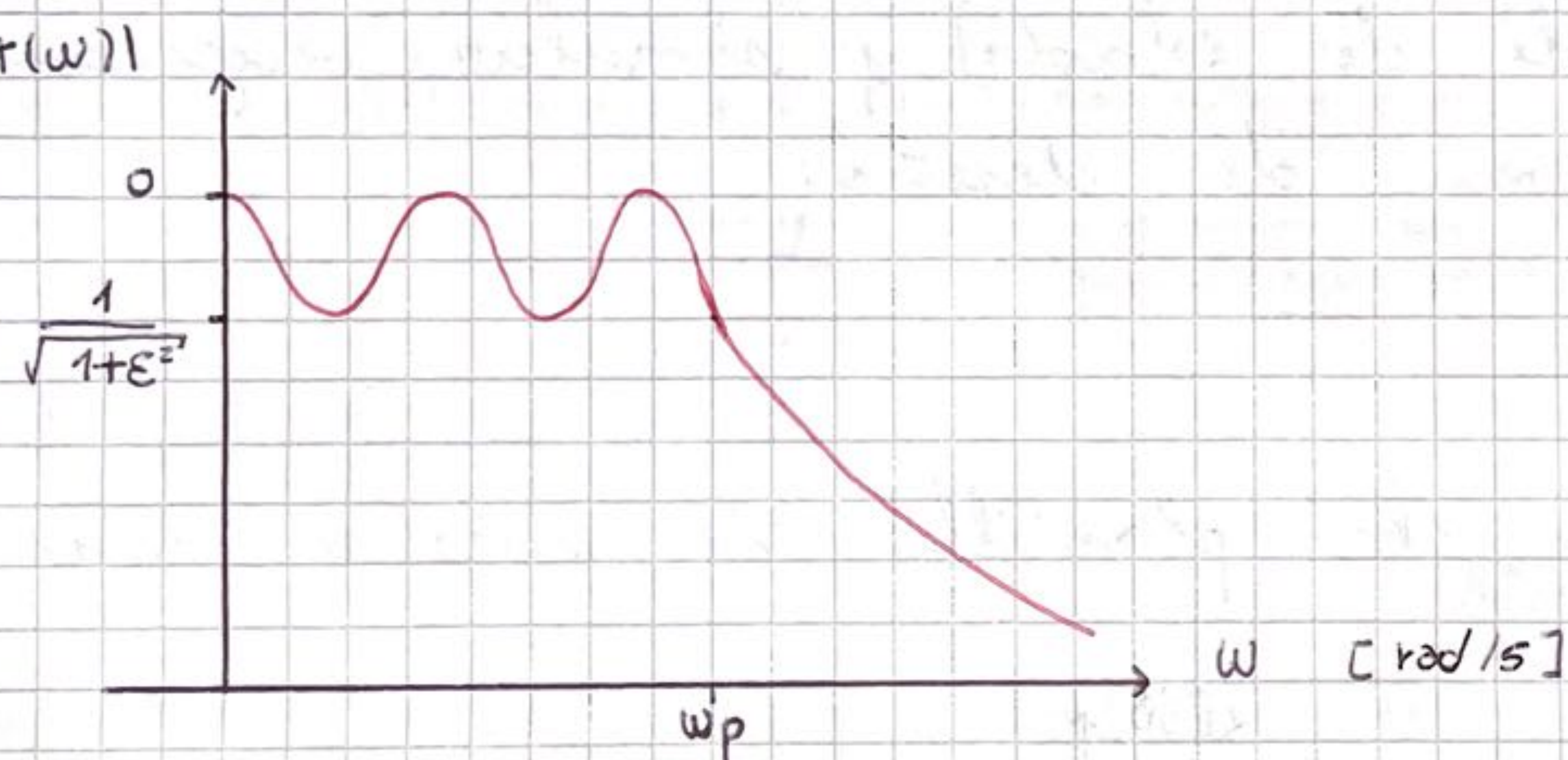
$$\begin{cases} \omega_p' = 1 \\ \omega_s' = 3 \end{cases}$$

Y finalmente, iteramos para encontrar n:

$$\alpha_{MIN} = 10 \log \left\{ 1 + \varepsilon^2 \cos^2 h \left[n \cos^{-1} h (\omega_s') \right] \right\}$$

Para $n = 5$, $\alpha_{MIN} = 54,3\, dB \geq 48\, dB$. $\rightarrow$ $\boxed{n = 5}$

b) Graficamos la respuesta en módulo de un filtro pasa-bajos Chevyshev de orden 5:



c) Planteamos:

$$|T(j\omega)|^2 = \frac{1}{1 + C^2_n(\omega)} \longrightarrow |T(\omega)|^2 \Big|_{\omega = s/j} = \frac{1}{1 + C^2_n(s/j)}$$

Donde:

$$\begin{cases} \sigma_k = -\operatorname{senh} a \cdot \operatorname{sen}\left(\pi \cdot (2k - 1/2n)\right) \\ \omega_k = \cosh a \cdot \cos\left(\pi (2k - 1/2n)\right) \end{cases}$$

Siendo $a = \frac{1}{n} \operatorname{senh}^{-1}\left(\frac{1}{\varepsilon}\right) = 0,3771$

NOTA

Además, la transferencia de segundo orden de la estructura KHN es:

$$\frac{V_2}{V_1} = \underbrace{\frac{R_6(R_2+R_3)}{R_3(R_1+R_6)}}_{K} \cdot \frac{\dfrac{R_3}{R_4 R_5 C_2 C_1 R_2}}{s^2 + s\,\dfrac{R_6(R_2+R_3)}{R_4 . R_2 (R_1+R_6) . C_1} + \dfrac{R_3}{R_4 R_5 C_2 C_1 R_2}}$$

Donde:

$$\omega_0 = \sqrt{\frac{R_3}{R_4 R_5 C_2 C_1 R_2}} \quad y \quad \frac{\omega_0}{Q} = \frac{R_6(R_2+R_3)}{R_4 R_2 (R_1+R_6) C_1}$$

Entonces, comenzamos a desarrollar sabiendo que $K=1$ y que como tenemos más grados de libertad que parámetros, debemos adoptar ciertos valores.

$$K = 1 \longrightarrow \frac{R_6(R_2+R_3)}{R_3(R_1+R_6)} = 1 \longrightarrow R_6(R_3+R_3) = R_3(R_6+R_1)$$

Como tenemos 2 variables y 8 grados de libertad, adoptamos:

$$\begin{cases} C_1 = C_2 = 1\ mF \\ R_6 = R_4 = 1K\Omega \\ R_5 \rightarrow \text{controla } \omega_0 \qquad R_1 \rightarrow \text{controla } Q \\ R_2 = R_3 = 1K\Omega \end{cases}$$

Entonces:

$$\omega_0 = \sqrt{\frac{10^3}{R_5}} \quad y \quad Q = \overbrace{\sqrt{\frac{10^3}{R_5}}}^{\omega_0} \cdot \frac{R_1 + 1K\Omega}{2K\Omega}$$

NOTA

TP 2

HOJA Nº

FECHA

Calculamos:

(II) $\begin{cases} \omega_{0\,II}^2 = 1{,}053 \rightarrow \omega_0 = 1{,}0262 \\ Q = 4{,}312 \end{cases}$

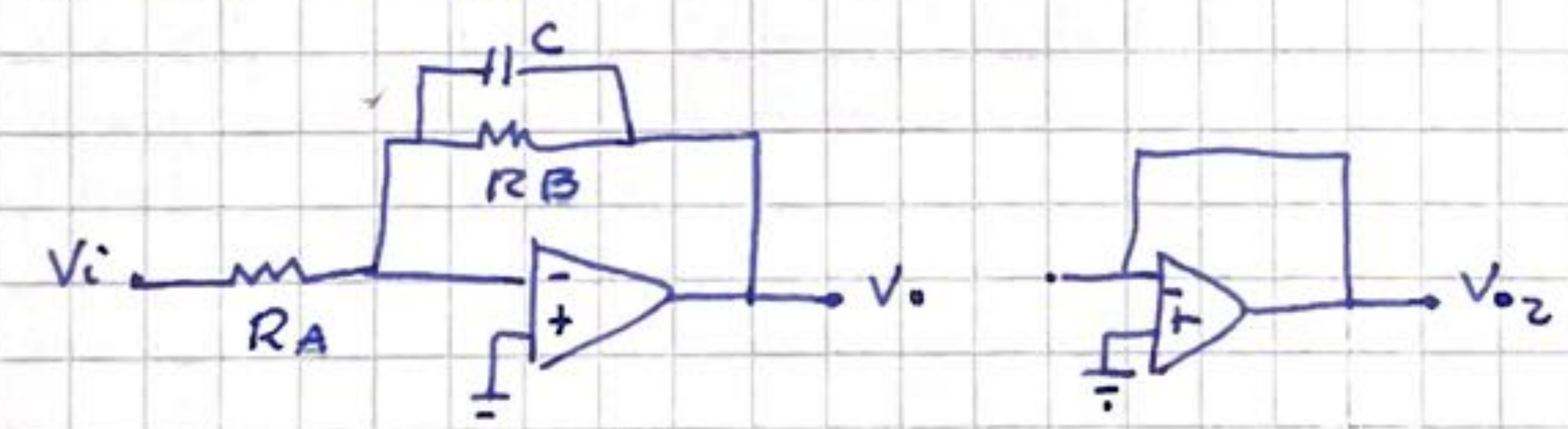
$\begin{cases} R_5 = 949{,}59 \approx 950\,\Omega \\ R_1 = 7403{,}82\,\Omega \end{cases}$

(III) $\begin{cases} \omega_{0\,III}^2 = 0{,}494 \rightarrow \omega_0 = 0{,}703 \\ Q = 1{,}125 \end{cases}$

$\begin{cases} R_5 = 2023{,}44\,\Omega \\ R_1 = 2200{,}57\,\Omega \rightarrow R_1 \approx 2200\,\Omega \end{cases}$

(I) Se trata de una estructura: $T(s) = \dfrac{A}{s+A}$

Planteamos:



$$\frac{V_{02}}{V_i} = \frac{R_B}{R_A} \cdot \frac{1/R_BC}{s + 1/R_BC}$$

Adoptamos $R_B = R_A$ y luego:

$\cdot\ 1/R_BC = \omega_0 = \sqrt{0{,}386}$

Adoptamos $R_B = 1\,K\Omega$ y despejamos C:

$C = 1{,}61 \times 10^{-3}$ F.

* De esta manera calculamos todos los

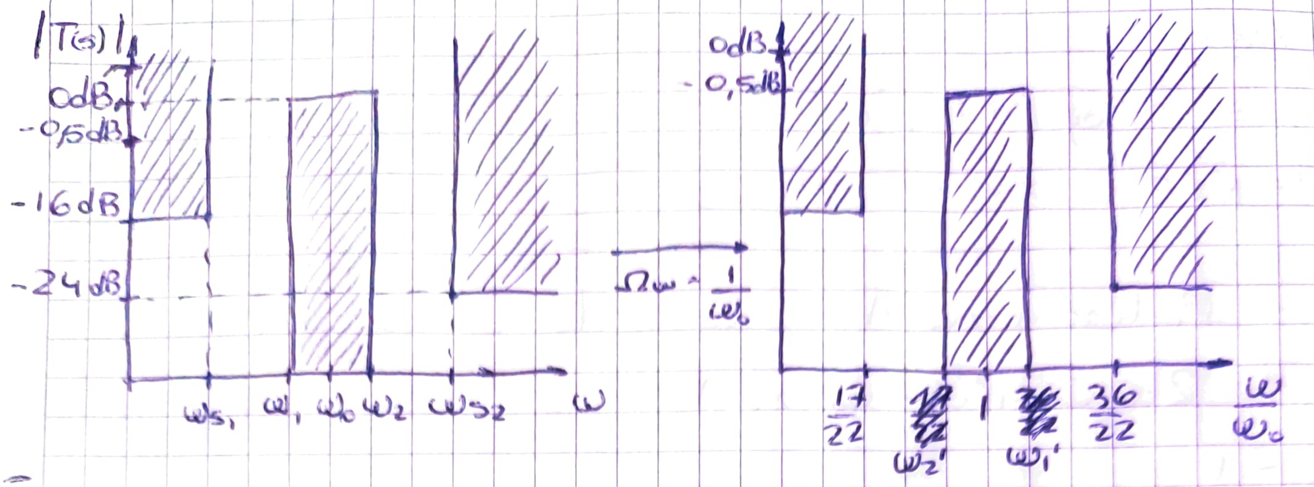
NOTA

componentes de nuestro filtro. Ahora, debemos desnormalizar los componentes que dependen de la frecuencia con nuestra $\Omega w = 3{,}2\,kHz \cdot 2\pi$

- $C_1 = C_2 = 10\,mF / \Omega w = 4{,}974 \times 10^{-7}\,F.$
- $C = 8{,}007 \times 10^{-8}\,F.$

NOTA

Ejercicio 4)



$$\omega_0 = \sqrt{\omega_1 \, \omega_2} = 1 \longrightarrow \omega_2 = \frac{1}{\omega_1}$$

$$Q = \frac{\omega_0}{\omega_2 - \omega_1} = 5 \longrightarrow \frac{1}{\omega_2 - \frac{1}{\omega_2}} = 5 \longrightarrow \omega_2^2 - \frac{1}{5}\,\omega_2 - 1 = 0$$

$$\boxed{\begin{aligned} \omega_2 &= 1{,}105 \\ \omega_1 &= 0{,}905 \end{aligned}}$$

$$\omega_{s_1} = \frac{17}{22} \quad , \quad \omega_{s_2} = \frac{36}{22}$$

$$\Omega_{s_1} = \frac{Q\,(\omega_{s_1}^2 - 1)}{\omega_{s_1}} = -2{,}607$$

$$\Omega_{s_2} = \frac{Q\,(\omega_{s_2}^2 - 1)}{\omega_{s_2}} = 5{,}126$$

Chebyshev:

$$|T(j\omega)|^2 = \frac{1}{1 + \xi^2 C_n^2(\omega)} \quad , \quad |T(j\omega_0)|^2 = \frac{1}{1 + \xi^2}$$

$$\alpha_{MAX} = 10 \log(1 + \xi^2)$$

$$\xi^2 = 10^{\frac{\alpha_{MAX}}{10}} - 1 \longrightarrow \boxed{\xi^2 = 0{,}122}$$

Para Ω_{s_1}:

$$\alpha_{MIN} = 10 \log\left(1 + \xi^2 C_n^2(\Omega_{s_1})\right)$$

$$\alpha_{MIN} = 10 \log\left(1 + \xi^2 \cosh^2(N \cosh^{-1}(\Omega_{s_1}))\right)$$

$\hookrightarrow N = 2$: $\alpha = 13{,}085$ dB ⊗ $< \alpha_{MIN}$

$\hookrightarrow N = 3$: $\alpha = 26{,}87$ dB ✓ $> \alpha_{MIN}$

Para Ω_{S2}:

$$\alpha_{MIN} = 10 \log \left(1 + \xi^2 \cosh^2 \left(N \cosh^{-1}(\Omega_{S2})\right)\right)$$

$\hookrightarrow N = 3 : \quad \alpha = 45{,}24\,dB$ ✓ $> \alpha_{MIN}$

Funciones Polinómicas Armónicas de Chebyshev

$$C_n(\omega) = 2\omega\, C_{n-1}(\omega) - C_{n-2}(\omega)$$

$$C_0(\omega) = 1$$

$$C_1(\omega) = \omega$$

$$C_2(\omega) = 2\omega^2 - 1$$

$$C_3(\omega) = 4\omega^3 - 3\omega$$

$$|T_L(\omega)|^2 = \frac{1}{1+\xi^2 C_3^2(\omega)} = \frac{1}{1+\xi^2(4\omega^3-3\omega)} = \frac{1}{1+16\xi^2\omega^6-24\xi^2\omega^4+9\xi^2\omega^2}$$

$$|T(s)|^2 = T(s).T(-s) = \frac{1}{1-16\xi^2 s^6-24\xi^2 s^4-9\xi^2 s^2} = \frac{1}{(s^3+as^2+bs+c)(-s^3+as^2-bs+c)}$$

$$|T_L(s)|^2 = \frac{1/16\xi^2}{-s^6-\frac{3}{2}s^4-\frac{9}{16}s^2+1/16\xi^2} = \frac{1}{-s^6+(a^2-2b)s^4+(2ac-b^2)s^2+c^2}$$

① $-\frac{3}{2} = a^2 - 2b \longrightarrow b = \frac{a^2}{2} + \frac{3}{4} \longrightarrow b^2 = \frac{a^4}{4} + a^2 \cdot \frac{3}{2} + \frac{9}{16}$ ④

② $-\frac{9}{16} = 2ac - b^2$

③ $c^2 = \frac{1}{16\xi^2} \longrightarrow \boxed{c = 0{,}7157}$

④ en ②: $\cancel{-\frac{9}{16}} = 2ac - \frac{a^4}{4} - a^2\frac{3}{2} \cancel{-\frac{9}{16}} \Rightarrow 2ac - \frac{a^4}{4} - a^2\frac{3}{2} = 0$

$$-a\left(\underbrace{\frac{a^3}{4} + a\frac{3}{2} - 2c}_{}\right) = 0$$

$$\boxed{a = 1{,}253}$$

①: $b = \frac{1{,}253^2}{2} + \frac{3}{4} = \boxed{1{,}535 = b}$

$$T_L(s) = \frac{c}{s^3+as^2+bs+c} = \frac{0{,}7157}{s^3+1{,}253s^2+1{,}535s+0{,}7157}$$

Factorizo: $T_L(s) = \dfrac{0{,}7157}{(s+0{,}6266)(s^2+0{,}6266s+1{,}1425)}$

$$T_L(s) = \underbrace{\frac{0{,}6266}{s+0{,}6266}}_{T_1(s)} \cdot \underbrace{\frac{1{,}142}{s^2+s\,0{,}6266+1{,}142}}_{T_2(s)}$$

$T_1(s)$: $\quad s \longrightarrow \dfrac{Q(s^2+1)}{s}$

$$T_1(s) = \frac{0{,}6266}{\dfrac{Q(s^2+1)}{s}+0{,}6266} = \frac{s\,\dfrac{0{,}6266}{Q}}{s^2+\dfrac{0{,}6266}{Q}s+1} = \frac{s.0{,}1253}{s^2+s.0{,}1253+1}$$

$T_2(s)$: $\quad s \longrightarrow \dfrac{Q(s^2+1)}{s}$

$$T_2(s) = \frac{1{,}142}{\dfrac{Q^2(s^2+1)^2}{s^2}+\dfrac{Q(s^2+1)}{s}.0{,}6266+1{,}142}$$

$$T_2(s) = \frac{s^2.1{,}142}{s^4Q^2+s^3(0{,}6266.Q)+s^2(2Q^2+1{,}142)+s(0{,}6266.Q)+Q^2}$$

Con $Q=5$:

$$T_2(s) = \frac{s^2\,\dfrac{1{,}142}{Q^2}}{s^4+s^3.\dfrac{0{,}6266}{Q}+s^2\left(2+\dfrac{1{,}142}{Q^2}\right)+s\,\dfrac{0{,}6266}{Q}+1}$$

$$T_2(s) = \frac{s^2.\quad 0{,}0457}{s^4+s^3.0{,}1253+s^2.2{,}046+s.0{,}1253+1}$$

↳ Polos en: $(-0{,}03452 \pm j\,1{,}107)$ y $(-0{,}02813 \pm j\,0{,}9022)$

$$\therefore T_2(s) = 12{,}58\,\frac{s.0{,}06904}{s^2+s.0{,}06904+1{,}227} \cdot \frac{s.0{,}0526}{s^2+s.0{,}0526+0{,}8148}$$

$$\Rightarrow T_B(s) = \underbrace{12{,}58}_{H}\,\underbrace{\frac{s.0{,}1253}{s^2+s.0{,}1253+1}}_{SOS\,1} \cdot \underbrace{\frac{s.0{,}06904}{s^2+s.0{,}06904+1{,}227}}_{SOS\,2} \cdot \underbrace{\frac{s.0{,}0526}{s^2+s.0{,}0526+0{,}8148}}_{SOS\,3}$$

SOS 1: $\omega_{01}=1$, $Q_1=7{,}98$

SOS 2: $\omega_{02}=1{,}1077$, $Q_2=16{,}04$

SOS 3: $\omega_{03}=0{,}9027$, $Q_3=16{,}04$

HOJA N°

FECHA

$\boxed{\text{EJ 5}}$

$n = 5$

$Att_{MIN} = 48\ dB$

$Att_{MAX} = 0{,}4\ dB$

CHEBYSHEV

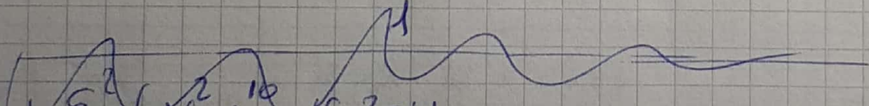
$$|T(s)|^2 = \frac{1}{1+\xi^2 C_5^2} = \frac{1}{1+\xi^2(16w^5 - 20w^3 - 4w)^2}$$

$$C_4 = 2w(4w^3 - 3w) - 2w^2 - 1$$

$$C_5 = 4w^2(4w^3 - 3w) - 4w^3 - 2w - 4w^3 - 3w$$

$$C_5 = 16w^5 - 12w^3 - 8w^3 - 4w$$

$$C_5 = 16w^5 - 20w^3 - 4w$$



$1 + \xi^2(16^2 w^{10} - 16 \cdot 20w$

$P_1 = -0{,}386$

$P_{2,3} = -0{,}312 \pm j0{,}63$

$P_{4,5} = -0{,}119 \pm j1{,}019$

~~SOS~~

$$\underbrace{\frac{0{,}386}{s+0{,}386}}_{SOS_1} \cdot \underbrace{\frac{0{,}494}{s^2+0{,}624s+0{,}494}}_{SOS_2} \cdot \underbrace{\frac{1{,}052}{s^2+0{,}238s+1{,}052}}_{SOS_3}$$

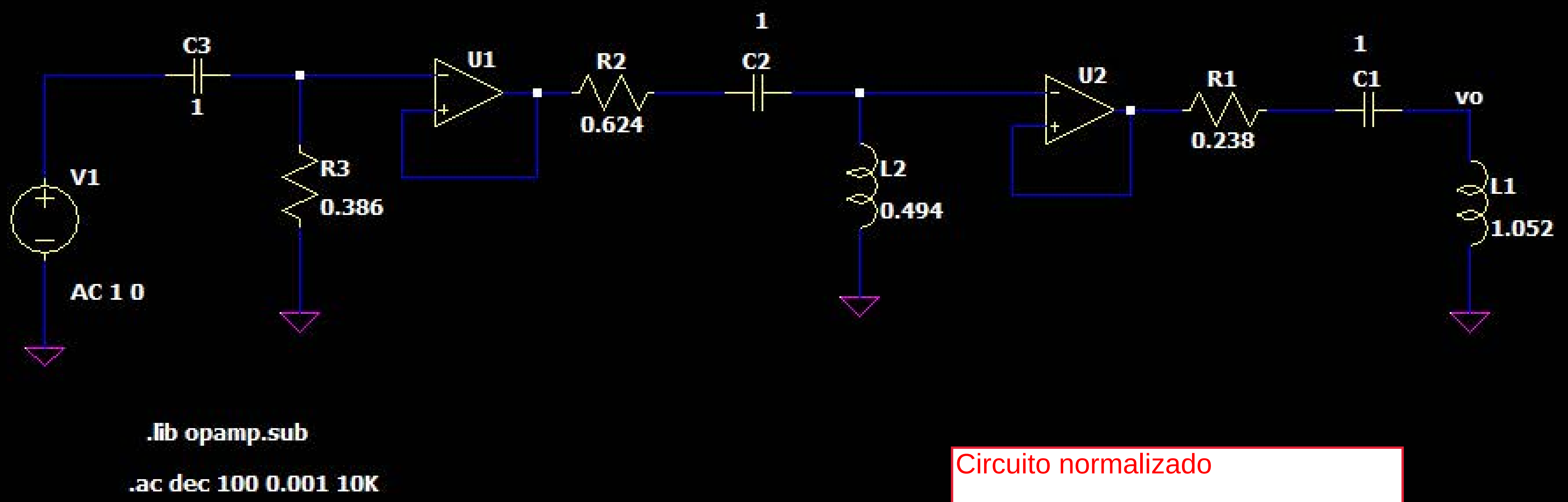
$$\underbrace{\frac{s}{s + 2{,}59}}_{SOS\_HP_1} \qquad \frac{s^2}{s^2 + 1{,}263\,s + 2{,}024} \qquad \frac{s^2}{s^2 + s\,0{,}226 + 0{,}95}$$

SOS_HP$_1$ SOS_HP$_2$ SOS_HP$_3$

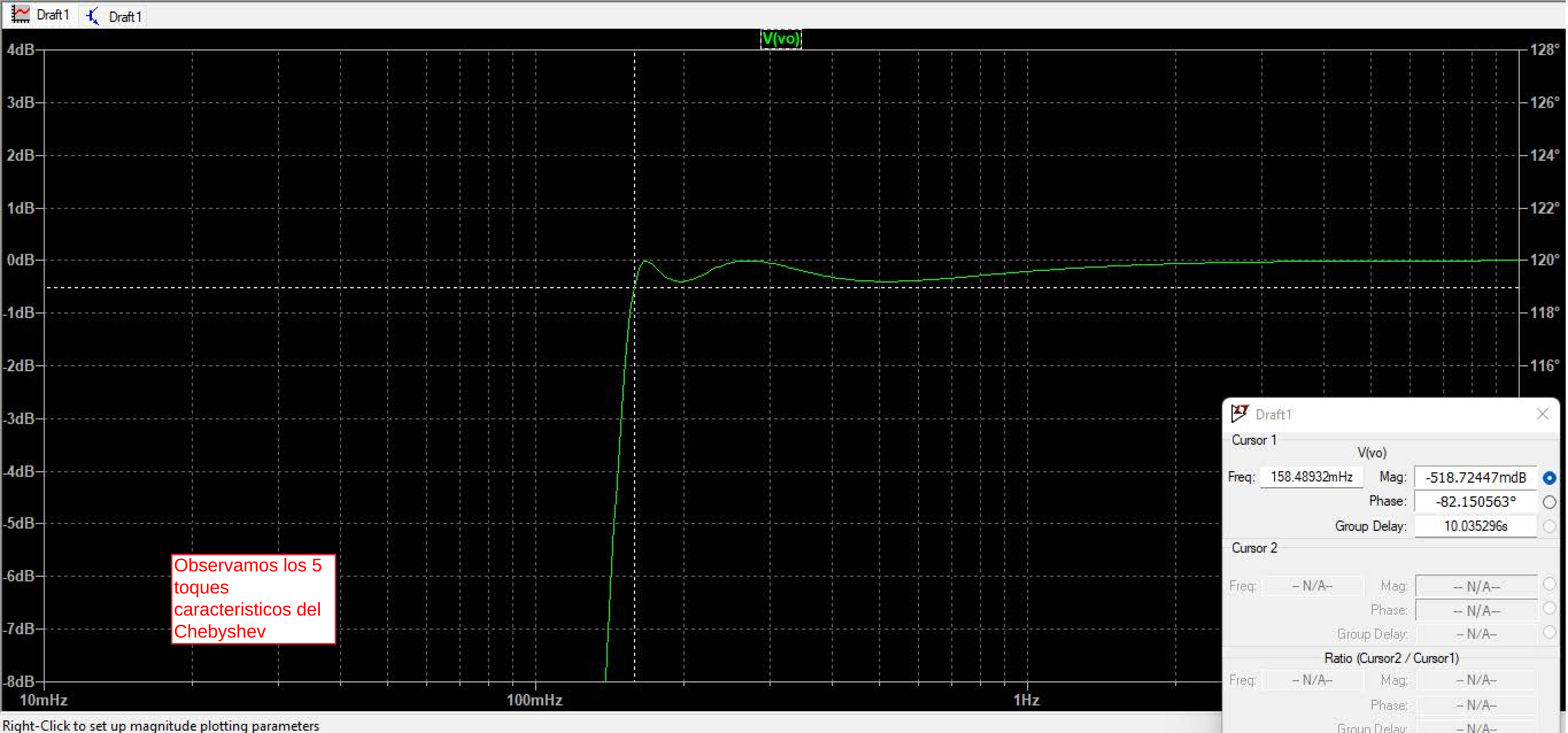
$$\text{forma}_{HP} = \frac{s^2}{s^2 + s\frac{R}{L} + \frac{1}{LC}}$$

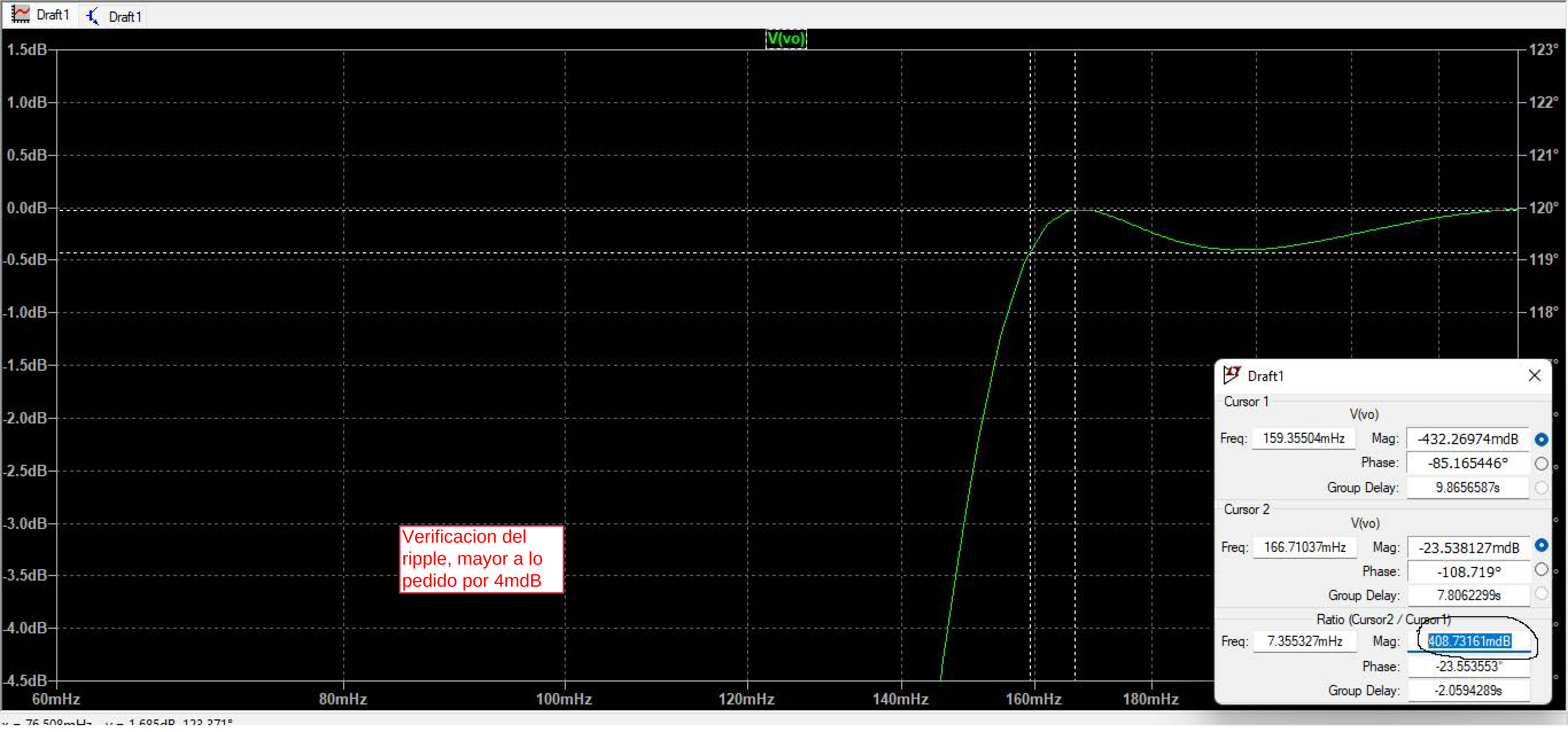
$C = 1F$

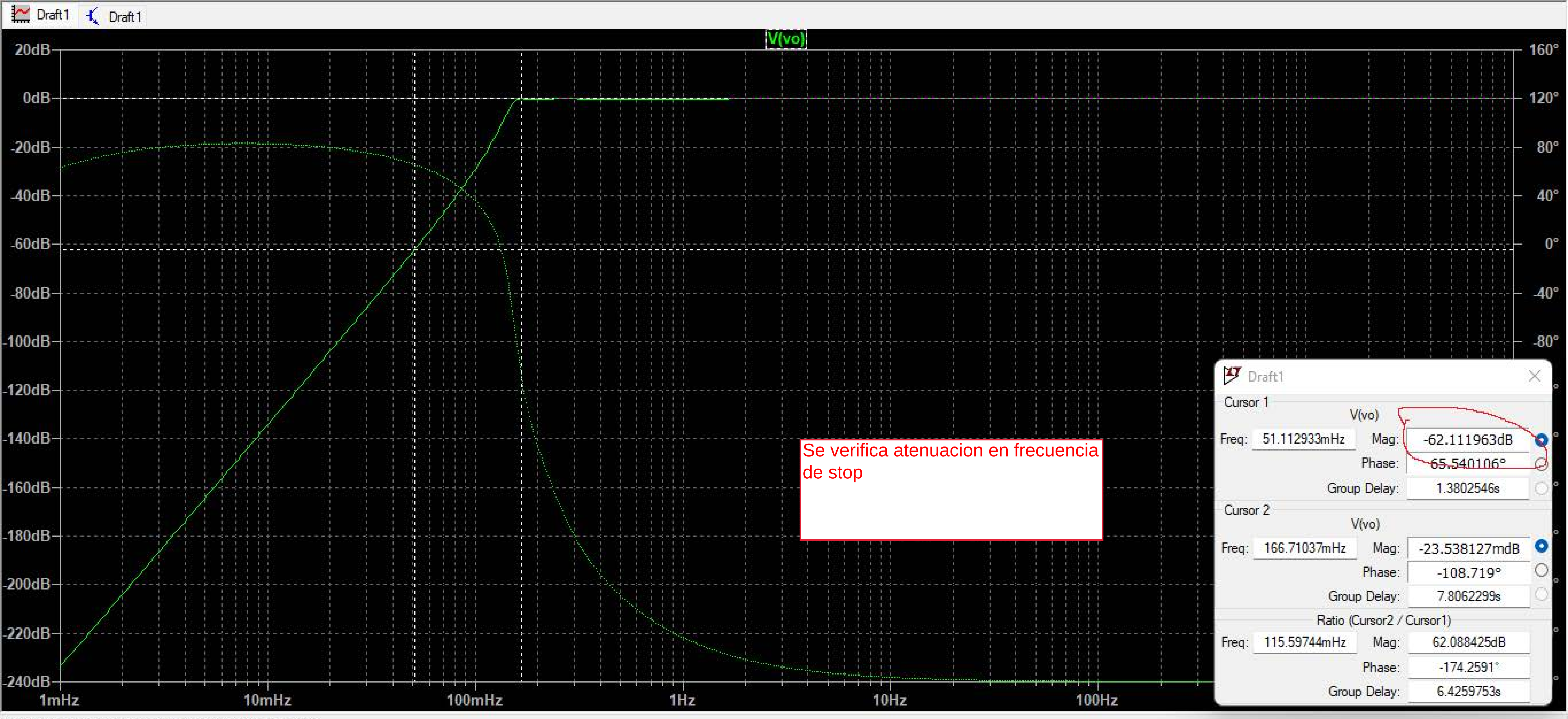
Escaneado con CamScanner

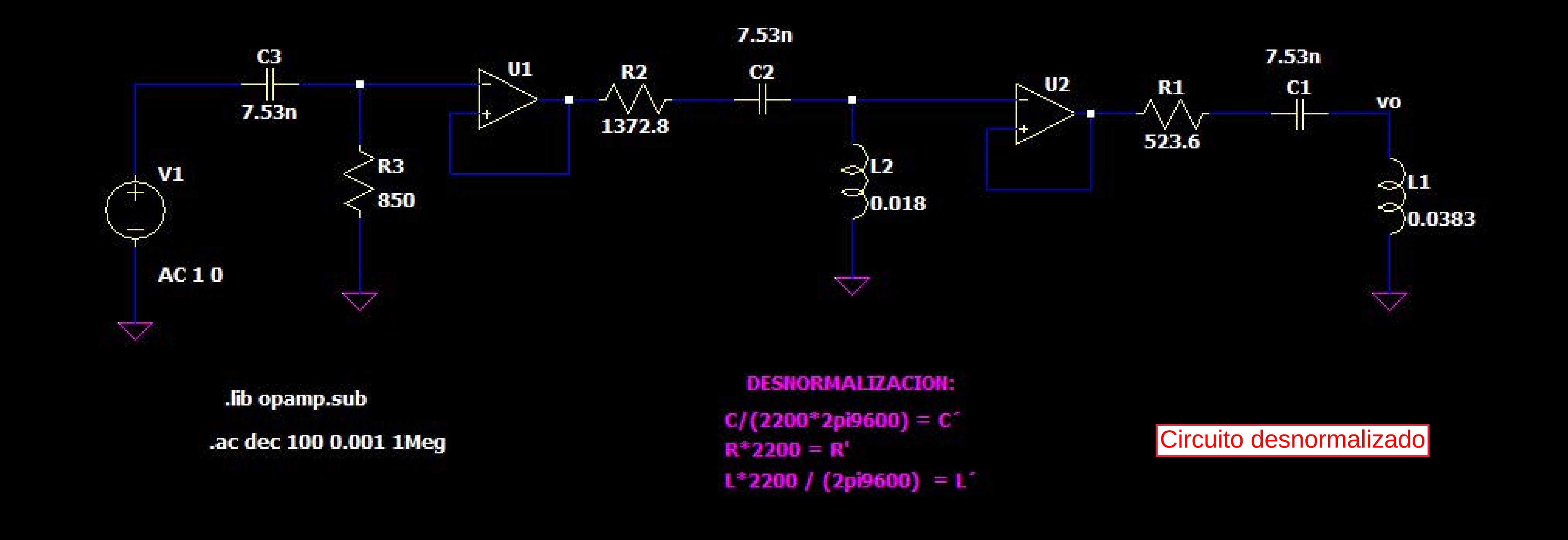


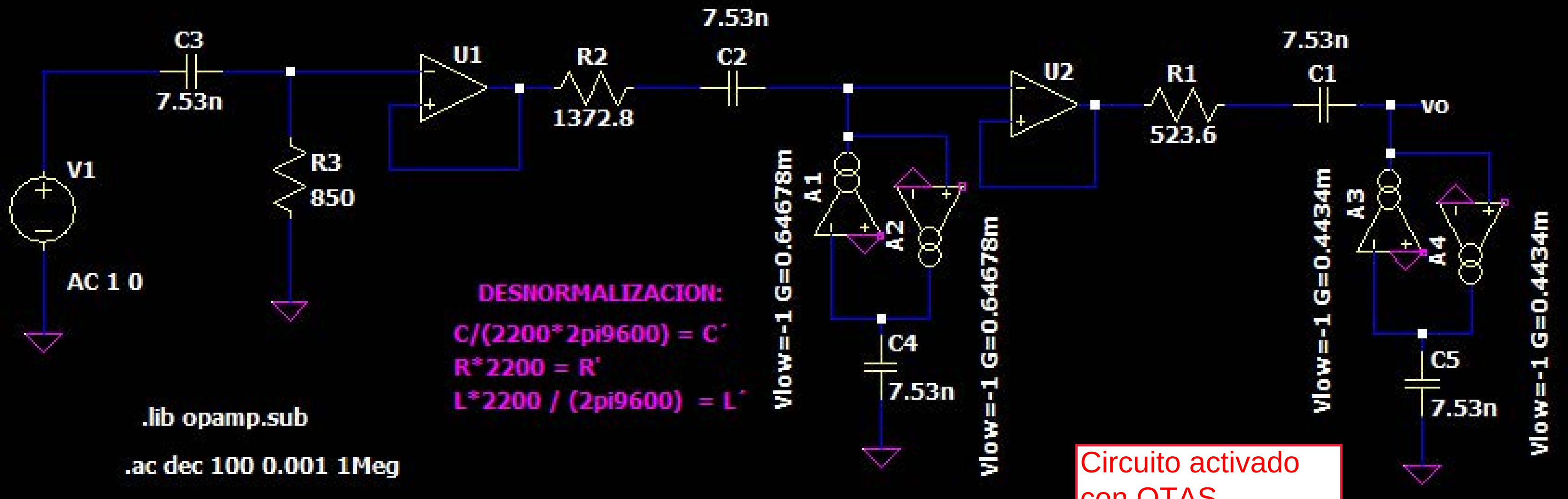
Circuito normalizado


Draft1
Draft1
V(vo)
4dB
3dB
2dB
1dB
0dB
-1dB
-2dB
-3dB
-4dB
-5dB
-6dB
-7dB
-8dB
128°
126°
124°
122°
120°
118°
116°
10mHz
100mHz
1Hz
Observamos los 5 toques caracteristicos del Chebyshev
Draft1
Cursor 1
V(vo)
Freq: 158.48932mHz
Mag: -518.72447mdB
Phase: -82.150563°
Group Delay: 10.035296s
Cursor 2
Freq: -- N/A--
Mag: -- N/A--
Phase: -- N/A--
Group Delay: -- N/A--
Ratio (Cursor2 / Cursor1)
Freq: -- N/A--
Mag: -- N/A--
Phase: -- N/A--
Group Delay: -- N/A--
Right-Click to set up magnitude plotting parameters


Draft1
V(vo)
1.5dB
1.0dB
0.5dB
0.0dB
-0.5dB
-1.0dB
-1.5dB
-2.0dB
-2.5dB
-3.0dB
-3.5dB
-4.0dB
-4.5dB
123°
122°
121°
120°
119°
118°
60mHz
80mHz
100mHz
120mHz
140mHz
160mHz
180mHz
Verificacion del ripple, mayor a lo pedido por 4mdB
Cursor 1
V(vo)
Freq: 159.35504mHz
Mag: -432.26974mdB
Phase: -85.165446°
Group Delay: 9.8656587s
Cursor 2
V(vo)
Freq: 166.71037mHz
Mag: -23.538127mdB
Phase: -108.719°
Group Delay: 7.8062299s
Ratio (Cursor2 / Cursor1)
Freq: 7.355327mHz
Mag: 408.73161mdB
Phase: -23.553553°
Group Delay: -2.0594289s


Draft1
Draft1
V(vo)
20dB
0dB
-20dB
-40dB
-60dB
-80dB
-100dB
-120dB
-140dB
-160dB
-180dB
-200dB
-220dB
-240dB
160°
120°
80°
40°
0°
-40°
-80°
1mHz
10mHz
100mHz
1Hz
10Hz
100Hz
Se verifica atenuacion en frecuencia de stop
Draft1
Cursor 1
V(vo)
Freq: 51.112933mHz
Mag: -62.111963dB
Phase: -65.540106°
Group Delay: 1.3802546s
Cursor 2
V(vo)
Freq: 166.71037mHz
Mag: -23.538127mdB
Phase: -108.719°
Group Delay: 7.8062299s
Ratio (Cursor2 / Cursor1)
Freq: 115.59744mHz
Mag: 62.088425dB
Phase: -174.2591°
Group Delay: 6.4259753s


7.53n
C3
U1
R2
C2
U2
R1
7.53n
C1
vo
7.53n
1372.8
523.6
V1
R3
850
L2
0.018
L1
0.0383
AC 1 0
.lib opamp.sub
.ac dec 100 0.001 1Meg
DESNORMALIZACION:
C/(2200*2pi9600) = C´
R*2200 = R'
L*2200 / (2pi9600) = L´
Circuito desnormalizado



Circuito activado con OTAS

6 Diseñar un filtro pasa-bajos con
D (retardo) = 100µs
Desvío de retardo = 10% para $W_1 = 25K \cdot 2\pi$ Hz
Atenuación de 1 dB a la $W_2 = 10K \cdot 2\pi$ Hz

$$\Omega_w = \frac{1}{100\mu s} = 10\,KHz = W_0$$

Por análisis del gráfico en el eje horizontal = 2,5 y en el 10% y busco los que estén por debajo de ese punto,
Obtengo $n = 4$

$\alpha_{max} = 1$ dB

$$W_0 = \frac{2}{D}$$

$$\xi^2 = 10^{\frac{\alpha_{max}}{10}} - 1 = 0,2589$$

utilizo aproximación de Bessel

$$H(S) = \frac{P(S)}{Q(S)} = \frac{1}{\operatorname{Senh}(S) + \operatorname{Cosh}(S)}$$

$$\operatorname{Senh}(S) = S + \frac{S^3}{3!} + \frac{S^5}{5!} + \frac{S^7}{7!}$$

$$\operatorname{Cosh}(S) = 1 + \frac{S^2}{2!} + \frac{S^4}{4!} + \frac{S^6}{6!}$$

$$\underset{n=4}{\operatorname{Coth}}(S) = \frac{1}{S} + \cfrac{1}{\cfrac{3}{S} + \cfrac{1}{\cfrac{5}{S} + \cfrac{1}{(7/S)}}}$$

$$\operatorname{Coth}(S) = \frac{1}{S} + \cfrac{1}{\cfrac{3}{S} + \cfrac{1}{\cfrac{5}{S} + \cfrac{S}{7}}} = \frac{1}{S} + \cfrac{1}{\cfrac{3}{S} + \cfrac{7 \cdot S}{35 + S^2}}$$

$$\operatorname{Coth}(S) = \frac{1}{S} + \frac{S^3 + 35 \cdot S}{10S^2 + 105}$$

$$Cth(s) = \frac{1(10\cdot s^2 + 105) + s^4 + 35\cdot s^2}{10\cdot s^3 + 105\cdot s}$$

$$Cth(s) = \frac{s^4 + 45\cdot s^2 + 105}{10\cdot s^3 + 105\cdot s}$$

$$H_4(s) = \frac{105}{s^4 + 10\cdot s^3 + 45\cdot s^2 + 105\cdot s + 105}$$

Ej. 7)

$f_{ci} = 1600\ KHZ$

$f_{cs} = 2500\ KHZ$

RIPPLE MAXIMO 3dB

MP.

GANANCIA MAXIMA EN LA BANDA DE PASO: 10 dB

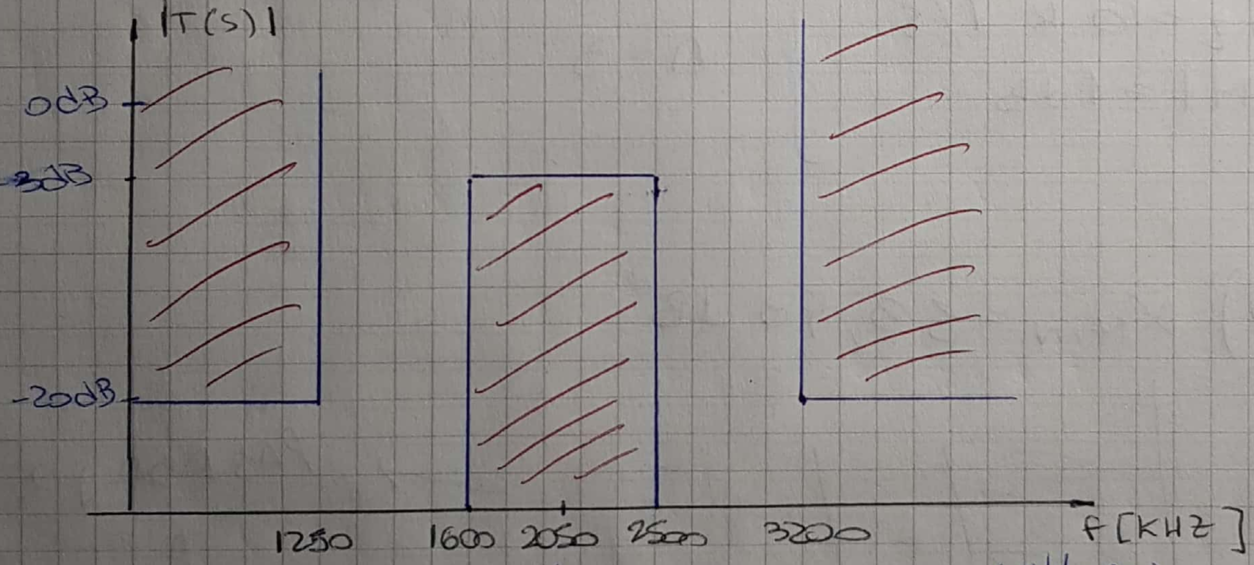
Att_{MIN}: 20 dB ⟶ 1250 KHZ y 3200 KHZ

a) $T(s)_n$

b) P y Z

c) GRAFICAR TRANSF. MODULO Y FASE

d) SINTETIZAR C/ ACKERBERG-MOSBERG



(MP)

$\alpha_{MAX} = 3dB$

$\alpha_{MIN} = 20dB$

$\xi^2 = 10^{\left(\frac{att_{MAX}}{10}\right)} - 1 = 0{,}99 \cong 1$

$n =$

$w_{ci_n} = $ ~~0,8~~ 0,8

$w_{cs_n} = $ ~~1,22~~ 1,25

$w_{s_n} = $ ~~0,609~~ 0,625

$w_{s2_n} = $ ~~1,56~~ 1,6

$K(s) = Q \cdot \frac{s^2+1}{s}$

$w_{0n} \to 1$ $\rightarrow Q = \frac{w_{0n}}{BW}$

$BW = w_{cs} - w_{ci}$

$Q = 2{,}273$

HOJA N°

FECHA

$$\Omega_s = 2,16 \quad \Omega_p = 1 \quad \Big\} \text{ TRASLADADAS A PASABAJO}$$

$n = 3 \longrightarrow Att = 20,16 \text{ dB}$

ITERAR

$$\alpha_{MIN} = 10 \log_{10}(1 + \xi^2 \Omega_s^{2n})$$

MODELO PASABAJOS

$$\frac{1}{1 - \xi^2 s^6} = \frac{1}{as^3 + bs^2 + cs + d} \cdot \frac{1}{-as^3 + bs^2 - cs + d}$$

$$+\xi^2 = +a^2 \Rightarrow a = \xi$$

$$d^2 = 1 \longrightarrow d = 1$$

$n = 4$

$$0 = b^2 \cancel{+} ac - ac \Rightarrow +2ac = b^2$$

$n = 2$

$$c^2 = 2bd$$

$$c^2 = 2b \longrightarrow c = \sqrt{2b}$$

$$2\xi c = b^2 \longrightarrow 2\xi \sqrt{2b} = b^2$$

$$4\xi^2 2\cancel{b} = b^{3}$$

$$\boxed{2\xi^{2/3} = b}$$

$$c = \sqrt{2b} = \sqrt{4\xi^{2/3}}$$

$$= 2\xi^{2/6} = \boxed{2\xi^{1/3} = c}$$

$$\frac{1}{\xi s^3 + 2\xi^{2/3} s^2 + 2\xi^{1/3} s + 1} = T(s)$$

NOTA

$P_1 = \cancel{\quad} s + 1$

$P_2 = s - (-0{,}5 + j0{,}866)$

$P_3 = s - (-0{,}5 - j0{,}866)$

$$T(s) = \frac{1}{s+1} \quad \frac{1}{s^2 + s + 1}$$

DESNORMALIZO $\quad s = \dfrac{\$}{\xi^{-1/3}}$

$$T(s) = \frac{1}{\underbrace{\frac{\$}{\xi^{-1/3}}}_{\to 1} + 1} \quad \frac{1}{\underbrace{\frac{\$^2}{\xi^{-2/3}}}_{\to 1} + \underbrace{\frac{\$}{\xi^{-1/3}}}_{\to 1} + 1}$$

$$= \frac{1}{s+1} \quad \frac{1}{s^2 + s + 1}$$

NUCLEO: $Q\dfrac{(s^2+1)}{s}$

$$T(s)_{BP} = \frac{1}{\frac{Q(s^2+1)}{s} + 1} \quad \frac{1}{\frac{Q^2(s^2+1)^2}{s^2} + \frac{Q(s^2+1)}{s} + 1} =$$

$$= \frac{s}{Qs^2 + s + Q} \quad \frac{s^2}{Q^2s^4 + 2Q^2s^2 + Q^2 + Qs^3 + Qs + s^2}$$

$$= \frac{s/Q}{s^2 + \frac{s}{Q} + 1} \quad \frac{s^2/Q^2}{s^4 + \frac{s^3}{Q} + \underbrace{s^2}_{2+\frac{1}{Q^2}} + \frac{s}{Q} + 1}$$

$-0{,}225 \pm 0{,}974$ $\qquad$ Polos $\to$ $-0{,}162 \pm j1{,}595$

$\pm 0{,}063 \pm j0{,}62$

$$= \frac{s/Q}{s^2 + \frac{s}{Q} + 1} \quad \frac{s/Q}{s^2 + s0{,}324 + 2{,}57} \quad \frac{s/Q}{s^2 + s0{,}126 + 0{,}388}$$

NOTA

Polos:

$$p_{1,2} = -0,134 \pm j1,207$$
$$p_{3,4} = -0,225 \pm 0,974$$
$$p_{5,6} = -0,09 \pm j0,818$$
$$z = (0)^3$$

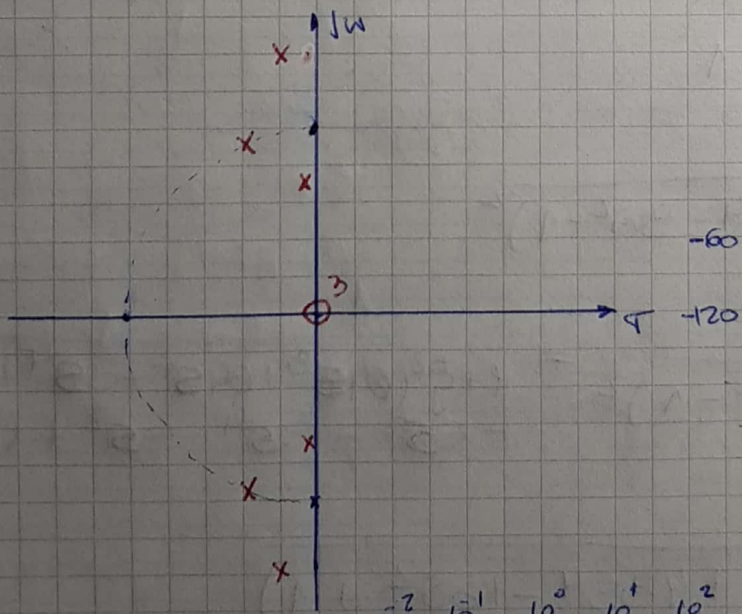
SOS 1 · SOS 2 · $\frac{\omega_{o2}}{Q_2}$ · K_2 · $\frac{\omega_{o3}}{Q_3}$ · K_3

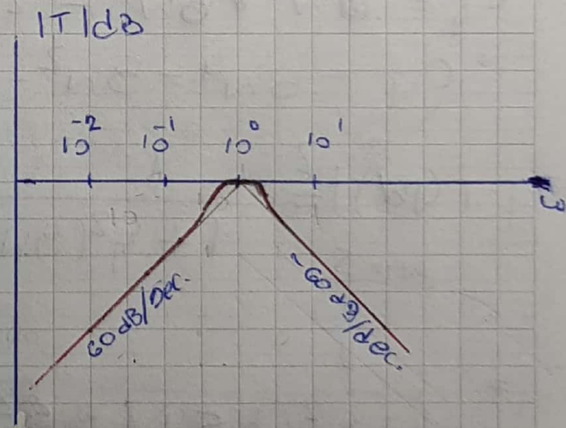
$$\overbrace{\frac{S/Q}{s^2+\frac{s}{Q}+1}}^{SOS\ 1} \cdot \frac{\overbrace{0,268 \cdot S\left(\frac{1}{Q \cdot 0,268}\right)}^{SOS\ 2}}{s^2+0,268s+1,475} \cdot \frac{0,18\ S\left(\frac{1}{Q \cdot 0,18}\right)}{s^2+0,18+0,677}$$

$\omega_{o1} = 1$ | $\omega_{o2} = 1,21$ | $\omega_{o3} = 0,822$

$Q_1 = Q$ | $Q_2 = 4,53$ | $Q_3 = 4,56$

$K_1 = 1$ | $K_2 = 1,68$ | $K_3 = 2,5$

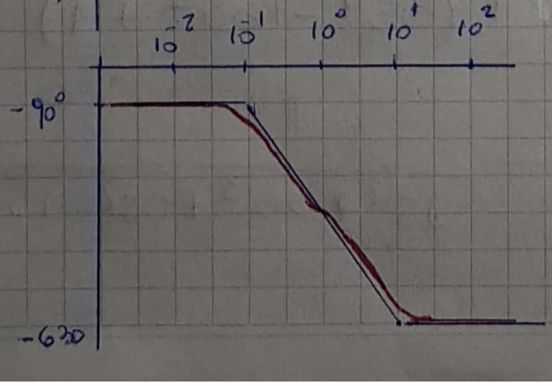


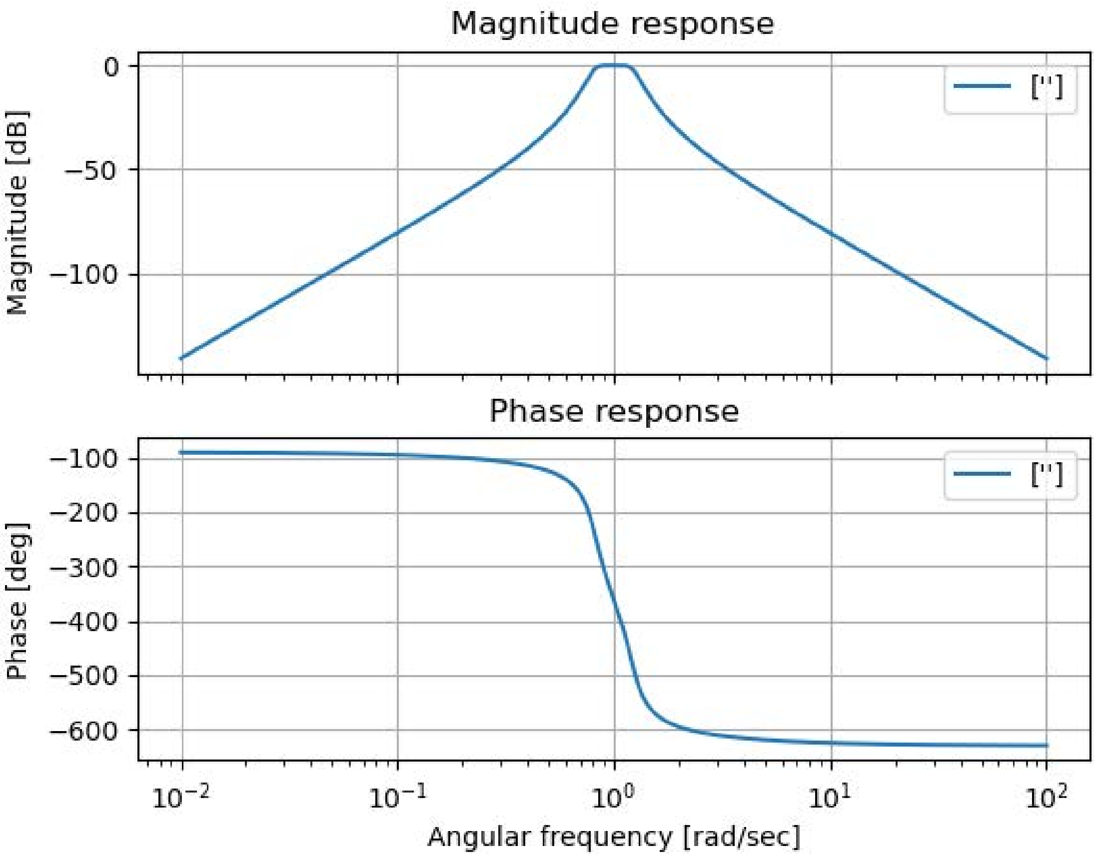


• TENES EL APORTE DE LOS CEROS → 60dB / DEC QUE SE VERAN COMPENSADOS CON LOS CEROS, LOS CUALES TERMINARAN APORTANDO -60dB / dec

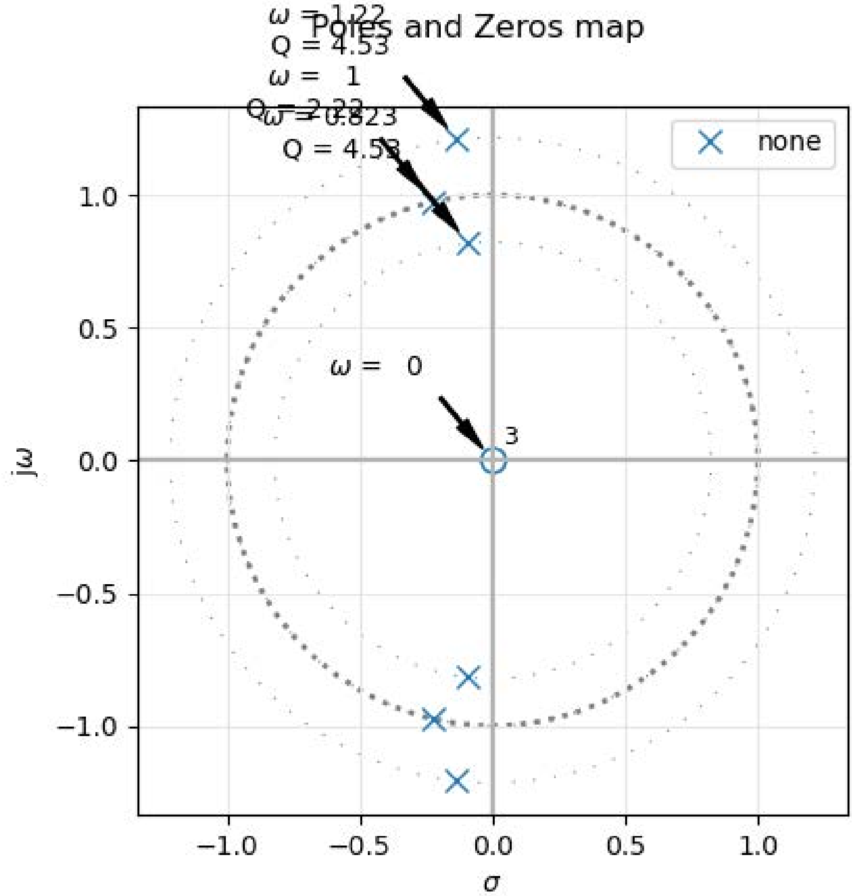
$z^3 \to 270°$
$ -90°$

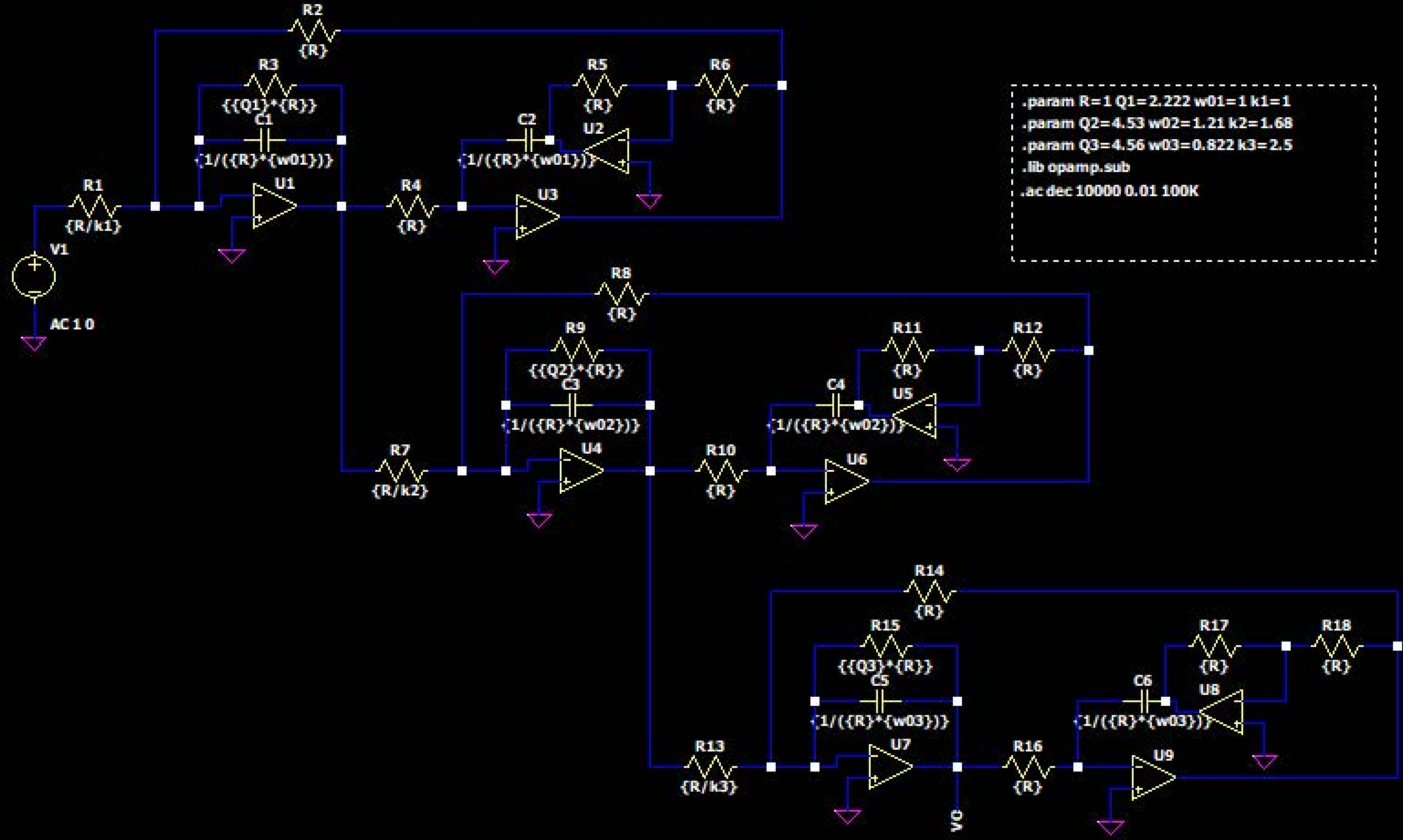
$p^2 \to 3 \cdot -180°$
$ -540°$

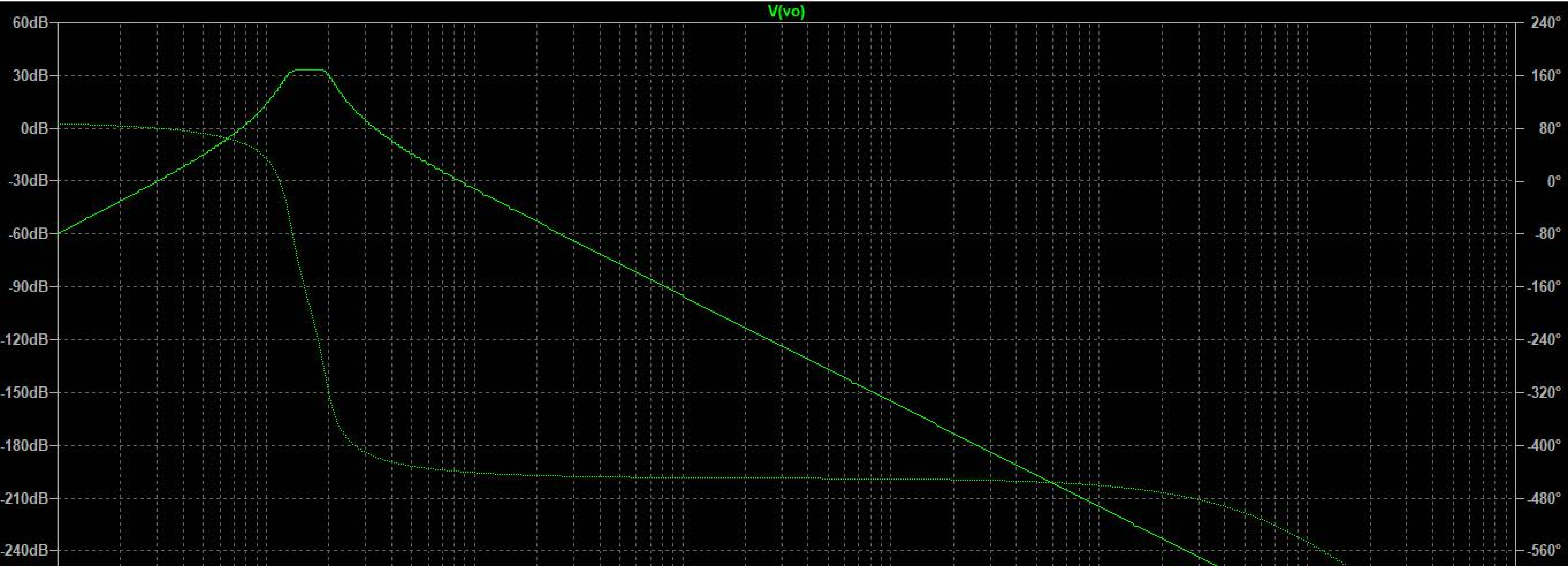


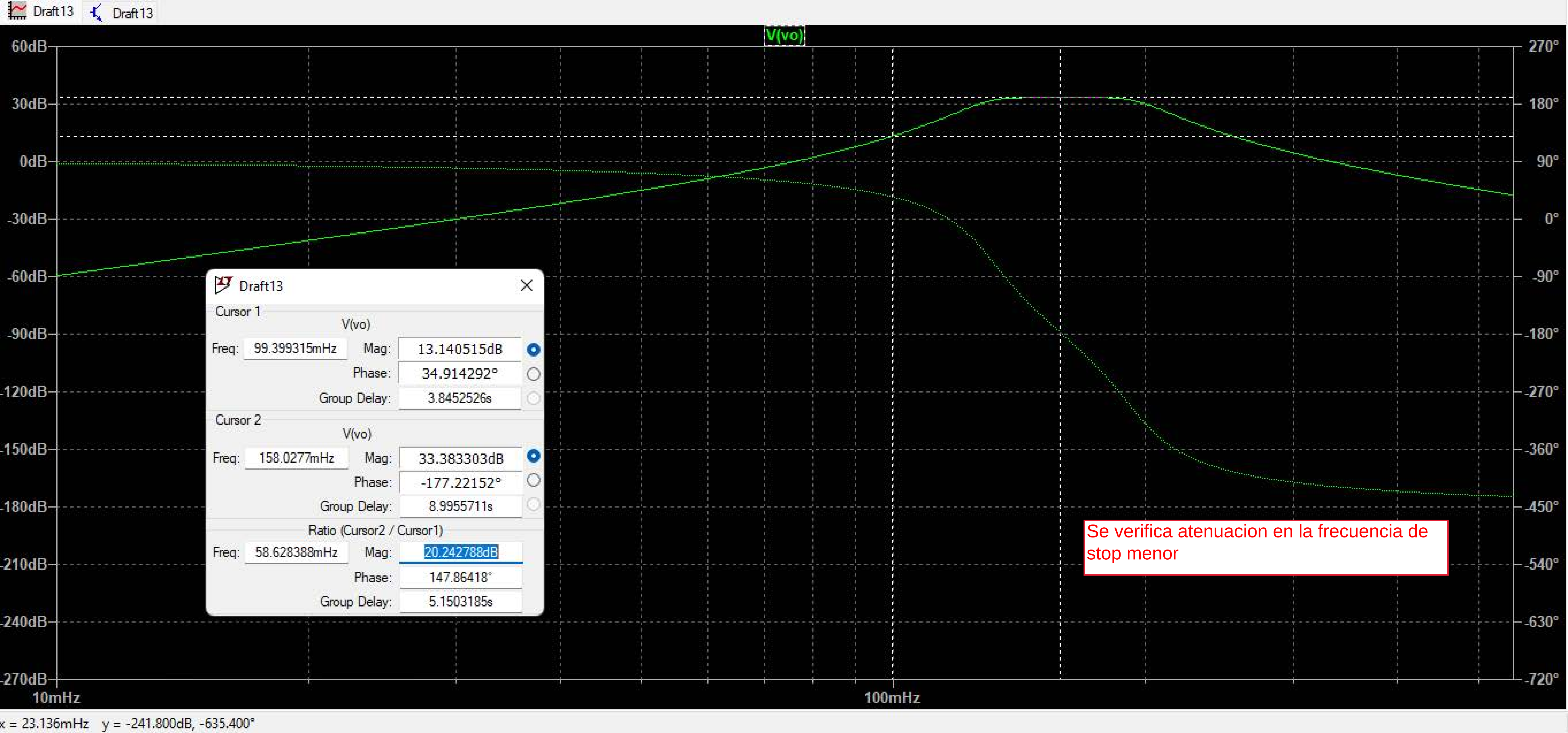


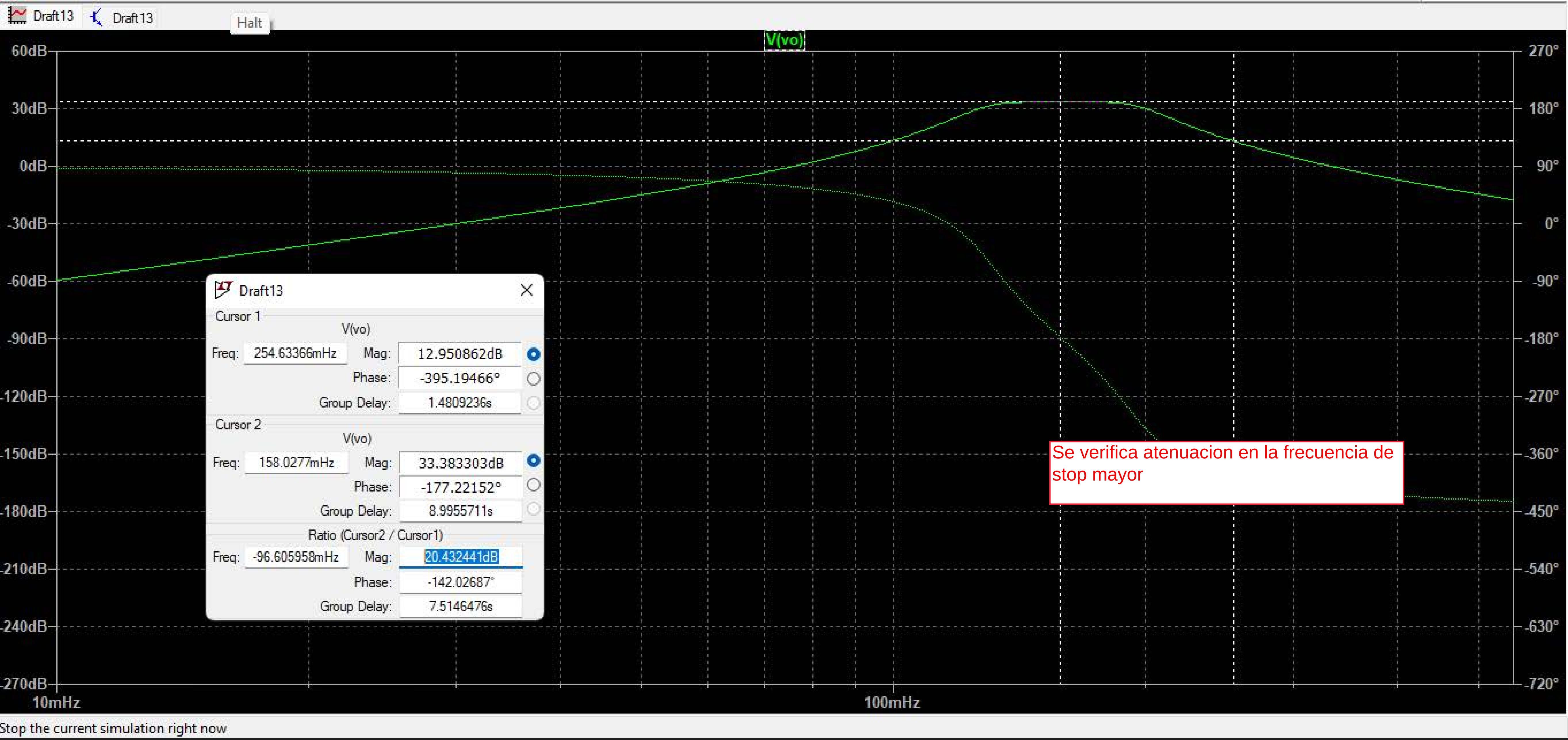
Magnitude response
Magnitude [dB]
0
−50
−100
['']
Phase response
Phase [deg]
−100
−200
−300
−400
−500
−600
['']
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
Angular frequency [rad/sec]

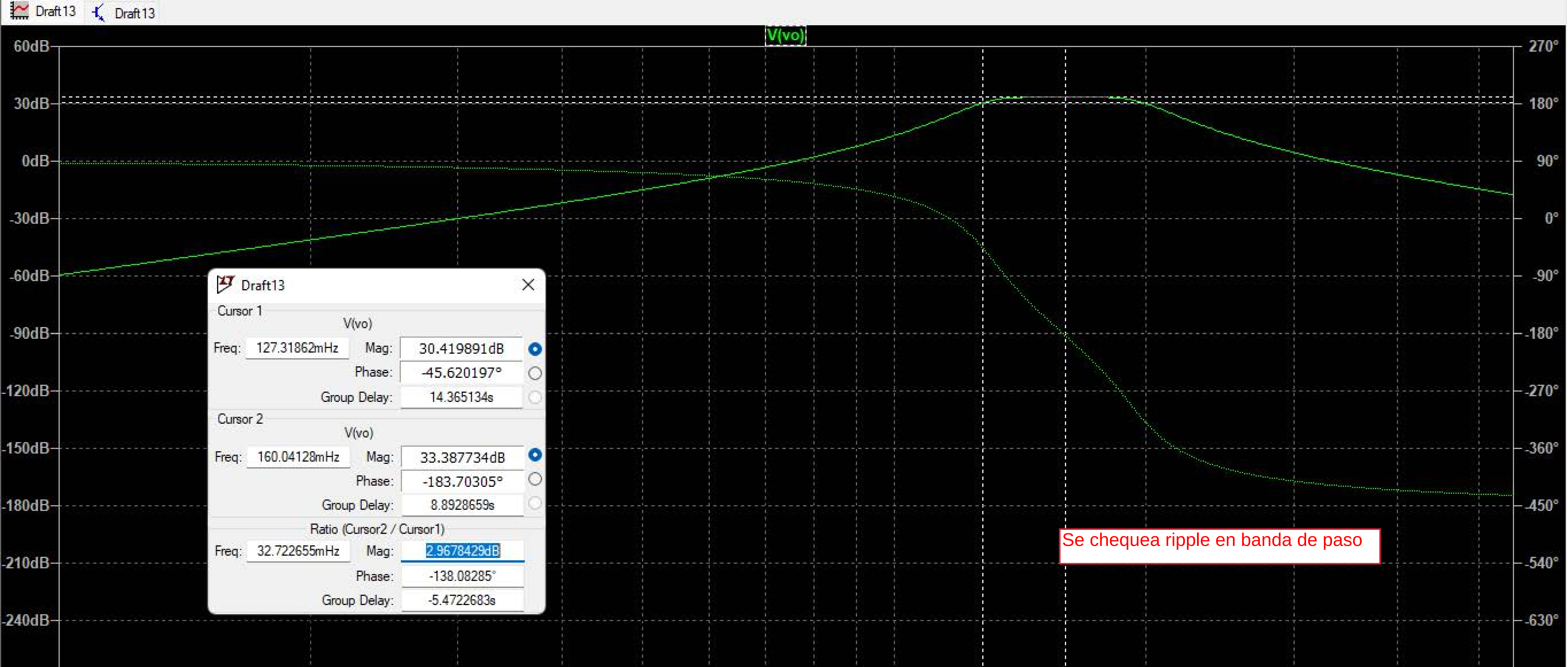

Poles and Zeros map
ω = 1.22
Q = 4.53
ω = 1
Q = 2.22
ω = 0.823
Q = 4.53
ω = 0
3
none
1.0
0.5
0.0
−0.5
−1.0
jω
−1.0
−0.5
0.0
0.5
1.0
σ


R2
{R}
R3
{{Q1}*{R}}
C1
{1/({R}*{w01})}
R5
{R}
R6
{R}
C2
{1/({R}*{w01})}
U2
R1
{R/k1}
U1
R4
{R}
U3
V1
AC 1 0
R8
{R}
R9
{{Q2}*{R}}
C3
{1/({R}*{w02})}
R11
{R}
R12
{R}
C4
{1/({R}*{w02})}
U5
R7
{R/k2}
U4
R10
{R}
U6
R14
{R}
R15
{{Q3}*{R}}
C5
{1/({R}*{w03})}
R17
{R}
R18
{R}
C6
{1/({R}*{w03})}
U8
R13
{R/k3}
U7
R16
{R}
U9
VO
.param R=1 Q1=2.222 w01=1 k1=1
.param Q2=4.53 w02=1.21 k2=1.68
.param Q3=4.56 w03=0.822 k3=2.5
.lib opamp.sub
.ac dec 10000 0.01 100K


V(vo)
60dB
30dB
0dB
-30dB
-60dB
-90dB
-120dB
-150dB
-180dB
-210dB
-240dB
240°
160°
80°
0°
-80°
-160°
-240°
-320°
-400°
-480°
-560°


Draft13
Draft13
V(vo)
60dB
30dB
0dB
-30dB
-60dB
-90dB
-120dB
-150dB
-180dB
-210dB
-240dB
-270dB
270°
180°
90°
0°
-90°
-180°
-270°
-360°
-450°
-540°
-630°
-720°
10mHz
100mHz
Draft13
Cursor 1
V(vo)
Freq: 99.399315mHz
Mag: 13.140515dB
Phase: 34.914292°
Group Delay: 3.8452526s
Cursor 2
V(vo)
Freq: 158.0277mHz
Mag: 33.383303dB
Phase: -177.22152°
Group Delay: 8.9955711s
Ratio (Cursor2 / Cursor1)
Freq: 58.628388mHz
Mag: 20.242788dB
Phase: 147.86418°
Group Delay: 5.1503185s
Se verifica atenuacion en la frecuencia de stop menor
x = 23.136mHz y = -241.800dB, -635.400°

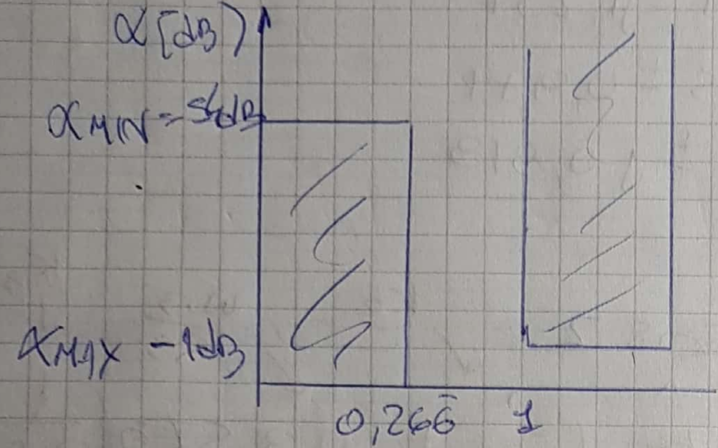

Draft13
Draft13
Halt
V(vo)
60dB
30dB
0dB
-30dB
-60dB
-90dB
-120dB
-150dB
-180dB
-210dB
-240dB
-270dB
270°
180°
90°
0°
-90°
-180°
-270°
-360°
-450°
-540°
-630°
-720°
10mHz
100mHz
Draft13
Cursor 1
V(vo)
Freq: 254.63366mHz
Mag: 12.950862dB
Phase: -395.19466°
Group Delay: 1.4809236s
Cursor 2
V(vo)
Freq: 158.0277mHz
Mag: 33.383303dB
Phase: -177.22152°
Group Delay: 8.9955711s
Ratio (Cursor2 / Cursor1)
Freq: -96.605958mHz
Mag: 20.432441dB
Phase: -142.02687°
Group Delay: 7.5146476s
Se verifica atenuacion en la frecuencia de stop mayor
Stop the current simulation right now



Draft13
Draft13
V(vo)
60dB
30dB
0dB
-30dB
-60dB
-90dB
-120dB
-150dB
-180dB
-210dB
-240dB
270°
180°
90°
0°
-90°
-180°
-270°
-360°
-450°
-540°
-630°
Draft13
Cursor 1
V(vo)
Freq: 127.31862mHz
Mag: 30.419891dB
Phase: -45.620197°
Group Delay: 14.365134s
Cursor 2
V(vo)
Freq: 160.04128mHz
Mag: 33.387734dB
Phase: -183.70305°
Group Delay: 8.8928659s
Ratio (Cursor2 / Cursor1)
Freq: 32.722655mHz
Mag: 2.9678429dB
Phase: -138.08285°
Group Delay: -5.4722683s
Se chequea ripple en banda de paso

3) $\alpha_{MIN} = 53{,}98\,dB$ $\quad \omega_p = 2\pi\, 45\,kHz$

$\alpha_{MAX} = 1\,dB$ $\quad \omega_s = 2\pi\, 12\,kHz$



$\Omega_s = 3{,}75$ $\quad \xi^2 = 0{,}259$

$\Omega_p = 1$ $\quad n = 4$

$$C_4 = 2w(4w^3 - 3w) - 2w^2 - 1$$

$$C_4 = 8w^4 - 6w^2 - 2w^2 - 1$$

$$C_4 = 8w^4 - 8w^2 - 1$$

$$|T(jw)|^2 = \frac{1}{1 + \xi^2(8w^4 - 8w^2 - 1)^2}$$

$w = \frac{s}{j}$

$$= \frac{1}{1 + \xi^2(8s^4 + 8s^2 - 1)^2} = \frac{1}{1 + \xi^2(64s^8 + 64s^6 - 8s^4 + 64s^6 + 64s^4 - 8s^2 - 8s^4 - 8s^2 + 1)}$$

$$= \frac{1}{1 + \xi^2(64s^8 + 128s^6 + 48s^4 - 16s^2 + 1)}$$

$$\frac{1}{as^4 + bs^3 + cs^2 + ds + e} \quad \frac{1}{as^4 - bs^3 + cs^2 - ds + e}$$

NOTA

$e = \sqrt{1+\xi_1^2}$

$\xi^2 64 = a^2 \longrightarrow \boxed{a = \xi 8}$

$n=6$

$\xi^2 128 = 2ac - b^2 \qquad b^2 = 2\xi 8c - \xi^2 128$

$b = \sqrt{2\xi 8c - \xi^2 128}$

$n=4$

$48\xi^2 = 2ae - bd - bd + c^2$

$n=2$

$-16\xi^2 = 2ce\,1 - d^2 \rightarrow \quad d = \sqrt{2\sqrt{(1+\xi^2)}c + 16\xi^2}$

$48\xi^2 = 2ae - 2bd + c^2$

$48\xi^2 = 2\sqrt{2\sqrt{(1+\xi^2)} + 16\xi^2}\sqrt{(1+\xi^2)} - 2\sqrt{2\xi 8c - \xi^2 128}$

Python:

$$T(s) = \frac{0{,}2456}{s^4 + 0{,}9528s^3 + 1{,}4539s^2 + 0{,}7426s + 0{,}2756}$$

$s = \frac{1}{\$}$

$$T(\$) = \frac{0{,}2456}{\frac{1}{\$^4} + 0{,}9528\frac{1}{\$^3} + 1{,}489\frac{1}{\$^2} + 0{,}7426\frac{1}{\$} + 0{,}2756}$$

$$T(\$) = \frac{\$^4\, 0{,}2456}{\$^4 0{,}2756 + \$^3 0{,}7426 + \$^2 1{,}4539 + \$ 0{,}9528 + 1}$$

$$T(\$) = \frac{0{,}891\,\$^4}{\$^4 + 2{,}694\$^3 + 5{,}275\$^2 + 3{,}457\$ + 3{,}62}$$

NOTA

$$P_{1,2} = -0,143 \pm j0,996$$
$$P_{3,4} = -1,2 \pm j1,46$$

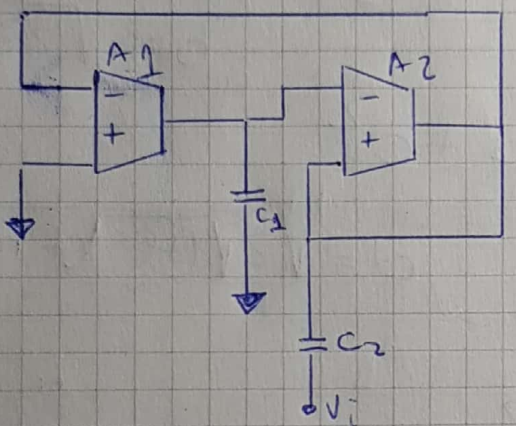
K

SOS 1

$$0,891 \frac{s^2}{s^2+0,286s+1,012}$$

SOS 2

$$\frac{s^2}{s^2+2,4s+3,571}$$



$$\frac{s^2 C_1 C_2}{s^2 C_1 C_2 + s C_1 g_{M2} + g_{M1} g_{M2}}$$

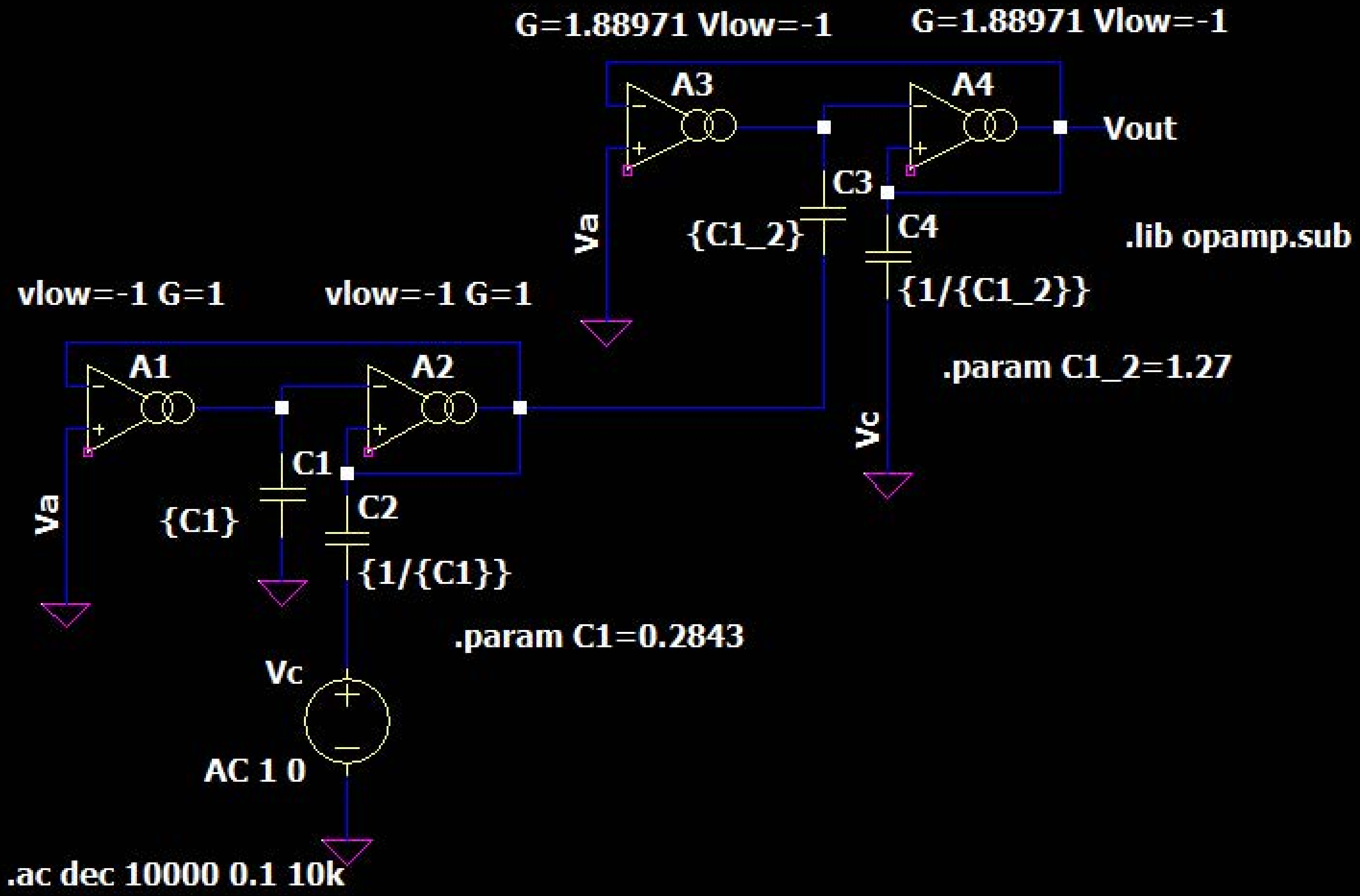
$$w_0 = \frac{g_M}{\sqrt{C_1 C_2}} \qquad \sqrt{\frac{C_2}{C_1}} = Q$$

SOS 1

$$C_1 g_{M2} = 0,286$$
$$g_{M1} g_{M2} = 1,012$$
$$C_1 C_2 = 1$$

SOS 2

$$C_1 g_{M2} = 2,4$$
$$g_{M1} g_{M2} = 3,571$$
$$C_1 C_2 = 1$$


G=1.88971 Vlow=-1
G=1.88971 Vlow=-1
A3
A4
Vout
Va
C3
{C1_2}
C4
{1/{C1_2}}
.lib opamp.sub
vlow=-1 G=1
vlow=-1 G=1
.param C1_2=1.27
A1
A2
Vc
Va
C1
{C1}
C2
{1/{C1}}
.param C1=0.2843
Vc
AC 1 0
.ac dec 10000 0.1 10k