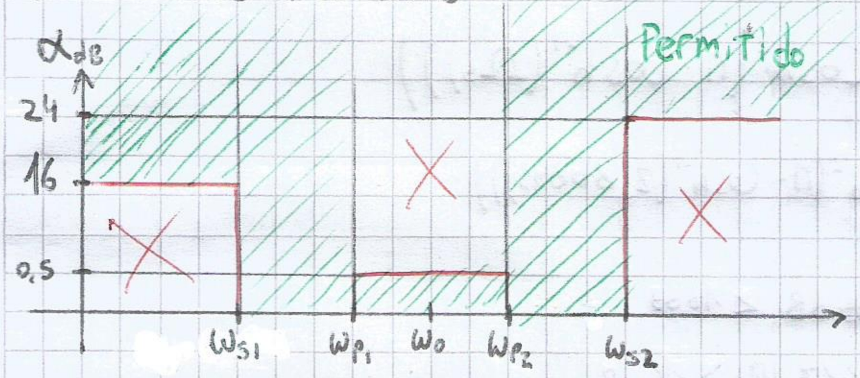
TS4

Diseño de Pasabanda:



$W_0 = 2\pi \cdot 22\,KHz$

$Q = 5$

$W_{S_1} = 2\pi \cdot 17\,KHz$

$W_{S_2} = 2\pi \cdot 36\,KHz$

Calculo W_{P_1} y W_{P_2} para hacer la plantilla normalizada

- Normalizando $W_0 \to 1$ $\quad (\Omega_w = w_0)$

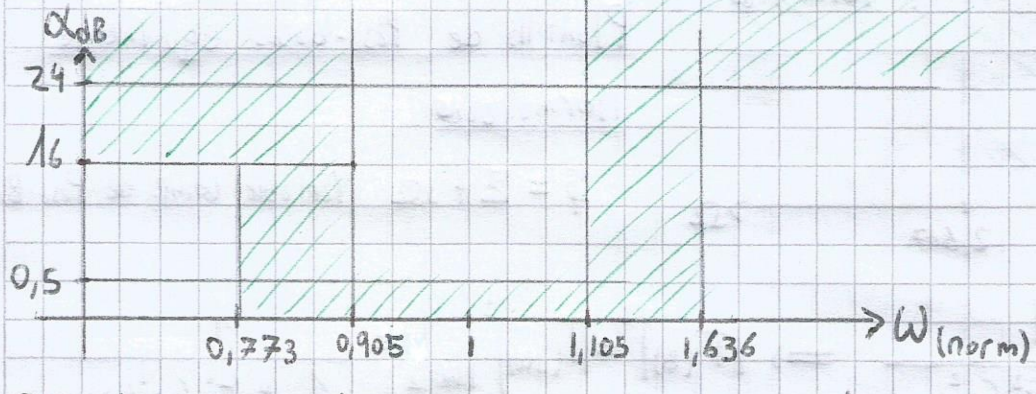
$$\therefore \begin{cases} W_{P_1} \cdot W_{P_2} = 1 \\ W_{P_2} - W_{P_1} = \frac{1}{Q} \end{cases} \implies W_{P_2} = \frac{1}{W_{P_1}} \implies \frac{1}{W_{P_1}} - W_{P_1} = \frac{1}{Q}$$

$$1 - W_{P_1}^2 = \frac{W_{P_1}}{Q} \implies W_{P_1}^2 + W_{P_1}\frac{1}{Q} - 1 = 0 \implies W_{P_1} = -\frac{1}{2Q} \pm \sqrt{\frac{1}{4Q^2} + 1}$$

$$W_{P_1} > 0 \implies W_{P_1} = -\frac{1}{2Q} + \sqrt{\frac{1}{4Q^2}+1} = \underline{0{,}9049876} \quad \text{Desnorm. } (W_{P_1} = 2\pi \cdot 19909{,}73\,Hz)$$

$$W_{P_2} = \frac{1}{W_{P_1}} = \underline{1{,}1049876} \quad (\text{Desnorm: } W_{P_2} = 2\pi \cdot 24309{,}73\,Hz)$$

Para luego Verif. en simulación.



Para la plantilla del pasabajos equivalente debo elegir la transición más exigente $\implies$ el α_{min} con el Ω_s que de el mayor orden.

$$|\Omega_{p_1}| = |\Omega_{p_2}| = \left| Q\,\frac{1 - W_{P_{1-2}}^2}{W_{P_{1-2}}} \right| = \underline{1} \quad \text{(siempre)}$$

$$|\Omega_{S_1}| = \left| Q\,\frac{1 - W_{S_1}^2}{W_{S_1}} \right| = \underline{2{,}60695} \qquad |\Omega_{S_2}| = \left| Q\,\frac{1 - W_{S_2}^2}{W_{S_2}} \right| = \underline{5{,}1\overline{26}}$$

Evalúo el orden para cada transición:

$\xi^2 = 10^{\frac{\alpha_{max}}{10}} - 1 = \boxed{0,122} \Rightarrow \xi = 0,349$

- Transición 1 : Ω_{s_1} y $\alpha_{min} = 16\,dB$

$$\alpha_{min} = 10 \cdot \log\left(1 + \xi^2 \cdot \cosh^2\left(n \cdot \cosh^{-1}(\Omega_s)\right)\right)$$

$$16\,dB = 10 \cdot \log\left(1 + \xi^2 \cdot \cosh^2\left(n_1 \cdot \cosh^{-1}(2,60695)\right)\right)$$

con $n_1 = 2 \rightarrow \alpha_{min} = 13,085\,dB < 16\,dB$

con $\boxed{n_1 = 3} \rightarrow \alpha_{min} = 26,8667\,dB > 16\,dB$

- Transición 2: Ω_{s_2} y $\alpha_{min} = 24\,dB$

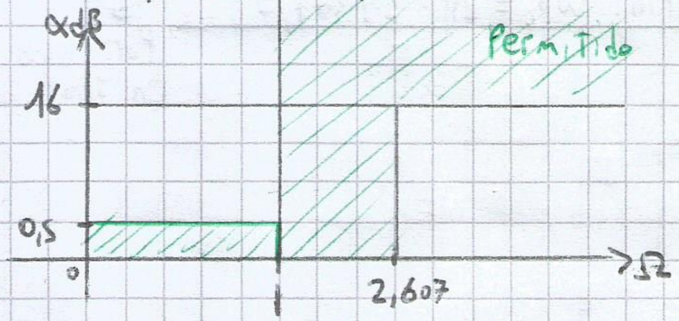
$$24\,dB = 10 \cdot \log\left(1 + \xi^2 \cdot \cosh^2\left(n_2 \cdot \cosh^{-1}(5,126)\right)\right)$$

Con $n_2 = 1 \rightarrow \alpha_{min} = 6,24\,dB < 24\,dB$

Con $\boxed{n_2 = 2} \rightarrow \alpha_{min} = 25,12\,dB > 24\,dB$

La transición 1 es la más exigente porque requiere el mayor orden

$\therefore$ $n = 3$, $\Omega_s = \Omega_{s_1}$, $\alpha_{min} = 16\,dB$ ← (aunque se sabe que será $26,8667\,dB$)



Plantilla de Pasa-bajos equivalente normalizado

$\$ = \Sigma + j\Omega$ Variable comp. de Pasa-Bajos

$\therefore$ $$|T(j\Omega)|^2 = \frac{1}{1 + \xi^2 C_3^2(\Omega)} \Longrightarrow |T(\$)|^2 = |T(j\Omega)|^2\Big|_{\Omega = \frac{\$}{j}} = \frac{1}{1 + \xi^2 C_3^2\left(\frac{\$}{j}\right)}$$

- $C_n(\Omega) = 2\Omega\, C_{n-1}(\Omega) - C_{n-2}(\Omega)$; $C_0(\Omega) = 1$ y $C_1(\Omega) = \Omega$

$\therefore$ $C_2(\Omega) = 2 \cdot \Omega \cdot \Omega - 1 = 2\Omega^2 - 1$

$C_3(\Omega) = 2\Omega \cdot (2\Omega^2 - 1) - \Omega = 4\Omega^3 - 2\Omega - \Omega = \boxed{4\Omega^3 - 3\Omega} \Rightarrow C_3\left(\frac{\$}{j}\right) = 4\$^3 \cdot j - 3\frac{\$}{j}$

$\boxed{C_3\left(\frac{\$}{j}\right) = j(4\$^3 + 3\$)}$

$$|T(\$)|^2 = \frac{1}{1 + \xi^2 j^2 (4\$^3 + 3\$)^2}$$

NOTA

$$|T(\$)|^2 = \frac{1}{1-\xi^2(16\$^6 + 2\cdot 4\$^3\cdot 3\$ + 9\$^2)}$$

Polos: $1-\xi^2(16\$^6+24\$^4+9\$^2)=0$

$$16\$^6 + 24\$^4 + 9\$^2 - \frac{1}{\xi^2} = 0$$

$$\$^6 + \frac{3}{2}\$^4 + \frac{9}{16}\$^2 - \frac{1}{16\xi^2} = 0$$

$$\$ = \begin{cases} \pm 0{,}626456 & \text{(2 Polos reales)} \\ \pm 0{,}313228 \pm j1{,}02193 & \text{(4 Polos Complejos)} \end{cases}$$

$$|T(\$)|^2 = T(\$)\cdot T(-\$) = \frac{T(-\$)}{4\xi}\cdot\frac{1}{\$+0{,}626456}\cdot\frac{1}{(\$+0{,}313228+j1{,}02193)(\$+0{,}313228-j1{,}02)}$$

$$|T(\$)|^2 = \underbrace{\frac{1}{4\xi}\,\frac{1}{\$+0{,}626}\cdot\frac{1}{\$^2+\$\cdot 2\cdot 0{,}313+0{,}313^2+1{,}02^2}}_{T(\$)}\cdot T(-\$)$$

$$T(\$) = \frac{1}{4\xi}\,\frac{1}{\$+0{,}626456}\cdot\frac{1}{\$^2+\$\,0{,}626456+1{,}142452705}$$ Pasa bajos 3° orden

$\$ = K(s) = Q\cdot\frac{s^2+1}{s}$ (S Variable Comp. de Pasa banda ; $s=\sigma+j\omega$)

$\therefore$ Pasa banda: $$T(s) = \frac{1}{4\xi}\,\frac{1}{Q\cdot\frac{s^2+1}{s}+0{,}626}\cdot\frac{1}{Q^2\frac{(s^2+1)^2}{s^2}+Q\frac{(s^2+1)}{s}0{,}626+1{,}14}$$

$$T(s) = \frac{1}{4\xi}\,\frac{s}{Qs^2+Q+s\,0{,}626}\;\frac{s^2}{Q^2(s^2+1)^2+s\,Q(s^2+1)\,0{,}626+s^2 1{,}14}$$

$$T(s) = \frac{1}{4\xi}\,\frac{s\cdot\frac{1}{Q}}{s^2+s\frac{0{,}626}{Q}+1}\;\frac{s^2}{Q^2s^4+2Q^2s^2+Q^2+Qs^3\,0{,}626+Q\cdot s\cdot 0{,}626+s^2\cdot 1{,}14}$$

$$T(s) = \frac{1}{4\xi} \cdot \frac{\frac{1}{0{,}626}\, s \frac{0{,}626}{Q}}{s^2 + s\frac{0{,}626}{Q} + 1} \cdot \frac{s^2 \frac{1}{Q^2}}{s^4 + s^3 \frac{0{,}626}{Q} + s^2\left(\frac{1{,}14}{Q^2} + 2\right) + s \cdot \frac{0{,}626}{Q} + 1}$$

$$T(s) = \frac{1}{4\xi\, 0{,}626} \cdot \frac{s \cdot 0{,}12529}{s^2 + s \cdot 0{,}12529 + 1} \cdot \frac{s^2 \cdot \frac{1}{25} \cdot \frac{0{,}069}{0{,}069} \cdot \frac{0{,}056}{0{,}056}}{(s^2 + s \cdot 0{,}069 + 1{,}226)(s^2 + s \cdot 0{,}056 + 0{,}815)}$$

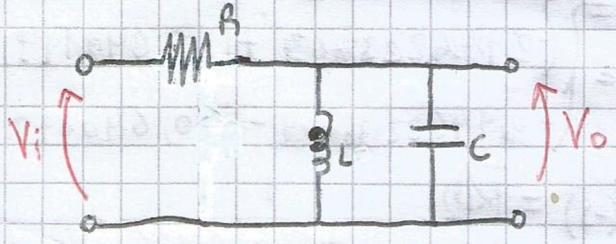
$$T(s) = 11{,}766 \cdot \underbrace{\frac{s \cdot 0{,}12529}{s^2 + s \cdot 0{,}1259 + 1}}_{T_1} \cdot \underbrace{\frac{s \cdot 0{,}069}{s^2 + s \cdot 0{,}069 + 1{,}226}}_{T_2} \cdot \underbrace{\frac{s \cdot 0{,}056}{s^2 \cdot s + 0{,}056 + 0{,}815}}_{T_3}$$

Paso banda de 6° orden

Paso bandas de: 3° orden (pasivos)

Diseño de Circuito

• Secciones pasivas:



$$V_o = V_i \cdot \frac{\frac{1}{\frac{1}{sL} + sC}}{R + \frac{1}{\frac{1}{sL} + sC}} \Longrightarrow \frac{V_o}{V_i} = \frac{\frac{1}{\cancel{\frac{1}{sL} + sC}}}{\frac{R\left(\frac{1}{sL} + sC\right) + 1}{\cancel{\frac{1}{sL} + sC}}} = \frac{1}{sRC + \frac{R}{sL} + 1} = \frac{s}{s^2 RC + s + \frac{R}{L}}$$

$$\boxed{\frac{V_o}{V_i} = \frac{s\frac{1}{RC}}{s^2 + s\frac{1}{RC} + \frac{1}{LC}}}$$

• Para T_1:

$$\frac{1}{L_1^{\circ} C_1^{\circ}} = 1$$

$$\frac{1}{R_1 C_1^{\circ}} = 0{,}1252912$$

Suponiendo $\boxed{R_1 = 10\,K\Omega}$

$$C_1^{\circ} = \frac{1}{10\,K\Omega \cdot 0{,}1252912} = 798{,}14 \cdot 10^{-6}\,F$$

$$L_1^{\circ} = \frac{1}{C_1^{\circ}} = 1252{,}912\ Hy$$

$$\therefore\ L_1 = \frac{L_1^{\circ}}{\Omega_w} = \boxed{9{,}06396\ mHy}$$

$$C_1 = \frac{C_1^{\circ}}{\Omega_w} = \boxed{5{,}7740014\ nF}$$

• Para T_2:

$$\frac{1}{L_2^{\circ} \cdot C_2^{\circ}} = 1{,}226462737$$

$$\frac{1}{R_2 C_2^{\circ}} = 0{,}0690174$$

Sup. $R_2 = 10\,K\Omega \longrightarrow C_2^{\circ} = \frac{1}{R_2 \cdot 0{,}069} = 1{,}4489\ mF$

$$\therefore\ L_2^{\circ} = \frac{1}{1{,}226 \cdot C_2^{\circ}} = 562{,}7354\ Hy$$

$\boxed{L_2 = 4{,}0710055\ mHy}$; $\boxed{C_2 = 10{,}4818721\ nF}$

NOTA

- **Para T_3:**

$$\frac{1}{L_3' C_3'} = 0,815355696 \qquad \text{Sup. } \boxed{R_3 = 10\,K\Omega} \Rightarrow C_3' = \frac{1}{R_3 \cdot 0,056} = 1,777025\ mF$$

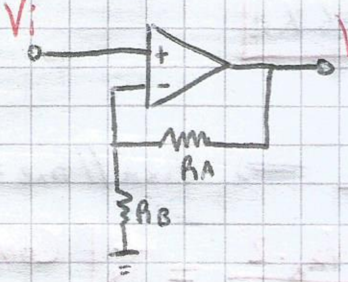
$$\frac{1}{R_3 C_3'} = 0,0562738 \qquad L_3' = \frac{1}{0,815 \cdot C_3'} = 690,174856\ Hy$$

$\boxed{L_3 = 4,992942723\ mHy}$; $\boxed{C_3 = 12,85556617\ nF}$

- **ETapa de ganancia**

ganancia positiva de $K = 11,76608089$

$\therefore$ no inversor



$$V_i = V_o \cdot \frac{R_B}{R_A + R_B}$$

$$\therefore \frac{V_o}{V_i} = \frac{R_A}{R_B} + 1 = 11,766$$

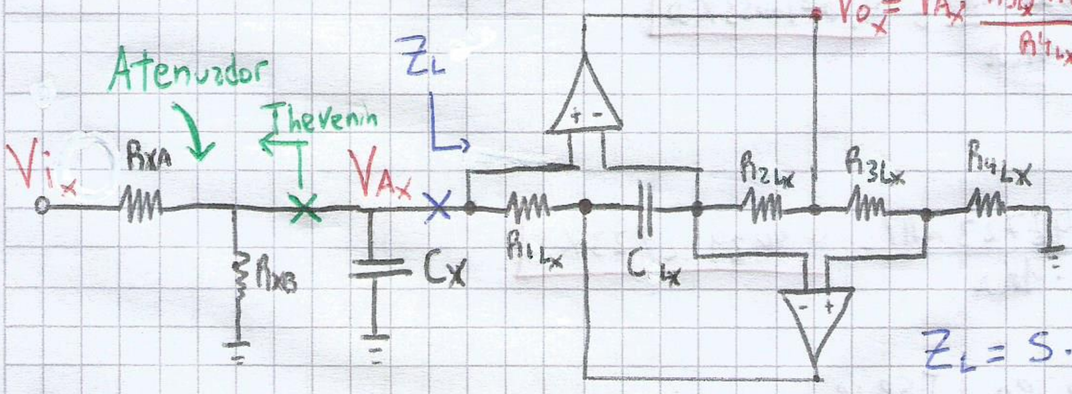
$$\therefore \frac{R_A}{R_B} = 10,766$$

$R_A = 107,6608089\,K\Omega$

$R_B = 10\,K\Omega$

Activación de Redes Pasivas

$$V_{o_x} = V_{A_x} \cdot \frac{R_{3_{Lx}} + R_{4_{Lx}}}{R_{4_{Lx}}}$$



$$Z_L = \underbrace{S \cdot \frac{C_{Lx} \cdot R_{1x} \cdot R_{2Lx} \cdot R_{4Lx}}{R_{3Lx}}}_{L_{xeq}}$$

Thevenin:

$$V_{th_x} = V_{i_x} \cdot \frac{R_{xB}}{R_{xA} + R_{xB}}$$

$R_{th_x} = R_{xA} // R_{xB} = R$ de cada Red Pasiva $(10\,K\Omega)$

• ~~La primer Red no requiere Atenuador, dado que no tiene una etapa anterior amplificada por el girador de impedancia.~~

• Mantengo el amp. no inversor para independizar parámetro K.

1°ra red:

• $L_{1eq} = 9{,}06396\ mHY = \frac{C_{L_1} \cdot R_{1L_1} \cdot R_{2L_1} \cdot R_{4L_1}}{R_{3L_1}}$

Para Todos
Para que la salida amp. por 2, y tener entonces que atenuar por 2 en entrada (mismas Res.)

Hago $R_{3Lx} = R_{4Lx}$

$\therefore R_{xA} = R_{xB}$

$\therefore L_{1eq} = C_{L_1} \cdot R_{1L_1} \cdot R_{2L_1}$

• $C_{Lx} = 1nF$ } Para Todos

• $R_{1Lx} = 1K\Omega$

$\therefore R_2L_1 = \frac{9{,}06396\ mHY}{1nF \cdot 1K\Omega} = \boxed{9{,}06396\ K\Omega}$

Para Todos

$R_3L_x = R_{4Lx} = 20K\Omega = R_{xA} = R_{xB} \Longrightarrow R_{xA} // R_{xB} = 10K\Omega$

$\therefore V_{O_x} = V_{A_x} \cdot 2$

$V_{Th_x} = V_{i_x} \cdot \frac{1}{2}$

$\therefore \frac{V_{Ox}}{V_{ix}} = \frac{V_{A_x} \cdot \cancel{2}}{V_{th_x} \cdot \cancel{2}} = \boxed{T_x}$ Compensado.

2°da Red:

$R_2L_2 = \frac{4{,}0710055\ mHY}{1nF \cdot 1K\Omega} = \boxed{4{,}0710055\ K\Omega}$

3°ra Red:

$R_2L_3 = \frac{4{,}992942723\ mHY}{1nF \cdot 1K\Omega} = \boxed{4{,}992942723\ K\Omega}$

Circuito Completo en LTspice

NOTA