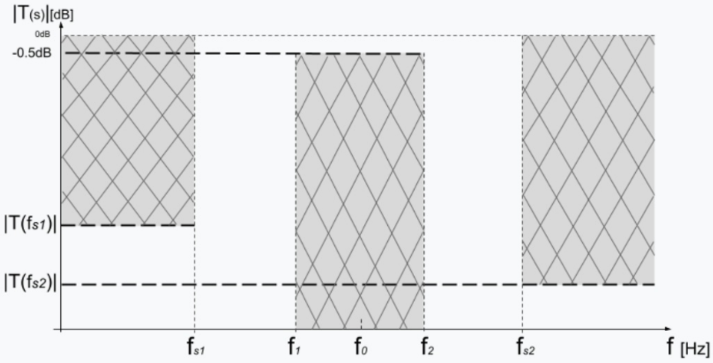
**Consigna del ejercicio**

Se pide diseñar un filtro pasabanda que cumpla con la siguiente plantilla:

- $\omega_0 = 2\pi\ 22$ kHz
- $Q = 5$
- Aproximación Chebyshev con ripple de 0,5 dB

También se sabe que la transferencia del filtro debe ser:

- $|T(f_{S1})| = -16\ dB$ para $f_{S1} = 17\ kHz$
- $|T(f_{S2})| = -24\ dB$ para $f_{S2} = 36\ kHz$




**Consignas de la actividad**:

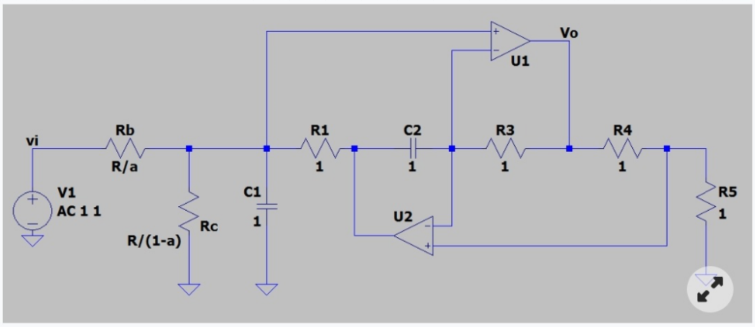
👉 Obtener la plantilla de diseño pasabanda normalizada

👉 Obtener la función transferencia normalizada del prototipo pasabajo que satisfaga el requerimiento del filtro pasabanda.

👉 Obtener la transferencia pasabanda normalizada

👉 Implementar mediante secciones pasivas separadas por seguidores de tensión activos.

👉 Activar las redes pasivas mediante la red propuesta aquí debajo y comprobar mediante simulación el comportamiento deseado.




**Informe**

Respecto al informe, se mantiene el mismo formato usado hasta el momento, informe en jupyter-notebook, simulaciones en python y LTspice. Se mantienen las [recomendaciones para la inclusión de gráficas y resultados de la simulación](), y se agrega:

+ Cada figura deberá tener una leyenda o un párrafo que haga referencia a ella

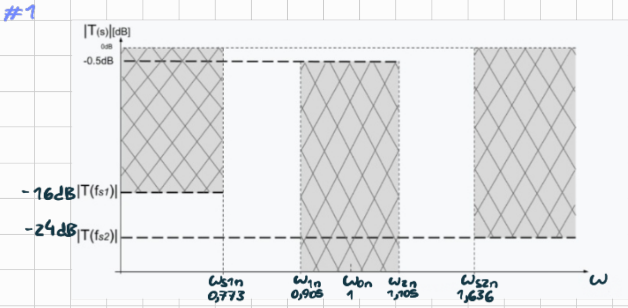
+ Al menos una sección donde:

* se discutan los resultados obtenidos, factibilidad de implementación de la red, componentes sensibles, etc.

* se informe las dificultades o problemas, si las hubiera

* se destaquen los aspectos salientes de la resolución propuesta.

#1




- $\omega_0 = 2\pi\, 22\,k\ ^1/_{seg} \longrightarrow \omega_{0n} = 1$

$$Q = \frac{\omega_{0n}}{\Delta\omega_n} \longrightarrow \Delta\omega_n = \omega_{2n} - \omega_{1n} = 0{,}2 \qquad \begin{cases} \omega_{2n} - \dfrac{1}{\omega_{2n}} = 0{,}2 \\ \omega_{1n} = \dfrac{1}{\omega_{2n}} \end{cases} \qquad \begin{cases} \omega_{2n}^2 - 0{,}2\,\omega_{2n} - 1 = 0 \\ \omega_{1n} = \dfrac{1}{\omega_{2n}} \end{cases}$$

$$\omega_{0n}^2 = \omega_{1n} \cdot \omega_{2n} = 1$$

- $\omega_{2n}^2 + 0{,}2\,\omega_{2n} - 1 = 0 \longrightarrow \omega_{2n} = \dfrac{1 - \sqrt{101}}{10} \cong -0{,}905$ X
  $\longrightarrow \omega_{2n} = \dfrac{1 + \sqrt{101}}{10} \cong 1{,}105$

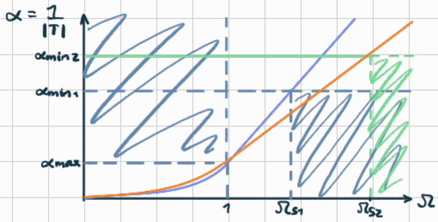
- $\omega_{1n} = \dfrac{-1 + \sqrt{101}}{10} \cong 0{,}905$

- $f_{s1} = 17\ kHz \longrightarrow \omega_{s1} = 2\pi f_{s1} \longrightarrow \omega_{s1n} = \dfrac{2\pi f_{s1}}{\omega_0} = \dfrac{17}{22} \cong 0{,}773$

- $f_{s2} = 36\ kHz \longrightarrow \omega_{s2} = 2\pi f_{s2} \longrightarrow \omega_{s2n} = \dfrac{2\pi f_{s2}}{\omega_0} = \dfrac{18}{11} \cong 1{,}636$

#2

Elijo cuál de los dos LP cumple con toda la plantilla




- Núcleo de transformación: $N_{(s)} = Q\,\dfrac{s^2+1}{s}$
  $\hookrightarrow \Omega = Q\left(\dfrac{\omega^2 - 1}{\omega}\right)$

$$\Omega_{s1n} = Q\left(\frac{\omega_{s1n}^2 - 1}{\omega_{s1n}}\right) = -\frac{975}{374} \cong -2{,}607 \longrightarrow \Omega_{s1n} \cong 2{,}607$$

$$\Omega_{s2n} = Q\left(\frac{\omega_{s2n}^2 - 1}{\omega_{s2n}}\right) = \frac{1015}{198} \cong 5{,}126$$

$$\Omega_{p1n} = Q\left(\frac{\omega_{p1n}^2 - 1}{\omega_{p1n}}\right) = -1 \longrightarrow \Omega_{p1n} = 1$$

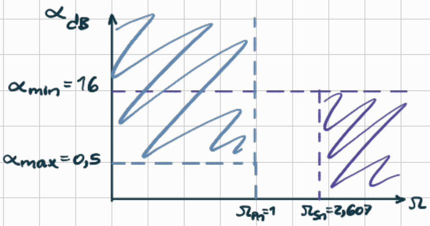
$$\Omega_{p2n} = Q\left(\frac{\omega_{p2n}^2 - 1}{\omega_{p2n}}\right) = 1$$

$$\frac{\alpha_{min1} - \alpha_{max}}{\Omega_{s1n} - \Omega_{p1n}} = \frac{16 - 0{,}5}{2{,}607 - 1} = 9{,}64$$

$$\frac{\alpha_{min2} - \alpha_{max}}{\Omega_{s2n} - \Omega_{p2n}} = \frac{24 - 0{,}5}{5{,}126 - 1} = 5{,}69$$

El filtro LP de $\Omega_{s1n} \cong 2{,}607$ y $\alpha_{min} = -16\,dB$ cumple con los requisitos del otro LP, por lo tanto, se buscará por medio de este lograr la plantilla del PB luego de la transformación

✳ Filtro Pasa Bajos Chebyshev:




$$\varepsilon^2 = 10^{\alpha_{max}/10} - 1 = 0{,}122 \longrightarrow \varepsilon = 0{,}349$$

Obtención de n a partir de iterar $\alpha_{dB}\big|_{\Omega = \Omega_{sn}}$ hasta que $\alpha_{dB} \geq \alpha_{min}$

$$\alpha_{dB} = 10 \log\left(1 + \varepsilon^2 \cosh^2\left(n\ \mathrm{arccos}(\Omega_{sn})\right)\right)$$

- $n = 2$: $\alpha_{dB} = 13{,}085 < 16$ X
- $n = 3$: $\alpha_{dB} = 26{,}867 > \underbrace{16}_{\alpha_{min}}$ ✓

∴ el filtro Chebyshev que cumple con la plantilla será de orden 3 y $\varepsilon \cong 0{,}349$

$$|T_{C3}(j\Omega)|^2 = \frac{1}{1+\varepsilon^2 C_3^2(\Omega)}$$

$$\left.\begin{cases} C_n = 2\Omega\, C_{n-1} - C_{n-2} \\ C_0 = 1 \\ C_1 = \omega \end{cases}\right\} C_n^2(\Omega)$$

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

$$C_3 = 2\Omega\left(2\Omega^2-1\right) - \Omega = 4\Omega^3 - 3\Omega$$

$$|T_{C3}(j\Omega)|^2 = \frac{1}{1+\varepsilon^2\left(4\Omega^3-3\Omega\right)^2} = \frac{1}{1+\varepsilon^2\left(16\Omega^6 - 24\Omega^4 + 9\Omega^2\right)} = \frac{1}{16\varepsilon^2\Omega^6 - 24\varepsilon^2\Omega^4 + 9\varepsilon^2\Omega^2 + 1}$$

$$|T_{C3}(s)|^2\Big|_{\Omega=\frac{s}{j}} = \frac{1}{-16\varepsilon^2 s^6 - 24\varepsilon^2 s^4 - 9\varepsilon^2 s^2 + 1} = \frac{-\frac{1}{16\varepsilon^2}}{s^6 + \frac{3}{2}s^4 + \frac{9}{16}s^2 - \frac{1}{16\varepsilon^2}}$$

se calculan las raices del polinomio del denominador:

(2) [-0.31322824+1.02192749j, -0.31322824-1.02192749j,
~~0.31322824+1.02192749j~~, ~~0.31322824-1.02192749j~~,
(1) -0.62645649+0.j , ~~0.62645649+0.j~~ ]

1 par de polos Comp. Conj. y un polo Real
No se tienen en cuenta aquellos que estén
en el semiplano derecho

(1) $T_{1(s)} = \frac{1}{s+0{,}626}$ ; $\alpha_1 = 0{,}626$

(2) $\alpha \pm j\beta \rightarrow \alpha_2 = 0{,}313 \quad \beta_2 = 1{,}022$ } $T_{2(s)} = \frac{1}{s^2 + 2\alpha_2 s + \alpha_2^2 + \beta_2^2} \longrightarrow T_{2(s)} = \frac{1}{s^2 + 0{,}626\, s + 1{,}142}$

$$T_{LP(s)} = T_{1(s)} \cdot T_{2(s)} = \sqrt{\frac{1}{16\varepsilon^2}} \cdot \frac{1}{s+0{,}626} \cdot \frac{1}{s^2+0{,}626\,s+1{,}142} = \frac{1}{4\varepsilon\alpha_1(\alpha_2^2+\beta_2^2)} \cdot \frac{0{,}626}{s+0{,}626} \cdot \frac{1{,}142}{s^2+0{,}626\,s+1{,}142}$$

$$T_{LP(s)} = \frac{\frac{1}{4\varepsilon}}{s^3 + (\alpha_1+2\alpha_2)\,s^2 + \left(2\alpha_1\alpha_2 + \alpha_2^2 + \beta_2^2\right)s + \alpha_1\left(\alpha_2^2+\beta_2^2\right)}$$

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#3

Se procede a obtenerse la función transferencia del filtro Pasa Banda a partir de aplicar el núcleo de transformación a la transferencia del Pasa Bajos

$$N_{(S)} = Q\,\frac{S^2+1}{S}$$

$$T_{LP(\$)} = \frac{\frac{1}{4\,\varepsilon}}{\$^3 + (\alpha_1 + 2\alpha_2)\,\$^2 + (2\alpha_1\alpha_2 + \alpha_2^2 + \beta_2^2)\,\$ + \alpha_1(\alpha_2^2 + \beta_2^2)}$$

$$T_{PB(S)} = T_{LP(\$)}\Big|_{\$ = Q\frac{S^2+1}{S}}$$

$$T_{PB(S)} = \frac{\frac{1}{4Q^3\varepsilon}\,S^3}{S^6 + \left(\frac{\alpha_1}{Q} + \frac{2\alpha_2}{Q}\right)S^5 + \left(3 + \frac{2\alpha_1\alpha_2}{Q^2} + \frac{\alpha_2^2+\beta_2^2}{Q^2}\right)S^4 + \left(\frac{2\alpha_1 + 4\alpha_2}{Q} + Q^3\alpha_1\alpha_2^2 + 4\alpha_1\beta_2^2\right)S^3 + \left(3 + \frac{2\alpha_1\alpha_2}{Q^2} + \frac{\alpha_2^2+\beta_2^2}{Q^2}\right)S^2 + \left(\frac{\alpha_1 + 2\alpha_2}{Q}\right)S + 1}$$

- Se reemplaza por los correspondientes valores:

$$T_{PB(S)} = \frac{5{,}725.10^{-3}\,S^3}{S^6 + 0{,}25\,S^5 + 3{,}061\,S^4 + 0{,}507\,S^3 + 3{,}061\,S^2 + 0{,}25\,S + 1}$$

- Se separa en funciones Bicuadráticas:

$$T_{PB(S)} = \frac{0{,}1512\,S}{S^2 + 0{,}1253\,S + 1} \cdot \frac{0{,}1411\,S}{S^2 + 0{,}06902\,S + 1{,}226} \cdot \frac{0{,}2683\,S}{S^2 + 0{,}05627\,S + 0{,}8154}$$

$$T_{PB(S)} = 11{,}7624\,\frac{0{,}1253\,S}{S^2 + 0{,}1253\,S + 1} \cdot \frac{0{,}06902\,S}{S^2 + 0{,}06902\,S + 1{,}226} \cdot \frac{0{,}05627\,S}{S^2 + 0{,}05627\,S + 0{,}8154}$$

- Transferencia Pasa Banda genérica:

$$* \quad T_{(S)} = k_i\,\frac{S\,\frac{\omega_{0i}}{Q_i}}{S^2 + S\,\frac{\omega_{0i}}{Q_i} + \omega_{0i}^2}$$

$$T_{PB(S)} = k\,.\,\overbrace{\frac{S\,\frac{\omega_{01}}{Q_1}}{S^2 + S\,\frac{\omega_{01}}{Q_1} + \omega_{01}^2}}^{T_{1(S)}} \cdot \overbrace{\frac{S\,\frac{\omega_{02}}{Q_2}}{S^2 + S\,\frac{\omega_{02}}{Q_2} + \omega_{02}^2}}^{T_{2(S)}} \cdot \overbrace{\frac{S\,\frac{\omega_{03}}{Q_3}}{S^2 + S\,\frac{\omega_{03}}{Q_3} + \omega_{03}^2}}^{T_{3(S)}}$$

$$\left\{\begin{array}{lll} \omega_{01} = 1 & Q_1 = 7{,}981 & k = 11{,}7624 \\ \omega_{02} = 1{,}107 & Q_2 = 16{,}042 & \\ \omega_{03} = 0{,}903 & Q_3 = 16{,}048 & \end{array}\right\}$$

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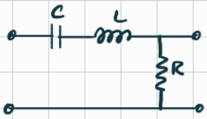
#4

- Celda de red pasiva Pasa Banda




$$\frac{V_2}{V_1} = k \frac{s\,{}^{R}\!/_{L}}{s^2 + s\frac{R}{L} + \frac{1}{LC}} = k_i \frac{s\frac{\omega_{oi}}{Q_i}}{s^2 + s\frac{\omega_{oi}}{Q_i} + \omega_{oi}^2}$$

- síntesis de la transferencia $T_{PB(s)}$ en la red mencionada

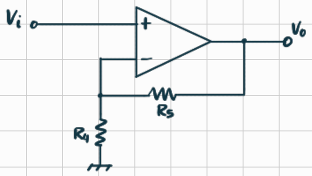
$$\begin{cases} L_i C_i = \frac{1}{\omega_{oi}^2} \\ \frac{R_i}{L_i} = \frac{\omega_{oi}}{Q_i} \end{cases} \qquad \begin{cases} R_{ni} = 1 \\ C_{ni} = \frac{1}{\omega_{oi} Q_i} \cdot \frac{1}{R_{ni}} \\ L_{ni} = \frac{Q_i}{\omega_{oi}} \cdot R_{ni} \end{cases}$$

* $T_{1(s)}$ : . $R_{n_1} = 1$
  - $C_{n1} = \frac{1}{\omega_{o1} Q_1} \frac{1}{R_{n1}} = 0{,}125$
  - $L_{n1} = \frac{Q_1}{\omega_{o1}} \cdot R_{n1} = 7{,}981$

* $T_{2(s)}$ : . $R_{n_2} = 1$
  - $C_{n2} = \frac{1}{\omega_{o2} Q_2} \frac{1}{R_{n2}} = 0{,}0563$
  - $L_{n2} = \frac{Q_2}{\omega_{o2}} \cdot R_{n2} = 14{,}491$

* $T_{3(s)}$ : . $R_{n_3} = 1$
  - $C_{n3} = \frac{1}{\omega_{o3} Q_3} \frac{1}{R_{n3}} = 0{,}069$
  - $L_{n3} = \frac{Q_3}{\omega_{o3}} \cdot R_{n3} = 17{,}772$

* $K = 11{,}7624$ ← Para lograr el K requerido, se agregará una etapa activa en la salida de la red. Compuesta por un Opamp en configuración no inversora.




$$V_o = V_i \underbrace{\left(1 + \frac{R_5}{R_4}\right)}_{K}$$

$$K = 1 + \frac{R_{5n}}{R_{4n}} \qquad \begin{cases} R_{4n} = 1 \\ R_{5n} = (K-1)\, R_{4n} = 10{,}7624 \end{cases}$$

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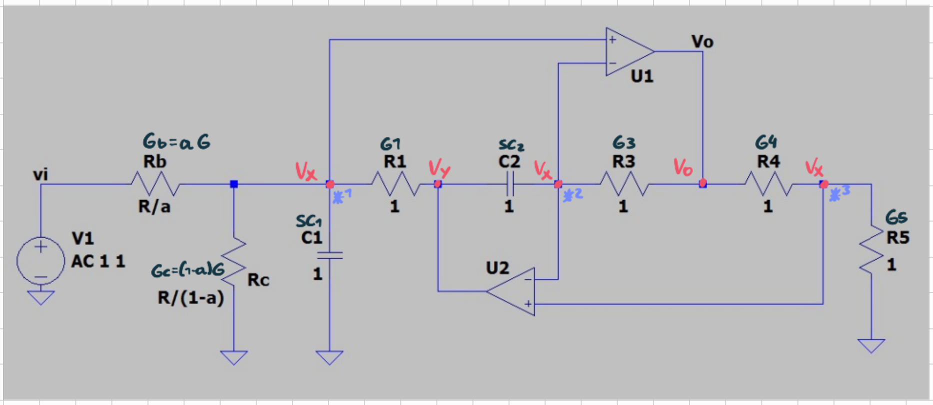
#5




$$\left.\begin{aligned} &*_1 \quad V_x\,(G_b+G_c+G_1+sC_1) - V_i\,G_b - V_y\,G_1 = 0 \\ &*_2 \quad V_x\,(G_3+sC_2) - V_y\,sC_2 - V_o\,G_3 = 0 \\ &*_3 \quad V_x\,(G_4+G_5) - V_o\,G_4 = 0 \end{aligned}\right\}$$

Resolución con cálculo simbólico

$$T(s) = \frac{a(G_4+G_5)}{G_4}\;\frac{s\,\frac{G}{C_1}}{s^2 + s\,\frac{G}{C_1} + \frac{G_1G_3G_5}{C_1C_2G_4}} = a\,\frac{R_4+R_5}{R_5}\;\frac{s\,\frac{1}{RC_1}}{s^2 + s\,\frac{1}{RC_1} + \frac{R_4}{R_1R_3R_5C_1C_2}} = k_i\,\frac{s\,\frac{\omega_{oi}}{Q_i}}{s^2 + s\,\frac{\omega_{oi}}{Q_i} + \omega_{oi}^2}$$

$$\left\{\begin{aligned} k_i &= a\,\frac{R_4+R_5}{R_5} \\ \omega_{oi}^2 &= \frac{R_4}{R_1R_3R_5C_1C_2} \\ Q_i &= R\,C_1\,\omega_o \end{aligned}\right.$$

* Se realiza la síntesis de la transferencia Pasa Banda de orden 6 como cascada de 3 Bicuadráticas, a partir de la red analizada compuesta por el GIC.

$$T_{PB(s)} = k_1\,k_2\,k_3 \cdot \overbrace{\frac{s\,\frac{\omega_{o1}}{Q_1}}{s^2 + s\,\frac{\omega_{o1}}{Q_1} + \omega_{o1}^2}}^{T_1(s)} \cdot \overbrace{\frac{s\,\frac{\omega_{o2}}{Q_2}}{s^2 + s\,\frac{\omega_{o2}}{Q_2} + \omega_{o2}^2}}^{T_2(s)} \cdot \overbrace{\frac{s\,\frac{\omega_{o3}}{Q_3}}{s^2 + s\,\frac{\omega_{o3}}{Q_3} + \omega_{o3}^2}}^{T_3(s)}$$

$$\left\{\begin{array}{lll} \omega_{o1} = 1 & Q_1 = 7{,}981 & K = 11{,}7624 \\ \omega_{o2} = 1{,}107 & Q_2 = 16{,}042 & \\ \omega_{o3} = 0{,}903 & Q_3 = 16{,}048 & \end{array}\right\}$$

* $K_1 = k_2 = k_3 = \sqrt[3]{K} = 2{,}2742$

* $R_{1i} = R_{3i} = R_{5i} = 1$
$C_{1i} = C_{2i} = C_i$
$a_i = 0{,}5$

$$\left\{\begin{aligned} a_i &= \frac{k_i}{Q_i^2+1} \\ R_{4i} &= Q_i^2 \\ C_i &= \frac{Q_i}{\omega_{oi}} \end{aligned}\right. \qquad \begin{aligned} R_i &= \frac{Q_i\,a_i\,\sqrt{\frac{k_i-a_i}{a_i}}}{k_i-a_i} \\ R_4 &= \frac{k_i-a_i}{a_i} \\ C_i &= \frac{\sqrt{\frac{k_i-a_i}{a_i}}}{\omega_{oi}} \end{aligned}$$