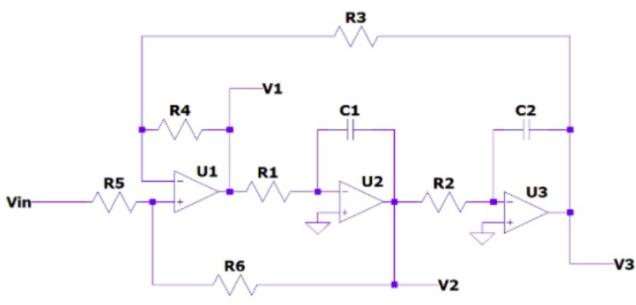


Diseñar un filtro pasabajas **Chebyshev** para obtener una atenuación de 48 dB para frecuencias mayores a 900 Hz, con una atenuación máxima de 0.4 dB desde continua hasta 300 Hz. ( Ancho de Banda reducido para canal Sub Lows )

$\alpha_{\text{Max}}$ [dB]	$\alpha_{\text{min}}$ [dB]	$f_p$ [Hz]	$f_s$ [Hz]
0.4	48	300	900

1. Determinar el orden del filtro y el parámetro  $\epsilon$ .
2. Obtener la expresión completa de la Transferencia NORMALIZADA de  $T(s)$
3. Obtener el diagrama de polos y ceros y graficar a mano alzada en forma cualitativa la respuesta de modulo y fase.
4. Sintetizar el circuito NORMALIZADO utilizando estructuras Kerwin–Huelsman–Newcomb (KHN, también conocido como Variable de Estado) saliendo desde la salida  $V_3$  como indica el siguiente circuito de referencia:



#### BONUS

- +10 💡 Simulación numérica en python
- +10 💡 Simulación Circuital con los valores DESNORMALIZADOS ( cumpliendo la plantilla pedida )
- +10 🍷 Presentación en jupyter notebook

#1

$$\epsilon^2 = 10^{\frac{\alpha_{\text{max}}}{10}} - 1 = 0,0964782 \longrightarrow \epsilon = 0,310604$$

Normalizando:

$$\left. \begin{aligned} \omega_p &= 2\pi f_p = 1884,96 \text{ rad/seg} \\ \omega_s &= 2\pi f_s = 5654,87 \text{ rad/seg} \end{aligned} \right\} \quad \begin{aligned} \omega_{p_n} &= 1 \\ \omega_{s_n} &= \frac{\omega_s}{\omega_p} = 3 \end{aligned}$$

Obtención de  $n$  a partir de iterar  $\alpha_{\text{dB}}$  hasta que  $\alpha_{\text{dB}} \geq \alpha_{\text{min}}$

$$\alpha_{\text{dB}} = 10 \log (1 + \epsilon^2 \cosh^2(n \arccos(\omega_{s_n})))$$

$$\cdot n=4 : \alpha_{\text{dB}} = 45,07 < 48 \times$$

$$\cdot n=5 : \alpha_{\text{dB}} = 60,38 > 48 \checkmark$$

∴ el filtro Chebyshev que cumple con la plantilla será de orden 5 y  $\epsilon \approx 0,310604$

$$\#2 \quad |T_{CS(j\omega)}|^2 = \frac{1}{1 + \varepsilon^2 C_s^2(\omega)}$$

$$\left. \begin{array}{l} C_n = 2\omega C_{n-1} - C_{n-2} \\ C_0 = 1 \\ C_1 = \omega \end{array} \right\} C_n(\omega)$$

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

$$C_3 = 2\omega(2\omega^2 - 1) - \omega = 4\omega^3 - 3\omega$$

$$C_4 = 2\omega(4\omega^3 - 3\omega) - (2\omega^2 - 1) = 8\omega^4 - 8\omega^2 + 1$$

$$C_5 = 2\omega(8\omega^4 - 8\omega^2 + 1) - (4\omega^3 - 3\omega) = 16\omega^5 - 20\omega^3 + 5\omega$$

$$|T_{CS(j\omega)}|^2 = \frac{1}{1 + \varepsilon^2 (16\omega^5 - 20\omega^3 + 5\omega)^2} = \frac{1}{1 + \varepsilon^2 (256\omega^{10} + 400\omega^6 + 25\omega^2 - 640\omega^8 + 160\omega^6 - 200\omega^4)}$$

$$|T_{CS(j\omega)}|^2 = \frac{1}{256\varepsilon^2 \omega^{10} - 640\varepsilon^2 \omega^8 + 560\varepsilon^2 \omega^6 - 200\varepsilon^2 \omega^4 + 25\varepsilon^2 \omega^2 + 1}$$

$$|T_{CS}(s)|^2 \Big|_{\omega=\frac{s}{j}} = \frac{1}{-256\varepsilon^2 s^{10} - 640\varepsilon^2 s^8 - 560\varepsilon^2 s^6 - 200\varepsilon^2 s^4 - 25\varepsilon^2 s^2 + 1}$$

$$|T_{CS}(s)|^2 = \frac{-\frac{1}{256\varepsilon^2}}{s^{10} + \frac{5}{2}s^8 + \frac{35}{16}s^6 + \frac{25}{32}s^4 + \frac{25}{256}s^2 - \frac{1}{256\varepsilon^2}}$$

Se calculan las raíces del polinomio del denominador:

$$\begin{aligned} & -0.11932228+1.01949544j, \quad -0.11932228-1.01949544j, \\ (3) & -0.11932228+1.01949544j, \quad -0.11932228-1.01949544j, \\ & -0.31238979+0.63008283j, \quad -0.31238979-0.63008283j, \\ (2) & -0.31238979+0.63008283j, \quad -0.31238979-0.63008283j, \\ (1) & -0.38613502+0.j \quad , \quad -0.38613502+0.j \end{aligned}$$

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

$$(1) \quad T_1(s) = \frac{1}{s + 0,386}$$

$$(2) \quad \alpha \pm j\beta \rightarrow \alpha_2 = 0,312 \quad \beta_2 = 0,63 \quad \left. \right\} \quad T_2(s) = \frac{1}{s^2 + 2\alpha_2 s + \alpha_2^2 + \beta_2^2} \quad \rightarrow \quad T_2(s) = \frac{1}{s^2 + 0,625 s + 0,495}$$

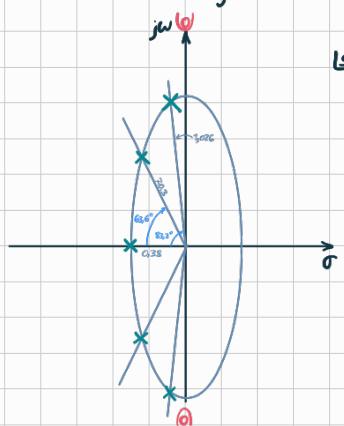
$$(3) \quad \alpha \pm j\beta \rightarrow \alpha_3 = 0,119 \quad \beta_3 = 1,019 \quad \left. \right\} \quad T_3(s) = \frac{1}{s^2 + 2\alpha_3 s + \alpha_3^2 + \beta_3^2} \quad \rightarrow \quad T_3(s) = \frac{1}{s^2 + 0,239 s + 1,054}$$

$$T(s) = T_1(s) \cdot T_2(s) \cdot T_3(s) = \frac{1}{s + 0,386} \cdot \frac{1}{s^2 + 0,625 s + 0,495} \cdot \frac{1}{s^2 + 0,239 s + 1,054} \quad (-0,2012)$$

$$T(s) = -\frac{0,2012}{s^5 + 1,2496 s^4 + 2,0307 s^3 + 1,4317 s^2 + 0,8209 s + 0,2012}$$

#3

Diagrama de Polos y Ceros:



LS

Polos:

$$[-0.11932228+1.01949544j, -0.11932228-1.01949544j, -0.31238979+0.63008283j, -0.31238979-0.63008283j, -0.38613502+0.j]$$

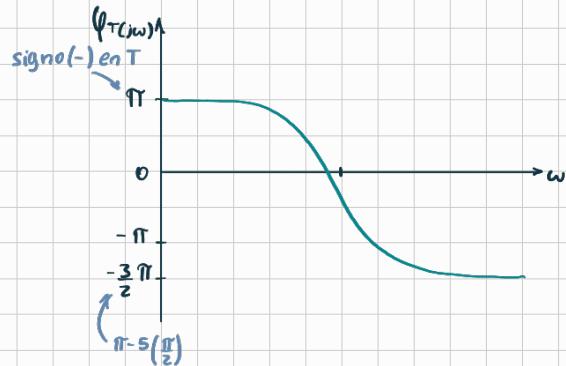
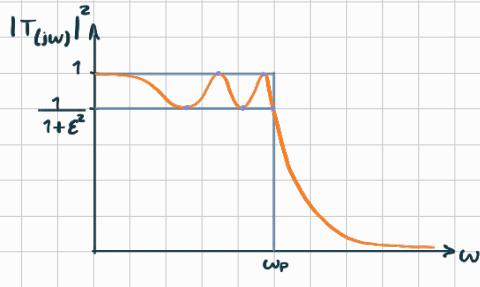
\*Ángulos:

$$[96.67555691, -96.67555691, 116.37182893, -116.37182893, 180.]$$

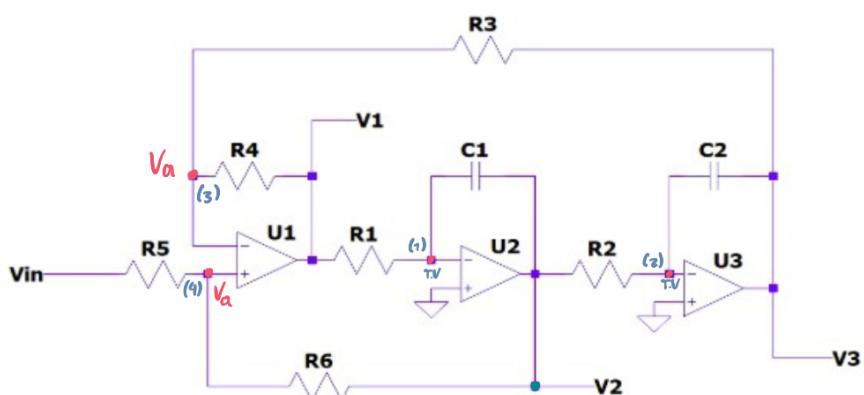
\*Módulos:

$$[1.02645446, 1.02645446, 0.70327218, 0.70327218, 0.38613502]$$

Diagrama aproximado de módulo y fase:



#4



$$(1) V_1 G_1 + V_2 S C_1 = 0$$

$$(2) V_2 G_2 + V_3 S C_2 = 0$$

$$(3) V_{\alpha} (G_3 + G_4) - V_1 G_4 - V_3 G_3 = 0$$

$$(4) V_{\alpha} (G_5 + G_6) - V_{in} G_5 - V_2 G_6 = 0$$

\* Se obtiene  $T(s)$  por medio de cálculo simbólico:

$$T(s) = \frac{V_3}{V_{in}} = \frac{G_1 G_2 G_5 (G_3 + G_4)}{S^2 G_4 C_1 C_2 (G_5 + G_6) + S G_1 G_6 C_2 (G_3 + G_4) + G_1 G_2 G_3 (G_5 + G_6)}$$

$$T(s) = \frac{G_1 G_2 G_5 (G_3 + G_4)}{G_4 C_1 C_2 (G_5 + G_6)} \frac{1}{s^2 + s \frac{G_1 G_6 (G_3 + G_4)}{G_4 C_1 (G_5 + G_6)} + \frac{G_1 G_2 G_3}{G_4 C_1 C_2}} \quad \leftarrow \text{Chequeo de unidades OK}$$

$$T(s) = \frac{G_5 (G_3 + G_4)}{G_3 (G_5 + G_6)} \frac{\frac{G_1 G_2 G_3}{G_4 C_1 C_2}}{s^2 + s \frac{G_1 G_6 (G_3 + G_4)}{G_4 C_1 (G_5 + G_6)} + \frac{G_1 G_2 G_3}{G_4 C_1 C_2}} = K \frac{\frac{\omega_0^2}{s^2 + s \frac{\omega_0^2}{Q} + \omega_0^2}}{Q}$$

$$\left. \begin{aligned} \omega_0 &= \sqrt{\frac{G_1 G_2 G_3}{G_4 C_1 C_2}} \\ \frac{\omega_0}{Q} &= \frac{G_1 G_6 (G_3 + G_4)}{G_4 C_1 (G_5 + G_6)} \end{aligned} \right\} Q = \frac{G_4 C_1 (G_5 + G_6)}{G_1 G_6 (G_3 + G_4)} \sqrt{\frac{G_1 G_2 G_3}{G_4 C_1 C_2}} \quad ; \quad K = \frac{G_5 (G_3 + G_4)}{G_3 (G_5 + G_6)}$$

Partiendo de la func. transferencia obtenida para el filtro Chebyshew

$$T_{CS}(s) = T_1(s) \cdot T_2(s) \cdot T_3(s) = \underbrace{\frac{1}{s + 0,386}}_{T_1(s)} \cdot \underbrace{\frac{1}{s^2 + 0,625s + 0,495}}_{T_2(s)} \cdot \underbrace{\frac{0,2012}{s^2 + 0,239s + 1,054}}_{T_3(s)}$$

$$*2) T(s) = T_2(s)$$

$$T(s) = K \frac{\frac{\omega_0^2}{s^2 + s \frac{\omega_0^2}{Q} + \omega_0^2}}{Q} = \frac{1}{0,495} \frac{0,495}{s^2 + s 0,625 + 0,495}$$

$$\left. \begin{aligned} K &= \frac{G_5 (G_3 + G_4)}{G_3 (G_5 + G_6)} = \frac{1}{0,495} \\ \omega_0^2 &= \frac{G_1 G_2 G_3}{G_4 C_1 C_2} = 0,495 \\ \frac{\omega_0}{Q} &= \frac{G_1 G_6 (G_3 + G_4)}{G_4 C_1 (G_5 + G_6)} = 0,625 \end{aligned} \right\}$$

Como hay 8 incógnitas y solo 3 dtos, establezco relaciones p/ poder resolver el sist.

$$\left. \begin{aligned} C_1 &= C_2 = C \\ G_3 + G_4 &= G_5 + G_6 \\ G_1 &= G_4 \\ G_5 &= G_6 = 1 \end{aligned} \right\} \left. \begin{aligned} K &= \frac{1}{G_3} = \frac{1}{0,495} \\ \omega_0^2 &= \frac{G_2 G_3}{C^2} = 0,495 \\ \frac{\omega_0}{Q} &= \frac{1}{C} = 0,625 \end{aligned} \right\} \begin{array}{l} \text{Resolución por cálculo simbólico:} \\ C = 1,6 \\ G_2 = 2,56 \\ G_3 = 0,495 \end{array}$$

$$\left. \begin{array}{l} C_1 = C_2 = 1,6 \\ G_1 = G_4 = 1,505 \\ G_2 = 2,56 \\ G_3 = 0,495 \\ G_5 = G_6 = 1 \end{array} \right\} \quad \left. \begin{array}{l} C_1 = C_2 = 1,6 \\ R_1 = R_4 = 0,664 \\ R_2 = 0,397 \\ R_3 = 2,02 \\ R_5 = R_6 = 1 \end{array} \right\}$$

$$*3) T_{(S)} = T_{z(S)}$$

$$T_{CS} = K \frac{\omega_0^2}{S^2 + S \frac{\omega_0}{Q} + \omega_0^2} = 0,1909 \frac{1,054}{S^2 + S 0,239 + 1,054}$$

$$k = \frac{G_5(G_3+G_4)}{G_3(G_5+G_6)} = 0,1909$$

$$\left. \right\} w_0^2 = \frac{G_1 G_2 G_3}{G_4 C_1 C_2} = 1,054$$

$$\frac{w_0}{Q} = \frac{G_1 G_6 (G_3 + G_4)}{G_4 C_1 (G_5 + G_6)} = 0,239$$

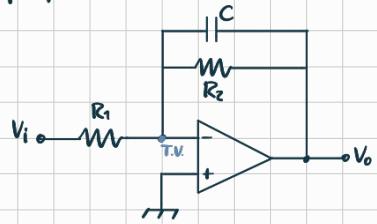
De forma similar a la resolución anterior, establezco relaciones p/poder resolver el sist.

$$\left\{ \begin{array}{l} C_1 = C_2 = 1 \\ G_5 = G_3 \\ G_1 = G_4 = G_3 \end{array} \right. \quad \left\{ \begin{array}{l} K = \frac{2G_3}{G_3 + G_6} = 0,1909 \\ w_b^2 = G_2 G_3 = 1,054 \\ \frac{w_b}{Q} = G_6 \frac{2G_3}{G_3 + G_6} = 0,239 \end{array} \right. \quad \begin{array}{l} \text{Resolución por Cálculo simbólico:} \\ G_2 = 7,978 \\ G_3 = 0,132 \\ G_6 = 1,252 \end{array}$$

$$\left. \begin{array}{l} C_1 = C_2 = 1 \\ G_1 = G_4 = G_3 = G_5 = 0,132 \\ G_2 = 7,978 \\ G_6 = 1,252 \end{array} \right\} \quad \left. \begin{array}{l} C_1 = C_2 = 1 \\ R_1 = R_3 = R_4 = R_5 = 7,576 \\ R_2 = 0,125 \\ R_6 = 0,799 \end{array} \right\}$$

$$\text{*7) } T_1(s) = -\frac{1}{s + 0,386}$$

Se propone:



$$V_i G_1 + V_o (G_2 + SC) = 0$$

$$T_1(s) = \frac{V_o}{V_i} = -\frac{G_1}{SC + G_2} = -\frac{\frac{1}{R_1 C}}{S + \frac{1}{R_2 C}}$$

$$T_1(s) = -\frac{1}{s + 0,386} = -\frac{\frac{1}{R_1 C}}{S + \frac{1}{R_2 C}}$$

$$\left\{ \begin{array}{l} \frac{1}{R_1 C} = 1 \\ \frac{1}{R_2 C} = 0,386 \end{array} \right. , R_1 = 1 \quad \left\{ \begin{array}{l} R_1 = 1 \\ R_2 = 2,59 \\ C = 1 \end{array} \right.$$