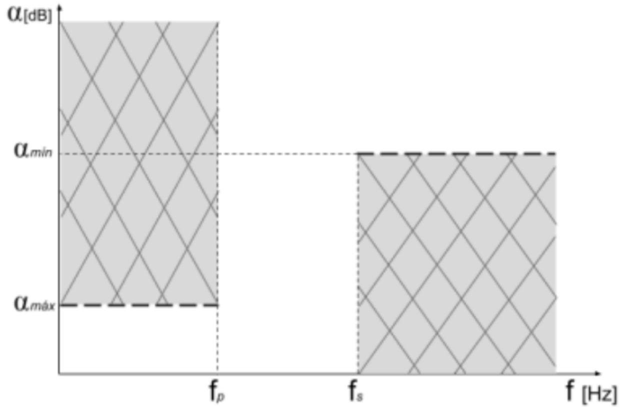


αmáx [dB]	ωp [r/s]	ωs [r/s]
1	1	2,5

1. Obtener la función transferencia T(s) de Bessel para N: 2, 3 y 4 normalizados para $D(\omega = 0) = 1s$ utilizando el método de Storch: ver *Schaumann, R. - Van Valkenburg, Mac E., Design of Analog Filters, Capítulo 10: Delay Filters. Sección 10.2: Bessel-Thomson Response. Página 403.*

N=2

$$\text{cotgh} \approx \frac{1}{s} + \frac{1}{\frac{3}{s}} = \frac{3+s^2}{3s} \rightarrow B_2 = s^2+3s+3$$

$$T_2(s) = \frac{B_2(0)}{B_2(s)} = \frac{3}{s^2+3s+3}$$

N=3

$$\text{Cotgh} \approx \frac{1}{s} + \frac{1}{\frac{3}{s} + \frac{1}{\frac{5}{s}}} = \frac{1}{s} + \frac{1}{\frac{3}{s} + \frac{s}{5}} = \frac{1}{s} + \frac{5s}{15+s^2}$$

$$= \frac{5s^2+15+s^2}{s^3+15s}$$

$$B_3 = s^3+6s^2+15s+15$$

$$T_3(s) = \frac{15}{s^3+6s^2+15s+15}$$

N=4

$$B_4 = (2\cdot 4-1)\cdot B_3 + s^2 B_2 = 7\cdot(s^3+6s^2+15s+15) + s^2\cdot(s^2+3s+3)$$

$$= 7s^3+42s^2+105s+105+s^4+3s^3+3s^2 = s^4+10s^3+45s^2+105s+105$$

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

2. Elegir la T(s) con el <u>mínimo orden</u> que cumpla con $\alpha_{máx} = 1dB$.

N = 2

$$T_2(\omega) = \frac{3}{-\omega^2 + 3\cdot j\omega + 3} = \frac{3}{3 - \omega^2 + j\,3\omega}$$

$$|T_2(\omega)| = \frac{3}{\sqrt{(3-\omega^2)^2 + (3\omega)^2}} = \frac{3}{\sqrt{9 - 6\omega^2 + \omega^4 + 9\omega^2}} = \frac{3}{\sqrt{\omega^4 + 3\omega^2 + 9}}$$

$$|\alpha_2(\omega_p = 1)| = \left(\frac{3}{\sqrt{1 + 3 + 9}}\right)^{-1} = \frac{\sqrt{13}}{3} \simeq 1{,}2$$

$$\alpha_2(\omega_p = 1)\Big|_{dB} = 10\log\left(\frac{\sqrt{13}}{3}\right) \simeq 0{,}7985\,dB$$ $\sqrt{}$ CUMPLE

N=3

$$T_3(\omega) = \frac{15}{-j\omega^3 - 6\omega^2 + 15\cdot j\omega + 15} = \frac{15}{-6\omega^2 + 15 + j(-\omega^3 + 15\omega)}$$

$$|T_3(\omega)| = \frac{15}{\sqrt{(15 - 6\omega^2)^2 + (15\omega - \omega^3)^2}}$$

$$|T_3(\omega_p = 1)| = \frac{15}{\sqrt{(15-6)^2 + (15-1)^2}} = \frac{15}{\sqrt{81 + 196}} \simeq 0{,}901$$

$$\alpha(\omega_p = 1)_{dB} = -10\log\left(\frac{15}{\sqrt{277}}\right) = 0{,}451\,dB$$

$N = 4$

$$T_4(\omega) = \frac{105}{\omega^4 - j\omega^3 10 - 45\omega^2 + j\omega 105 + 105}$$

$$|T_4(\omega)| = \frac{105}{\sqrt{(\omega^4 - 45\omega^2 + 105)^2 + (-\omega^3 10 + \omega \cdot 105)^2}}$$

$$|T_4(\omega_p = 1)| = \frac{105}{\sqrt{(1 - 45 + 105)^2 + (-10 + 105)^2}} = \frac{105}{\sqrt{12.746}} \simeq 0,93$$

$$\alpha_4(\omega_p = 1)\Big|_{dB} = 10 \cdot \log\left(\frac{\sqrt{12476}}{105}\right) \simeq 0,315\,dB$$

con $n=2$ ya cumple...

3. Evaluar el retardo de grupo $D(\omega = 2.5)$ y expresar en forma *porcentual [%]* el error o desviamiento respecto a $D(\omega = 0)$.

$$D(\omega) = -\frac{\partial \measuredangle T(\omega)}{\partial \omega} \qquad \measuredangle T_2(\omega) = -\tan^{-1}\left(\frac{3\omega}{3-\omega^2}\right)$$

$$D(\omega) = \frac{1}{1 + \frac{3\omega}{3-\omega^2}} \cdot \left[\frac{3 \cdot (3-\omega^2) - (-2\omega) \cdot 3\omega}{(3-\omega^2)^2}\right]$$

$$D(\omega) = \frac{3 - \omega^2}{-\omega^2 + 3\omega + 3} \cdot \frac{9 + 3\omega^2}{(3-\omega^2)^2}$$

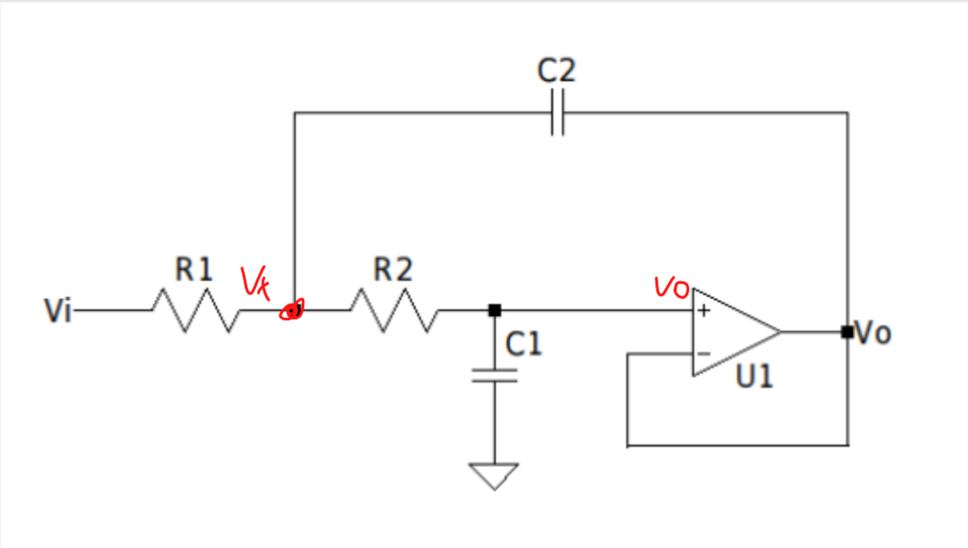
$$D_{(\omega=0)} = \frac{3 \cdot 9}{3 \cdot 3^2} = 1$$ Se cumple

$$D_{(\omega_s=2,5)} = \frac{\left(3 - \frac{25}{4}\right)\left(9 + 3 \cdot \frac{25}{4}\right)}{\left(-\frac{25}{4} + 3 \cdot \frac{5}{2} + 3\right)\left(3 - \frac{25}{4}\right)^2} = \frac{-1443/16}{2873/64} \simeq -2$$

En $D_{(\omega_s=2,5)}$, el $E\%$ es del -100%.

$$E\% = \frac{D(0) - D(2,5)}{D(0)} \cdot 100\% = \frac{1-2}{1} \cdot 100\% = -100\%$$

4. Sintetizar el circuito **NORMALIZADO** con estructuras *Sallen-Key con K=1 (real, negativa y unitaria).*



$$V_x(G_1+G_2+sC_2) - V_i(G_1) - V_o(sC_2+G_2) = 0$$

$$V_o(G_2+sC_1) - V_x(G_2) = 0$$

$$V_x = V_o\left(\frac{sC_1}{G_2} + 1\right)$$

$$V_o \cdot \left(\frac{sC_1}{G_2} \cdot G_1 + sC_1 + \frac{s^2 C_1 C_2}{G_2} + G_1 + G_2 + sC_2 - sC_2 - G_2\right) = V_i(G_1)$$

$$\frac{V_o}{V_i} = \frac{G_1}{\frac{S^2 C_1 C_2}{G_2} + S \cdot C_1 \left(\frac{G_1}{G_2} + 1\right) + G_1} = \frac{G_2 \cdot G_1 / C_1 C_2}{S^2 + S \cdot \frac{1}{C_2} \cdot (G_1 + G_2) + G_1 . G_2 / C_1 C_2}$$

$$T_{(S)} = \frac{\frac{G_1 \cdot G_2}{C_1 \cdot C_2}}{S^2 + S \cdot \frac{G_1 + G_2}{C_2} + \frac{G_1 G_2}{C_1 \cdot C_2}}$$

$$\omega_0 = \sqrt{\frac{G_1 G_2}{C_1 C_2}} \qquad Q = \frac{\sqrt{\frac{G_1 G_2}{C_1 C_2}}}{\frac{G_1 + G_2}{C_2}} \rightarrow Q = \frac{\sqrt{G_1 \cdot G_2 \cdot \frac{C_2}{C_1}}}{G_1 + G_2}$$

no tomo ninguna simplificación pq me limita Q a un valor fijo

y antes..

$$T_2(S) = \frac{3}{S^2 + 3S + 3} \qquad \omega_0 = \sqrt{3} \ , \ Q = \frac{\sqrt{3}}{3}$$

entonces

① ω_0 $\quad 3 = \frac{G_1 G_2}{C_1 C_2} \ , \ \frac{\sqrt{3}}{3} = \frac{\sqrt{3}}{\frac{G_1 + G_2}{C_2}}$ ① Q

$$3 = \frac{G_1 + G_2}{C_2} \quad \text{①} \qquad y \qquad 3 = \frac{G_1 \cdot G_2}{C_1 \cdot C_2} \quad \text{①}$$

$$\frac{3}{3} = \frac{(G_1+G_2)/C_2}{G_1 \cdot G_2 / C_1 \cdot C_2} \qquad 1 = \frac{(G_1+G_2)\, C_1}{G_1\, G_2} \qquad \frac{1}{C_1} = G_1 // G_2$$

$$C_1 = 1 \;,\; G_1 = G_2 = 2 \;\longrightarrow\; C_2 = \frac{4}{3}$$

COMPRUEBO

$$T(s) = \frac{\frac{G_1 \cdot G_2}{C_1 \cdot C_2}}{S^2 + S \cdot \frac{G_1+G_2}{C_2} + \frac{G_1 G_2}{C_1 \cdot C_2}} \Bigg|_{\substack{G_1=2\\ G_2=2\\ C_1=1\\ C_2=\frac{4}{3}}} = \frac{3}{S^2 + S \cdot 3 + 3}$$

- +10 💎 DESNORMALIZAR los componentes para obtener un $D(\omega=0) = 200\mu s$.

Recalculo $D(\omega)$ en función de ω_0 y Q

$$T(S) = \frac{\omega_0^2}{S^2 + S \cdot \frac{\omega_0}{Q} + \omega_0^2} \longrightarrow T(\omega) = \frac{\omega_0^2}{j\omega \frac{\omega_0}{Q} + \omega_0^2 - \omega^2}$$

$$\measuredangle T(\omega) = -\operatorname{tg}^{-1}\left(\frac{\omega \cdot \omega_0/Q}{\omega_0^2 - \omega^2}\right)$$

$$D(\omega) = \frac{1}{1 + \frac{\omega_0 \cdot \omega/Q}{\omega_0^2 - \omega^2}} \cdot \frac{\omega_0/Q \cdot (\omega_0^2 - \omega^2) + \omega \cdot \omega_0/Q \cdot 2\omega}{(\omega_0^2 - \omega^2)^2}$$

$$\omega_0' = \frac{\omega_0}{\Omega\omega}$$

Desnormalizo

$$\omega' = \frac{\omega}{\Omega\omega}$$

$$D(\omega) = \frac{1}{1 + \dfrac{\omega_0 \cdot \omega \cdot \Omega\omega^2 / Q}{\Omega\omega^2 (\omega_0^2 - \omega^2)}} \cdot \frac{\Omega\omega^3 \cdot \dfrac{\omega_0}{Q}(\omega_0^2 - \omega^2) + \Omega\omega^3 \dfrac{2\omega^2 \cdot \omega_0}{Q}}{\Omega\omega^4 (\omega_0^2 - \omega^2)^2}$$

Reemplazo con $\omega = 0$

$$D_{(0)} = \frac{1}{1 + \dfrac{0}{\Omega\omega^2 \cdot \omega_0^2}} \cdot \Omega\omega^3 \cdot \frac{\dfrac{\omega_0^3}{Q} + 0}{\Omega\omega^4 \cdot \omega_0^4}$$

$\omega_0 = \sqrt{3}$

$Q = \dfrac{\sqrt{3}}{3}$

$\dfrac{\omega_0}{Q} = 3$

$$D_{(0)} = 1 \cdot \Omega\omega^3 \cdot \frac{\cancel{Q}}{\Omega\omega^4 \cdot \cancel{Q}}$$

$$D_{(0)} = \frac{1}{\Omega\omega} = 200\mu s$$

$$\Omega\omega = (200 \cdot 10^{-6} s)^{-1}$$

$$\boxed{\Omega\omega = 5 \cdot 10^3}$$