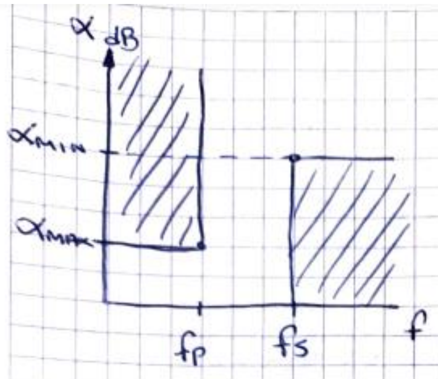


$\alpha_{MIN} = 20dB$ $\alpha_{MAX} = 0,5dB$

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

Normalizo con $\Omega_w = \omega_p$:

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

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

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

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

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

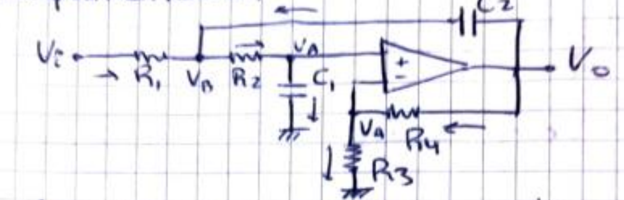
Itero N
- $N=2$: $\alpha = 4,7\,dB < \alpha_{MIN}$
- $N=3$: $\alpha = 9,45\,dB < \alpha_{MIN}$
- $N=4$: $\alpha = 15,08\,dB < \alpha_{MIN}$
- $N=5$: $\alpha = 21\,dB > \alpha_{MIN}$ ✓ $\boxed{N=5}$

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

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

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

Implementación



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

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

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

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

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

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

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

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

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

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

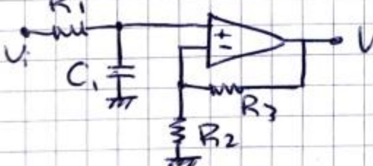
$$\omega_0^2 = \frac{1}{R_1 R_2 C_1 C_2}$$

$$\frac{\omega_0}{Q} = \frac{1}{R_1 C_2} + \frac{1}{R_2 C_2} + \frac{1-A}{R_2 C_1} = \frac{R_1 + R_2}{R_1 R_2 C_2} + \frac{1-A}{R_2 C_1}$$

$$\frac{\omega_0}{Q} = \frac{C_1(R_1+R_2) + R_1 C_2 (1-A)}{R_1 R_2 C_1 C_2} = \left[C_1(R_1+R_2) + R_1 C_2(1-A)\right]\omega_0^2$$

$$(C_1 R_1 + C_1 R_2 + R_1 C_2 - A R_1 C_2) \cdot \omega_0 = \frac{1}{Q}$$

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



$$T_1(s) = A \cdot \frac{\omega_{01}}{s + \omega_{01}} , \quad \omega_{01} = \frac{1}{R_1 C_1}$$

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

* 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: $\omega_{02}^2 = \frac{1}{R_5 R_6 C_2 C_3} = 1$

$$\frac{\omega_{02}}{Q_2} = 1{,}614 = \frac{1}{R_5 C_3} + \frac{1}{R_6 C_3} + \frac{1-A}{R_6 C_2}^{\to 0} = \frac{R_5 + R_6}{R_5 R_6 C_3} = (R_5 + R_6)\,\omega_{02}^2 C_2$$

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

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

$\Rightarrow \boxed{C_3 = 1{,}2289}$

Tercera etapa:

$Q_3 = 1,613$, $A = 1$

$\omega_{03} = 1$

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

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

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

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

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

$R_3 = 9 k\Omega$

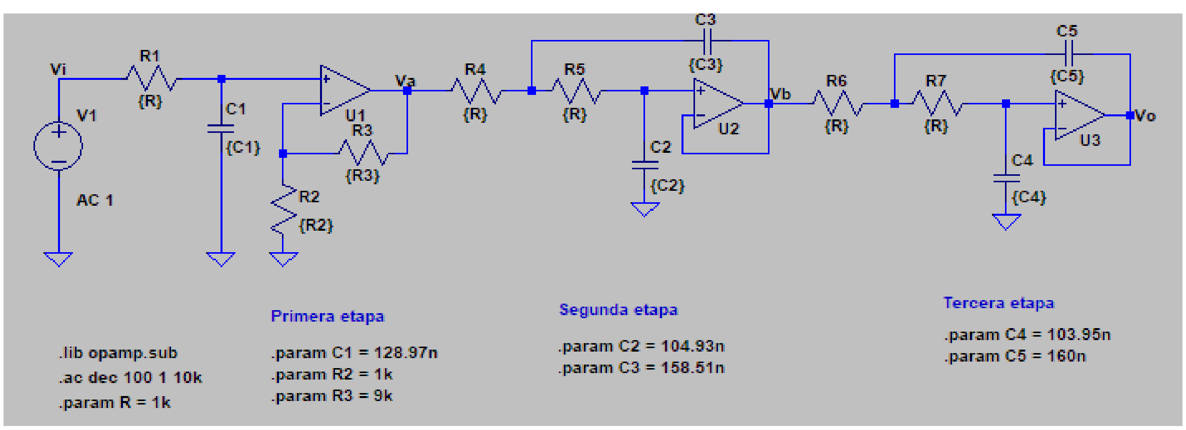
$C_1 = \frac{1}{\Omega_z} \cdot \Omega_w = 128,97 \, nf$

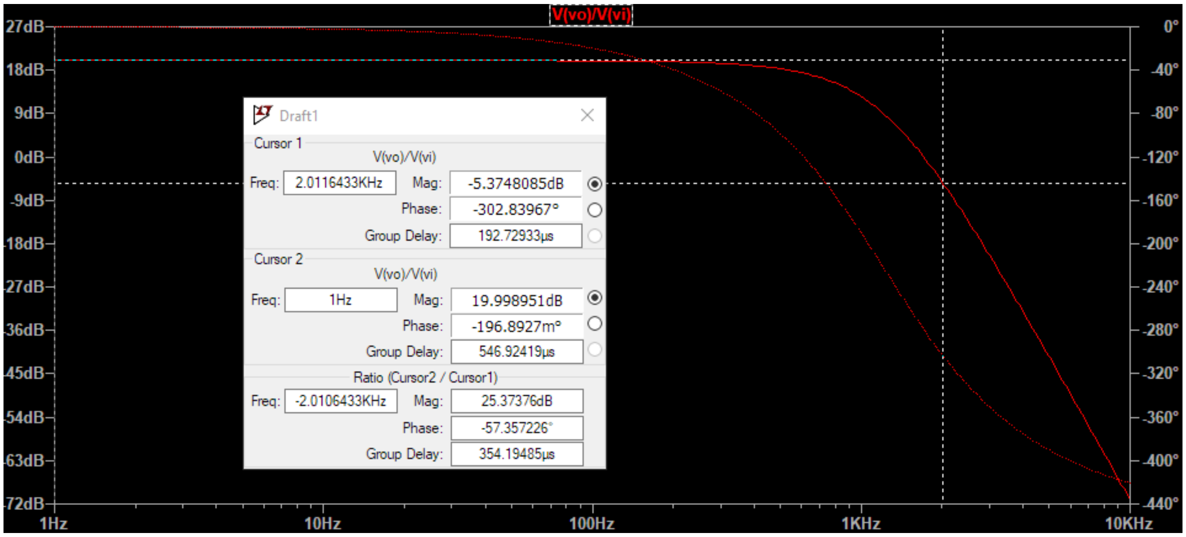
$C_2 = \frac{0,8136}{\Omega_z} \cdot \Omega_w = 104,93 \, nf$

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

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

$C_5 = \frac{\cancel{1,8}\ 1,2405}{\Omega_z} \cdot \Omega_w = 160 \, nf$





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