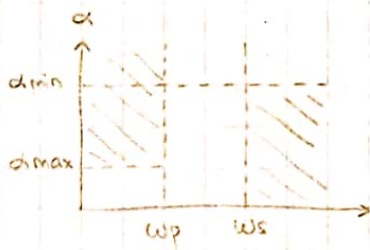


3)



$$\alpha_{\min} = 48 \text{ dB}$$

Chebyshev.

$$\alpha_{\max} = 0,48 \text{ dB}$$

$$f_s = 9,6 \text{ kHz} \rightarrow \omega_s = 3$$

$$f_p = 3,2 \text{ kHz} \rightarrow \omega_p = 1$$

$$a. \quad \epsilon_1^2 = 10^{\alpha_{\max}/10} - 1$$

$$\epsilon_1^2 = 10^{0,4/10} - 1 = 0,096$$

$$\boxed{\epsilon_1 = 0,31}$$

$$\alpha_{\min} = 10 \log \left\{ 1 + \epsilon_1^2 \cosh^2 \left[n \cosh^{-1}(\omega_s) \right] \right\}$$

$$n=2: \alpha_{\min} = 14,6 \text{ dB}$$

$$n=3: \alpha_{\min} = 29,7 \text{ dB}$$

$$n=4: \alpha_{\min} = 45 \text{ dB}$$

$$\boxed{n=5: \alpha_{\min} = 60,3 \text{ dB}}$$

$$c. \quad |T_C(j\omega)|^2 = \frac{1}{1 + \epsilon_1^2 C_5^2(\omega)} = \frac{1}{1 + \epsilon_1^2 (16\omega^5 - 20\omega^3 + 5\omega)^2}$$

$$= \frac{1}{1 + \epsilon_1^2 (256\omega^{10} + 400\omega^6 + 25\omega^2 - 640\omega^8 + 160\omega^6 - 200\omega^4)}$$

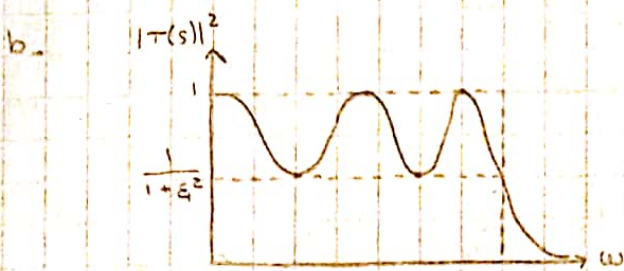
$$= \frac{1}{\omega^{10} \epsilon_1^2 256 - \omega^8 \epsilon_1^2 640 + \omega^6 \epsilon_1^2 560 - \omega^4 \epsilon_1^2 200 + \omega^2 \epsilon_1^2 25 + 1}$$

$$= \frac{1/\epsilon_1^2 256}{\omega^{10} - \omega^8 \cdot 2,5 + \omega^6 \cdot 2,187 - \omega^4 \cdot 0,781 + \omega^2 \cdot 0,097 + 0,04}$$

$$|T_C(j\omega)|^2 \Big|_{\omega=s/j} = \frac{1/\epsilon_1^2 256}{-s^{10} + s^8 \cdot 2,5 - s^6 \cdot 2,187 + s^4 \cdot 0,781 - s^2 \cdot 0,097 + 0,04} = T(s)T(-s)$$

$$T(s) = \frac{1/\epsilon_1 16}{(s + 1,069)(s + 0,563 + j0,221)(s + 0,563 - j0,221)(s + 0,329 + j0,356)(s + 0,329 - j0,356)}$$

$$T(s) = \frac{1,069 \quad 0,793 \quad 0,235}{(s + 1,069)(s^2 + 1,126s + 0,793)(s^2 + 0,658s + 0,235)}$$



$$cl. \quad T_{LP}(s) = \frac{-R_2}{R_4} \frac{R_3 / (C_2 R_2 R_4 R_5)}{s^2 + s \left[\frac{1}{C_1 R_4} \left(\frac{R_6}{R_6 + R_7} \right) \left(\frac{R_3}{R_1} + \frac{R_3}{R_2} + 1 \right) \right] + \frac{R_3}{C_1 C_2 R_2 R_4 R_5}}$$

$$SOS_1 \begin{cases} \omega_1 = 0,793 \\ \omega_{01} = 0,89 \\ Q_1 = 0,516 \end{cases}$$

$$SOS_2 \begin{cases} \omega_2 = 0,235 \\ \omega_{02} = 0,485 \\ Q_2 = 0,737 \end{cases}$$

$$\omega_1 = \frac{R_2}{R_4}$$

$$\omega_{01}^2 = \frac{R_3}{C_1 C_2 R_2 R_4 R_5}$$

$$\frac{\omega_{01}}{Q_1} = \frac{1}{C_1 R_4} \left(\frac{R_6}{R_6 + R_7} \right) \left(\frac{R_3}{R_1} + \frac{R_3}{R_2} + 1 \right)$$

$$\begin{cases} C_1 = C_2 = C \\ R_2 = R_3 \\ R_6 = R_7 \end{cases}$$

$$\omega_{02}^2 = \frac{1}{C^2 R_4 R_5}$$

$$\frac{\omega_{02}}{Q_2} = \frac{1}{2} \frac{1}{C R_4} \left(\frac{R_2}{R_1} + 2 \right)$$

$$\frac{\omega_{01}}{Q_1} = \frac{1}{2} \frac{1}{C R_4} (2 - \omega_1)$$

$$\omega_1 = 0,793 = \frac{R_2}{R_4}$$

$$R_4 = 1260$$

$$\omega_{01}^2 = 0,89^2 = \frac{1}{C^2 R_4 R_5}$$

$$R_5 = 3607$$

$$\frac{\omega_{01}}{Q_1} = \frac{0,89}{0,516} = \frac{1}{2} \frac{1}{C R_4} (2 - \omega_1)$$

$$3,45 \text{ m} = \frac{1}{R_4} (2 - 0,793)$$

$$R_4 = 350$$

$$C = 1 \text{ m}$$

$$R_2 = R_3 = 1 \text{ k}$$

$$R_6 = R_7 = 1 \text{ k}$$

$$k_2 = 0,235 = \frac{R_2}{R_1}$$

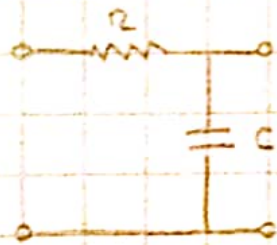
$$R_1 = 4,255$$

$$W_{02} = 0,485^2 = \frac{1}{C^2 R_1^2 R_5}$$

$$R_5 = 3,172$$

$$\frac{W_{02}}{R_2} = \frac{0,485}{0,737} = \frac{1}{2} \frac{1}{C R_4} (2 - 0,235)$$

$$R_4 = 1,340$$



$$T(s) = \frac{1/C R}{s + 1/C R} = \frac{W_0}{s + W_0}$$

$$W_0 = \frac{1}{C R} = 1,069 \quad C = 1m$$

$$R = 935$$

Valores normalizados $\rightarrow R_2 = R_2$

$$R_2 = 1,26 \quad R_2 = 1 \quad R_3 = 1 \quad R_4 = 0,35 \quad R_5 = 3,6 \quad R_6 = R_7 = 1 \quad C = 1 \rightarrow 2da etapa$$

$$R_1 = 4,2 \quad R_2 = 1 \quad R_3 = 1 \quad R_4 = 1,34 \quad R_5 = 3,17 \quad R_6 = R_7 = 1 \quad C = 1 \rightarrow 1er etapa$$

$$R = 0,9 \quad C = 1 \rightarrow 3er etapa$$