Fundamentals of Analog & Mixed Signal VLSI Design
Exercise 12 (11.12.2024)

Christian Enz

Swiss Federal Institute of Technology (EPFL), Lausanne, Switzerland

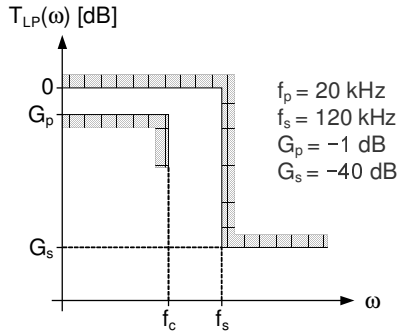

Figure 1: LP filter specifications.

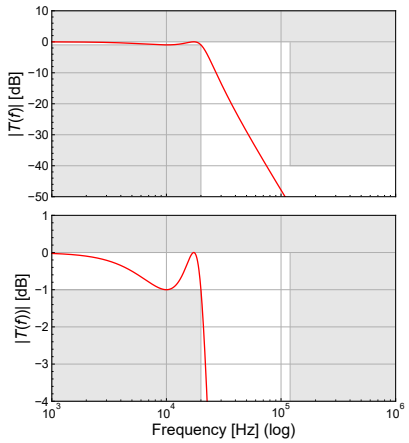

Figure 2: Magnitude of the transfer function given by (1) assuming a Chebyshev approximation.

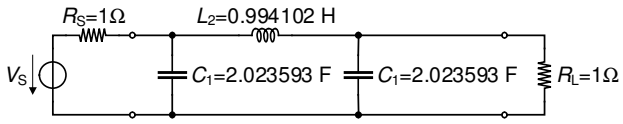

Figure 3: Corresponding low-pass prototype filter (LPPF).

We want to design a low-pass filter that satisfies the mask specifications given in Fig. 1 using the Chebyshev approximation. We can show that if we choose to use a Chebyshev approximation then the required order is $N = 3$. The transfer function is then given by

$$T(s) = \frac{\omega_{p1}}{s + \omega_{p1}} \cdot \frac{\omega_0^2}{s^2 + \frac{\omega_0}{Q}\, s + \omega_0^2}, \tag{1}$$

where $\omega_{p1} = 2\pi\, 9.883412\, krad/s$ is the cut-off frequency of the 1st-order section, $\omega_0 = 2\pi\, 19.941962\, krad/s$ is the resonance frequency and $Q = 2.017720$ is the quality factor of the 2nd-order section. The magnitude of the corresponding transfer function is plotted in Fig. 2

The corresponding low-pass prototype filter (LPPF) is shown in Fig. 3 with $\Omega_s = 6$.

Problem 1 Switched Capacitor Filter Design

Design a single-ended switched-capacitor (SC) filter that implements the same transfer function (1) for a clock frequency $f_{ck} = 2\,MHz$.

1.1 Cascade approach

Design the single-ended SC filter using a cascade approach. Hint: For the 1^{st}-order section use the section without transmission zero. Similarly, for the 2^{nd}-order section, use the biquad cell for low to medium-Q without finite transmission zeros.

1.2 Indirect simulation

Design the single-ended SC filter using the indirect simulation approach. Start from the LPPF given in Fig. 3 and follow these steps:

- Sketch the signal-flow graph corresponding to the LC ladder prototype filter, correcting for the DC gain to match the mask.
- Calculate the denormalized integration time constants.
- Draw the corresponding SC filter using stray-insensitive integrators and accounting for the -6dB DC gain correction.
- Calculate the values of the capacitor ratios.
- Choose the values of the integration and switched capacitances such that the minimum capacitance(s) are $\geq 100\,fF$.