Fundamentals of Analog VLSI Design
Exercise 13 - Problem

Design of Switched-capacitor Filters

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1 Problem 1: Design of a low-pass cascade switched-capacitor filter

1.1 Filter specifications

We want to design a low-pass (LP) switched-capacitor filter (SCF) that satisfies the specifications given in Table 1.1 using the Chebyshev approximation [1] and the cascade implementation. The filter mask corresponding to the specifications of Table 1.1 is shown in Figure 1.1.

Table 1.1: Filter specifications.

Specification	Symbol	Value	Unit
Cut-off frequency	f_c	20	kHz
Stop-band frequency	f_s	120	kHz
Pass-band gain	G_p	-1	dB
Stop-band gain	G_s	-40	dB
Clock frequency	f_{ck}	2	MHz

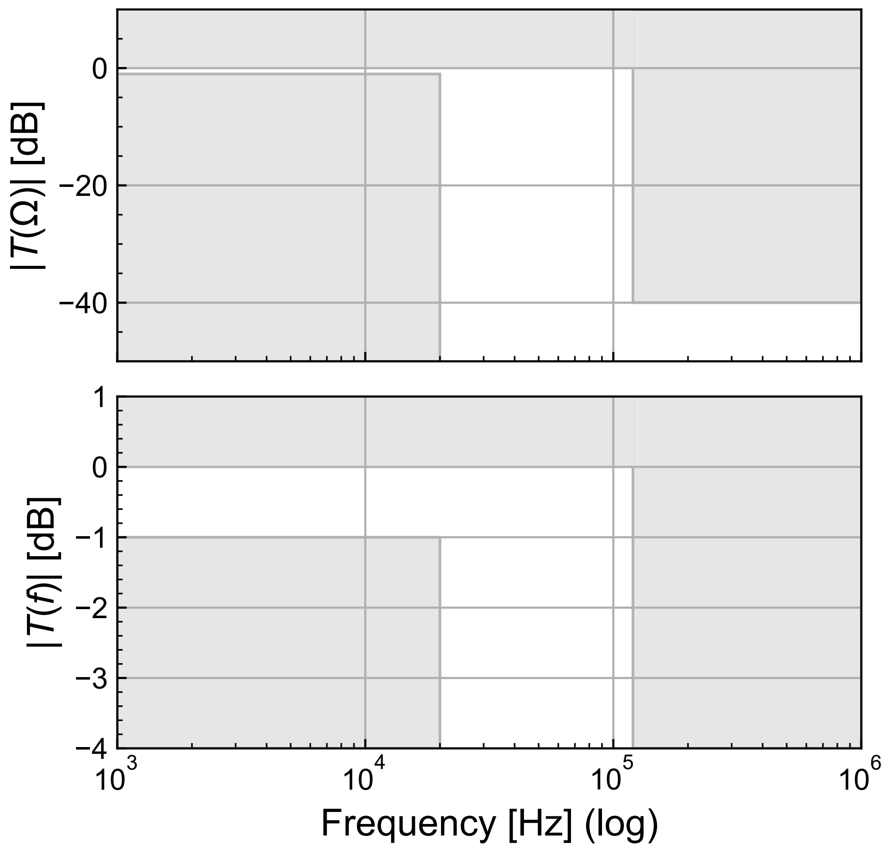

Figure 1.1: Filter mask.

It can be shown that the required order for achieving the specifications of Table 1.1 with a Chebyshev approximation is $N = 3$. The transfer function can then be factorized as

$$T(s) = \frac{\omega_{p1}}{s + \omega_{p1}} \cdot \frac{\omega_0^2}{s^2 + \frac{\omega_0}{Q}\, s + \omega_0^2}, \tag{1.1}$$

where $\omega_{p1} = 2\,\pi\ 9.883412\ krad/s$, $\omega_0 = 2\,\pi\ 19.941962\ krad/s$ and $Q = 2.017720$.

We then ask you to:

- Design a single-ended SC filter using a cascade approach that realizes the transfer function given by (1.1). 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.
- Choose the values of the integration and switched capacitors such that the minimum capacitance(s) are $\geq 100\ fF$.

2 Problem 2: Design of a low-pass switched-capacitor filter from an LC ladder prototype (indirect simulation)

In this problem we want to design a low-pass switched-capacitor filter that satisfies the same specifications given in Table 1.1 and filter mask shown in Figure 1.1 than in Problem 1, also with a Chebyshev approximation, but using the indirect simulation of an LC passive ladder filer.

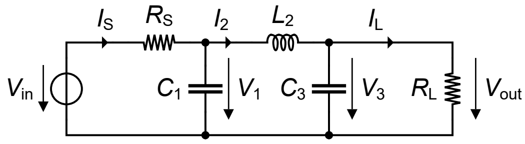

Figure 2.1: Low-pass prototype filter (LPPF).

From the order estimation made in Problem 1, we have found that we need an order $N = 3$ to meet the specifications. We can therefore start with the 3rd-order low-pass prototytpe filter (LPPF) shown in Figure 2.1. It can be shown that the component values of the LPPF for a Chebyshev approximation can be calculated directly from the order N and ε assuming that $R_S = 1\,\Omega$ [1] [2] [3]. The values are given in Table 2.1.

Table 2.1: LPPF component values for a Chebyshev approximation.

Symbol	Value	Unit
R_S	1	Ω
$C_{1,norm}$	2.02359	F
$L_{2,norm}$	0.994102	H
$C_{3,norm}$	2.02359	F
R_L	1	Ω

Design the single-ended SC filter using the indirect simulation approach. Start from the LPPF given in Figure 2.1 and follow these steps:

- Sketch the signal-flow graph corresponding to the LC ladder prototype filter of Figure 2.1, 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 $-6\,dB$ DC gain correction.
- Calculate the values of the capacitance ratios.
- Choose the values of the integration and switched capacitors such that the minimum capacitance(s) are $\geq 100\ fF$.

References

[1] P. Brackett and A. Sedra, *Filter Theory and Design: Active and Passive.* Matrix Pub, 1984.
[2] W.-K. Chen, *The Circuits and Filters Handbook: Passive, Active and Digital Filters*, 3rd. ed. CRC Press, 2009.
[3] M. Steer, *Microwaves and RF Design IV: Modules.* LibreTexts, 2025.