Fundamentals of Analog & Mixed Signal VLSI Design
Exercise 11 (4.12.2024)

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Problem 1 Design of a Cascade G_m-C Continuous-time Filter

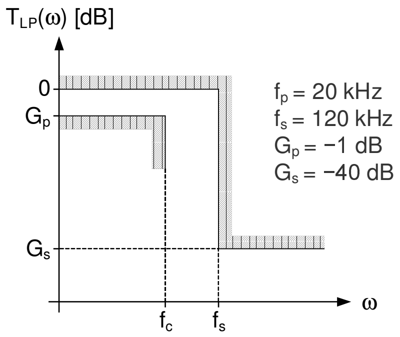

Figure 1: LP filter specifications.

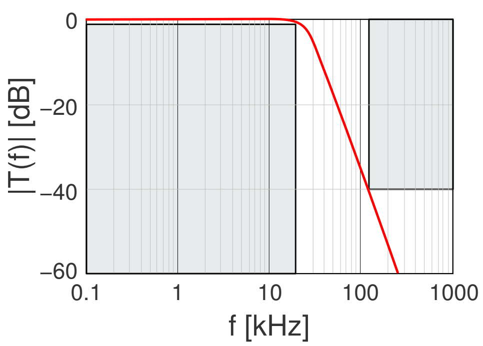

Figure 2: Magnitude of the transfer function given by (1) assuming a Butterworth approximation.

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

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

where $\omega_0 = 2\pi\, 25.051528\, krad/s$ is the resonance frequency and $Q = 1$ is the quality factor of the 2$^{\text{nd}}$-order section. The magnitude of the corresponding transfer function is plotted in Fig. 2

Design a single-ended G_m-C cascade implementation that realizes the transfer function given by (1). To choose the transconductance or capacitance value (this is called defining the impedance level), we set the integrated kT/C thermal noise at the output of the filter to remain smaller than 50-μV. We assume that the transconductors have an equivalent thermal noise excess factor $\gamma_{neq} = 1$ and contribute equally to the integrated thermal noise at the filter output. Of course that is not exactly true but allows to get an initial capacitance value close to the final value.

Problem 2 Design of a MOSFET-C Continuous-time Filter

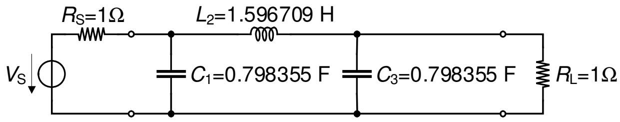

Figure 3: Corresponding low-pass prototype filter (LPPF).

In this problem, we want to design a fully-differential MOSFET-C filter that realizes the magnitude of the transfer function shown in Fig. 2. We propose to use the indirect simulation of an LC ladder approach, starting from the low-pass prototype filter (LPPF) corresponding to Fig. 2 which is shown in Fig. 3 with $\Omega_s = \omega_s/\omega_p = 6$.

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 resulting fully-differential MOSFET-C filter accounting for the -6dB DC gain correction.
- Denormalize the impedances by choosing the termination impedance such that the integrated kT/C thermal noise at the output of the filter remains smaller than 50-μV. It is assumed that all the transconductors have a thermal noise excess factor $\gamma_{neq} = 1$ and contribute equally to the integrated thermal noise at the filter output.
- Calculate the component values of the filter.
- Size the MOSFET transistors to match the resistance value assuming $V_c = 2V$ and $V_B = 0V$ with $\mu \cdot C_{ox} = 170\mu A/V$ and $V_{T0} = 0.6V$.