Analog Filter Design Projects

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1 Butterworth lowpass filter with imaginary zero

Your SSN number is composed of nine digits $d_8d_7d_6 - d_5d_4 - d_3d_2d_1d_0$. Let $a = 100d_8 + 10d_7 + d_6$, $b = 10d_5 + d_4$, and $c = 1000d_3 + 100d_2 + 10d_1 + d_0$. Derive the transfer function $T(s)$ of a minimum order lowpass filter to meet the following specifications:

1. The filter is to have a maximally-flat pass-band in $0 < f < (c)$ Hz.
2. The maximum pass-band attenuation is $A_1 = (\log(b + 10))$ dB.
3. The filter is to have a transmission zero at $f_0 = (c + a)$ Hz.
4. The minimum stop-band attenuation is $A_s = 15$ dB.

In your report describe the shape of the normalized magnitude-squared function in terms of the required specifications. Discuss the selection of all parameters of the filter transfer function such as the ripple factor and the filter order. Derive the s-plane transfer function for the filter and use appropriate frequency scaling to obtain the final $T(s)$. In your report include plots of the following characteristics of the filter obtained:

1. Magnitude characteristic versus frequency f on lin-lin scale.
2. Magnitude characteristic versus frequency f on $20\log_{10} - \log_{10}$ scale.
3. Phase characteristic versus frequency f on linear scale.
4. Group delay versus frequency f on linear scale.

The report should be typed. The plots must be appropriately labeled and the numeric values of coordinates must be shown.

2 OP-AMP implementation of a fifth-order lowpass filter

Your SSN number is composed of nine digits $d_8d_7d_6 - d_5d_4 - d_3d_2d_1d_0$. Let $a = 100d_8 + 10d_7 + d_6$, $b = 10d_5 + d_4$, and $c = 1000d_3 + 100d_2 + 10d_1 + d_0$.

Design and construct in hardware a fifth-order lowpass Butterworth filter which has a $3.01\,\mathrm{dB}$ passband extending to $(c)\,\mathrm{Hz}$. Use a cascade realization employing two infinite-gain single-amplifier biquads and a first order stage.

Your approach should start with deriving the normalized transfer function of the filter and calculating the frequency scaling factor for the required cut-off frequency. Successively, split the expression for the transfer function into three multiplicative terms to be implemented in hardware as the two biquads and the first order stage. Finally, derive the transfer functions of the prospective circuits and compare with the frequency-scaled multiplicative terms in order to determine the RLC component values.

In your report include the derivation of the filter transfer function and the determination of the RLC component values. Attach the complete schematic of the designed circuit. Justify your choice of the stage order in the cascade.

Acquire the necessary components and hardware, and build the designed circuit. Note that the LP filter should admit the DC component. In the laboratory, measure the magnitude characteristic and the phase characteristic of your circuit in the frequency range up to $(5c)\,\mathrm{kHz}$. Include the measurements in your report.

Sketch the filter response to a square wave of $1\,\mathrm{V}$ peak-to-peak and frequency $(c/20)\,\mathrm{Hz}$. Increase the frequency to $(c/2)\,\mathrm{Hz}$ and sketch the filter response.

The report should be typed. The plots must be appropriately labeled and the numeric values of coordinates must be shown.

3 Passive filter with transmission lines

Design and construct in hardware a third-order passive bandpass Chebyshev filter which has a passband with $(1 + 0.06a)$ dB ripple. The passband should extend from frequency f_L to frequency f_U, such that the geometric middle frequency is $(f_U f_L)^{1/2} = (80 + 0.4c)$ MHz and the fractional bandwidth is $(f_U - f_L)/(f_U f_L)^{1/2} = (0.2 + 0.002b)$. Numbers a, b, and c are derived from your nine-digit student identification number $d_8 d_7 d_6 - d_5 d_4 - d_3 d_2 d_1 d_0$, where $a = 10d_5 + d_4$, $b = 10d_3 + d_2$, and $c = 10d_1 + d_0$.

The filter should be constructed using pieces of coaxial cable and capacitors. First, you need to design a third-order lowpass prototype matching the filter specification. Then, use the lowpass to bandpass transformation to obtain the band-pass prototype in the form of a doubly terminated ladder structure with series and parallel LC resonators. Frequency-scale the prototype into the required frequency range. Successively, use immitance inverters to convert series resonators to their parallel equivalents. Also, replace the inductors with equivalent shorted stubs.

Before constructing the filter in hardware, use Ansoft Designer to simulate your design. Ansoft Designer is available in the School of Engineering computer laboratories. Print the magnitude characteristic and the schematic of the filter, and attach to the report. If the simulation confirms that the design satisfies the specification, construct the filter[1]. Using the 3 GHz network analyzer, available in the Senior Electronics Lab, measure and print the magnitude characteristic of your filter. Attach it to the report. You should be able to achieve 15 % tolerance for the lower and upper cutoff frequency of the passband.

In your report describe the design procedure. Include the schematics of your lowpas and bandpass prototypes with component values. Attach relevant fragments of code if a mathematical software was used. Your report should be self-contained. It must include all the information necessary to repeat the steps of your design.

Materials needed:

- RG-58 (50 Ω coaxial cable), 5 ft
- Two chassis-mount BNC connectors
- Capacitors, range of values 20 − 500 pF
- Soldering equipment (soldering iron, solder paste, solder)
- Sharp knife, edge cutter, wire stripper
- Metric tape measure

[1] http://www.ee.siue.edu/~alozows/courses/ece428/project/project.html

4 Microstrip implementation of a passive filter

Design and construct in hardware a third-order passive bandpass Chebyshev filter which has a passband with $(1 + 0.06a)$ dB ripple. The passband should extend from frequency f_L to frequency f_U, such that the geometric middle frequency is $(f_U f_L)^{1/2} = (2 + 0.004c)$ GHz and the fractional bandwidth is $(f_U - f_L)/(f_U f_L)^{1/2} = (0.1 + 0.001b)$. Numbers a, b, and c are derived from your nine-digit student identification number $d_8 d_7 d_6 - d_5 d_4 - d_3 d_2 d_1 d_0$, where $a = 10d_5 + d_4$, $b = 10d_3 + d_2$, and $c = 10d_1 + d_0$.

The filter should be constructed using parallel-coupled half-wavelength resonators. First, you need to design a third-order lowpass prototype matching the filter specification. Then, use the lowpass to bandpass transformation to obtain the band-pass prototype in the form of a doubly terminated ladder structure with series and parallel LC resonators. Frequency-scale the prototype into the required frequency range. Successively, use immitance inverters to convert series resonators to their parallel equivalents.

Before constructing the filter in hardware, use Ansoft Designer to simulate your design. Print the magnitude characteristic and the schematic of the filter, and attach to the report. If the simulation confirms that the design satisfies the specification, construct the filter[2]. Using the 3 GHz network analyzer, available in the Senior Electronics Lab, measure and print the magnitude characteristic of your filter. Attach it to the report. You should be able to achieve 15 % tolerance for the lower and upper cutoff frequency of the passband.

In your report describe the design procedure. Include the schematics of your lowpas and bandpass prototypes with component values. Attach relevant fragments of code if a mathematical software was used. Your report should be self-contained. It must include all the information necessary to repeat the steps of your design.

Materials needed:

- FR4 double-sided copper board (standard for making printed circuits boards), 5×15 cm
- Two chassis-mount BNC connectors
- One sheet of PnP-Blue transfer film
- Access to laser printer or xerox machine
- Etching solution, nail polish, natural rosin for violin, ethanol
- Hack saw, file, soldering equipment
- Metric ruler

[2]http://www.ee.siue.edu/~alozows/courses/ece428/project/project.html