Special Circuit

Spring 2017 – Due April 21st, 2016, 4:45pm

Before beginning the assignment, contact Dongwei Shi (dshi9@illinois.edu) or John Capozzo (capozzo2@illinois.edu) for a locker assignment

Overview

This assignment consists of designing an active filter. You will perform circuit analysis by-hand, simulate a design, and finally build the circuit.

You will be assigned a filter type—Butterworth, Chebyshev with 3dB passband ripple, or Bessel. Each of these filters has its own strengths and weaknesses—introducing an important design decision in any project with analog filtering.

Butterworth – Flat passband (minimal passband ripple).

Chebyshev – Sharp stopband roll-off can be obtained with a few dB of passband ripple.

Bessel – Constant phase delay within passband.

Assignment

1. Derivation of Design Equations

You have been assigned a certain filter type. We are assigning exclusively 2nd order, low-pass filters and we would like for all students to use the Sallen-Key topology.

Please derive the design equations for such a filter topology—the following guide from Texas Instrument provides all the background information you will need: https://focus.ti.com/lit/ml/sloa088/sloa088.pdf. To be clear, *design equations* relate the component values (resistances and capacitances) to the cutoff frequency.

In order to do this, you need to know about the pole locations for each filter type (as described in the TI document). Equation 1 shows the general transfer function in the Laplace domain of a unity-gain, 2nd order, low-pass filter. The coefficients a_i and b_i are functions of the 2nd order system's two poles. Commonly, filter design guides abstract out the pole locations and provide tables of a_i and b_i values. We will do so in this assignment as well. The important theory to understand is that the filter type and order determines the pole locations, and the pole locations are directly related to a_i and b_i. Use the coefficient values contained in the previously linked document for 2nd order Butterworth, Chebyshev (3dB ripple), and Bessel low-pass filters.

$$A(s) = \frac{1}{1 + a_i s + b_i s^2} \qquad \text{(EQ 1)}$$

Notice that you have more unknown resistor and capacitor values than design equations; thus, you must select *reasonable* values for some of the components and solve for the others (using the design equations). One important consideration when selecting component values is that components only exist at discrete values, and the ECE Electronics Service Shop has a limited (yet adequate) selection. Here is a [link to their inventory](), which can be found on their website—note that the inventory may not be up to date, but is still a useful tool in most cases. Look at what parts are available, and try to come up with a design where the two resistors and the two capacitors have values on the same order of magnitude (i.e. we do not want to see a huge capacitor and a small one in the same design).

2. Simulation

Please generate a schematic of your filter and simulate the forward voltage gain (Vout/Vin) over a range of frequencies. We recommend using LTSpice, but if you are attached to a certain simulation software, you may use that instead. Using an ideal op-amp model is fine for the purpose of this assignment. The plot you produce should be the forward gain (Vout/Vin) over frequency—this is best shown in dB on the vertical axis.

3. Circuit Assembly and Validation

You can find your passive components and op-amps at the ECE Electronic Services Shop. We recommend breadboarding your circuit first, as it is easiest to debug circuit issues on a breadboard. Your final submission must be soldered on a perf-board—sold in the ECE store. Power your system using the bench supplies in ECEB 2070.

In order to verify your design, input a frequency-swept sinusoidal signal using a waveform generator. Measure the output using a mixed-domain oscilloscope so that the frequency response can be viewed. Using the *max-hold* setting can be useful in the spectrum view on the scope—that will take the discrete swept frequency components and allow them to be displayed simultaneously—giving the appearance of a continuous frequency response.

Warning: Please be careful to NEVER input a higher voltage to an oscilloscope than it is rated for. Ratings are written clearly on all scopes.

Requirements

You will submit your assignment by meeting with the ECE 445 course staff during the posted office hours. You must successfully demonstrate the following:

1. Walk through a hand-written derivation of the filter design equations. You must have a thorough understanding of the derivation so that you can justify your work and answer any related questions our Course Staff has.
2. Run a simulation of the circuit you designed and display the forward voltage gain (Vout/Vin vs. frequency). Demonstrate that it meets the assigned specifications. We must see you run the simulation—we do not just want to look at a print-out of your frequency response. In order to do this, bring your own computer or use one of the lab computers—whichever has the simulation software you need.
3. Perform the verification as described under *Circuit Assembly and Validation.* Again, your circuit should be soldered onto a perf-board for submission. Demonstrate that your filter meets the specifications assigned to you.

References

TI Filter Design - https://focus.ti.com/lit/ml/sloa088/sloa088.pdf
ECE Electronic Services Shop Website - http://eshop.ece.illinois.edu/