Lab#4 Step Response of a Second Order Filter

# Objective

The purpose of this week's lab is to build a second order filter and analyze its step response. **This lab includes a pre-lab. You are expected to simulate a circuit before coming to the lab.**

# Theory



Fig. 1. A series RLC circuit

Consider the series RLC circuit in Fig. 1 where a step input  is applied. In order to find the output voltage, first we obtain a second order differential equation:



The solution of this equation consists of two parts: the complementary solution and the particular solution. Let us focus on the complementary solution. The form of this solution depends on the roots of the characteristic equation:



Where is called the damping ratio and  is called the undamped natural frequency or oscillating frequency. The roots of the quadratic equation are equal to,



For example, for our series RLC circuit, the characteristic equation can be written as:



Then the damping ratio and oscillating frequency can be found as  and. Depending on the value of the damping ratio, there can be three types of responses.

* **Case 1:** Critically damped response (),
* **Case 2:** Underdamped response (),
* **Case 3:** overdamped response ().

The three types of responses are shown in Fig. 2.



Fig. 2: Step responses of a series RLC circuit

This review will help you take the test and write the lab report.

# Pre-Lab

Using a circuit simulator (for example, Multisim), build the circuit in Fig. 1. For simulating the step response, a square wave input will be applied as a step input. Consider the circuit in Fig.1. Allow  to be a 1 kHz square wave with 1V amplitude (high voltage 1 and low voltage 0). Let R=100 , C=4.7 nF, and L=1 mH. This is the first circuit to simulate. Run your simulation (1ms should be enough) and print out what the step response (i.e.) looks like. Using the cursors, determine the frequency of oscillation (i.e. the reciprocal of the time between peaks) and the time it takes for the oscillations to damp out.

Then, repeat this process for a second circuit with R=1.5 k keeping other parameters same. In this case, the circuit will not oscillate. Measure the rise time of the circuit. The rise time of the circuit is defined as the time it takes for the capacitor voltage to go from 10% to 90% of the applied voltage (step input voltage). You will submit following in the beginning of the lab:

* For the first circuit, plot the step response (versus *t* plot). Mention the frequency of oscillation and the time it takes for the oscillations to damp out.
* For the second circuit, plot the step response (versus *t* plot). Mention the rise time.

# Procedure

## Filter 1

Using your Digilent EE board, build the first circuit from the pre-lab. Allow  to be a 1 kHz square wave with 1V amplitude (high voltage 1 and low voltage 0). In Waveforms software, you need to set the frequency at 1 kHz, amplitude 500 mV, and offset 500 mV in Wavegen section. Let R=100, C=4.7 nF, and L=1 mH. Save a printout of the step response. Measure the oscillation frequency and damping time.

For filter 1, answer the following questions in your report’s results section:

* ***Superimpose the step response from Pre-lab and Digilent EE board.***
* ***Do they agree? If not, why?***
* ***Determine the oscillation frequency and damping time from theory. Compare these values to the measured values from Digilent EE board. Calculate the percentage error between theoretical and Digilent EE board values.***

## Filter 2

Using your Digilent EE board, build the second circuit from the pre-lab. Allow  to be a 1 kHz square wave with 1V amplitude (high voltage 1 and low voltage 0). In Waveforms software, you need to set the frequency at 1 kHz, amplitude 500 mV, and offset 500 mV in Wavegen section. Let R=1.5 k, C=4.7 nF, and L=1 mH. Save a printout of the step response. Measure the oscillation frequency and rise time.

Answer the following questions in your report’s results section:

* ***Superimpose the step response from Pre-lab and Digilent EE board.***
* ***Do they agree? If not, why?***
* ***Determine the oscillation frequency and rise time from theory. Compare these values to the measured values from Digilent EE board. Calculate the percentage error between theoretical and Digilent EE board values.***

# Report

Write a standard report of 3 to 6 pages (excluding the cover page). Explain what you did, presenting your calculations, and observations. ***You must include the answers (for questions in Section 4.1 and 4.2) in the report’s results section.*** Submit it to our blackboard before the next lab (see syllabus for submission guideline).