LAB #5: Behavior of Second-Order Systems

Equipment:
Dell Optiplex GX260 PC
Digital Data Acquisition Card (National Instruments PCI-MIO-16E-4 DAQ board)
Virtual Oscilloscope (National Instruments VirtualBench)
Multimeter (FLUKE 187)
Function Generator (Tektronix CFG250)
Resistor-inductor-capacitor (RLC) box

Objectives:
In this experiment, you will study the behavior of a second-order system represented by an RLC circuit. You will use the virtual scope to acquire data. From this experiment, you should achieve a grasp of the concepts of natural frequency, damping, and frequency response.

1. FREQUENCY RESPONSE OF A SECOND-ORDER SYSTEM

1.1 Calculate the undamped natural frequency of the LC circuit using the nominal values of L and C. For your box, L=0.553 H and you can choose (with the switch) one of two capacitors with C=0.1 or 0.01 \( \mu \)F.

1.2 Open the virtual oscilloscope. From the Edit-Load Settings menu, recall the file default.sco.

1.3 Using a BNC-tee connector, connect the output of the function generator to Ch 0 of the DAQ and to the “to switch” input to the RLC circuit. Connect the “to scope” output of the RLC circuit to Ch 1. Activate both Ch 0 and Ch 1. Set the circuit damping resistance to minimum (i.e., to full CCW) and measure this minimum resistance with the digital multimeter.

1.4 Set the function generator to give a sine wave output of about 100 Hz with 0.5 V peak-to-peak amplitude. Set the Trigger Mode to Auto and Src to Ch 0.

1.5 Set scope to x-y Mode and observe the display as you sweep through frequencies from below to above the resonant frequency. Determine the undamped natural frequency of the system.

1.6 With the Cursors off, gradually increase the driving frequency from about 100 Hz to about 1 kHz and observe how the system output changes in amplitude and phase angle, particularly as you pass through the resonant frequency range and on to higher frequencies. Acquire enough data to plot amplitude ratio \( \frac{V_{out}}{V_{in}} \) vs frequency and phase angle vs frequency, for a frequency range that includes the resonant frequency. Take amplitude and
phase data for at least twenty frequencies; note that you must take more closely spaced data near resonance (when the amplitude varies rapidly with frequency). Also, make measurements as you increase and decrease the frequency.

**NOTE:** Since the output from the function generator may vary with frequency, it is wise to measure both the input amplitude and the output amplitude at each frequency. You will also need to measure the phase angle between the output signal and the input signal.

1.7 Calculate the resistance needed to give $\zeta=0.7$ (slightly underdamped). Using the multimeter, set this resistance on the potentiometer, and take the data necessary to determine frequency-response amplitude and phase curves (i.e., amplitude vs frequency and phase vs frequency) for this second-order system. Again take a minimum of twenty data points paying particular attention to frequencies near resonance.

2. **RESPONSE TO A STEP INPUT**

2.1 Return the resistance potentiometer to the full CCW minimum-damping setting. Set the function generator to produce a square wave with amplitude of 1.0 V pk-pk and select an appropriate frequency in order to observe the step-response. The following figure represents the plots of the input signal (Ch 0) and the output signal (Ch 1) for this square-wave input.

2.2 Set the circuit damping resistance to minimum (i.e., to full CCW) and measure (and record) this minimum resistance with the digital multimeter. Obtain the response to a square wave in this condition and record the signal. Repeat this for resistance values of 500Ω, 1kΩ, 4kΩ, 15kΩ, and compare the response for each setting.
3. HOMEWORK

1. Make a plot of amplitude ratio vs frequency for the minimum-damping case. Include the theoretical curve based on your values of R, L and C. Discuss the agreement between the experiment and theory.

2. Make a plot of phase angle vs frequency for the minimum-damping case. Include the theoretical curve based on your values of R, L and C. Discuss the agreement between the experiment and theory.

3. Make a plot of amplitude ratio vs frequency for the slightly underdamped case. Include the theoretical curve. Discuss the agreement between the experiment and theory.

4. Make a plot of phase angle vs frequency for the slightly underdamped case. Include the theoretical curve. Discuss the agreement between the experiment and theory.

5. Include one plot that shows the output voltage vs time for a square wave input for the five different cases of damping. (Show both input and output waveforms). Explain what you see.

6. From the square wave response, determine the system natural frequency and damping factor for the different cases and compare with theoretical calculations. Explain the agreement/disagreement with theory.

NOTE: The answers to these questions are to be written in the form of a FORMAL REPORT. The format requirements will be discussed in class. An analysis of errors in measurement must also be included in the report. A sample report will be posted on the class webpage.

NC: modified 2/03
Ravi. modified 1/04, 10/04