LABORATORY 6: RC, RL step responses

Note: If your partner is no longer in the class, please talk to the instructor.

Material covered:
- RC circuits
- RL circuits
- Thevenin circuits

Overall notes:

Review the material from Lab 5 if necessary. In your plots, you should compare input signals (sources) to outputs signals (component voltage/current).

In this lab, you will investigate an RL parallel circuit.

The derivation of the current across the inductor leads to the differential equation, \( \frac{L}{R} \frac{di}{dt} + i_L = I_s \). For a step function source current, \( I_1 u(t) \), the solutions to the differential equation take the form \( i_L(t) = K_1 e^{-\frac{t}{\tau}} + K_2 \). This form is similar to what we saw for the RC circuit, with a slightly different time constant \( \tau = L/R \).

Unfortunately, there are two problems with investigating the above circuit. The first problem is that we don’t have access to a current probe. One practical solution is to add a small resistor in series with the inductor. You want the resistor to be small enough such that it does not significantly change the circuit and large enough that you can obtain an accurate voltage reading.
Second, we don’t have a reliable current source. However, we can use source transformations to generate an equivalent circuit with a voltage source, as shown in the following circuit.

R2 is the test resistor and should be much smaller than R1, (R2 << R1). In the experiment that follows, you could easily just determine the current by measuring the voltage across R1 without any need for R2. However, we will treat the experiment as representative of a more complex model and use a small R2 resistor.

Note, you may want to prove to yourself that the source transformation circuit results in the same current response in L1.

_Discovery Board_

This lab investigates step responses. In Discovery Board, we use pulse streams and can’t easily make a step function source. To measure an equivalent response using a pulse stream, we make sure that each half cycle is much longer than the time constant for the circuit, T/2 >> τ. By letting the circuit response reach DC steady state in each half cycle, the V=Vo half cycle is equivalent to a source turning on at t = 0 with zero initial conditions and the V = 0 half cycle is equivalent to a source turning off at t = T/2 with initial conditions determined at t = T/2. 
Triggering: Oscilloscopes use a trigger to tell them when to start capturing data. For the Discovery Board, the trigger is available using the Source drop down list located near the top of the display, a bit to the right of center. Often, using the source in the circuit as a trigger is a good choice since that signal is reliable and known. In the experiments, you should connect Oscilloscope Channel 1 to the source to measure input voltages to the circuit and therefore set your Trigger Source to Channel 1 as well. We will want to use rising edge triggering, meaning we start capturing data when the slope of the signal is positive. Just to the right of the Source drop down list is a Cond. drop down list. Set that to Rising. Just below that drop box is the Level setting. This value tells the scope to start capturing data when you cross that voltage. You want to adjust the level somewhere between the maximum and minimum voltages of the channel input, which is again a good reason why you want to use a known signal like the source. With rising edge triggering and pulsed signals, setting the trigger Level slightly higher than low voltage of the pulse is a good choice.

**PSpice**
We will use the VPULSE component introduced in Lab 5.
Laboratory

Part 1) RC Circuits

Build the RC circuit shown in the top figure, with R1 = 12k, R2 = 12k, R3 = 4.7k and C1 = 0.1µF.

a) Using the Discovery Board, set your signal to a 0.5 V Amplitude square wave with a DC offset of 0.5 V (the source should switch from 1 V to 0 V, repeating). Set the frequency such that you see the voltage across the capacitor reach DC steady state response for each half cycle of the square wave. Measure the source signal using Channel 1 of the Oscilloscope and the output signal (capacitor voltage in this case) with Channel 2 of the Oscilloscope.

a. Analytically, determine the RC time constant for the above circuit. Finding the Thevenin equivalent circuit can help. (A similar circuit was discussed in class.)

b. Determine a differential expression for voltage across the capacitor. Solve the differential equation for a step function voltage source that turns on at t = 0 with a source voltage Vs = 1 V. Plot your result.

c. In Discovery Board, obtain plots for the voltage (use differential probes) across the capacitor. Compare your results to the expression in part b.

d. Estimate the RC time constant using the Discovery Board Oscilloscope.

e. Compare your result with the calculated value.

f. Simulate the circuit in PSpice using Vpulse as your source and again compare your results. You can copy PSpice plots into your report using the Window tab under the Schematic window where the plots are displayed. Under the tab, select “Copy to Clipboard” and use the default options (the colors will be inverted to save ink).
Part 2) *RL Circuits*

Build the RL circuit shown in the above figure, with \( R_1 = 1.8\, \text{k}\Omega \), \( R_2 = 18\, \Omega \), and \( L_1 = 100\, \text{mH} \).

a) In Discovery Board, set your signal to a 2.5 V amplitude square wave with a DC offset of 2.5 Volts (the source pulse switches from 5 V to 0 V, repeating). Set the frequency such that you see the voltage across the inductor reach DC steady state response for each half cycle of the square wave. Your measured voltages may have some spikes when the source square wave has low-high/high-low transitions. Try to ignore the spikes in your discussion of Discovery Board results/calculations. We will talk about why they occur when we discuss second order circuits.

   a. Analytically, determine the RL time constant for the above circuit.
   b. For the original RL parallel circuit, determine a differential expression for current through the inductor. Solve the differential equation for a step function current source (equivalent to a low to high transition). Plot your result.
   c. For the original RL parallel circuit, determine a differential expression for voltage across the inductor. Solve the differential equation for a step function current source (equivalent to a low to high transition). Plot your result.
d. Implement the equivalent circuit and measure the voltage across R2. Scale your result by R2 to estimate the current through L1 as a function of time. Compare your result to part b.

e. Estimate the RL time constant using the Discovery Board Oscilloscope. Note, as discussed in class, since the solution to the homogeneous differential equation is the same for all components, the RL time constant for this circuit can be found from any voltage or current plot across any component. The experimental result is probably a bit different than the calculated time constant. In the circuit, there is a ‘hidden’ resistance that is not negligible. Where is that resistance?

f. Compare your result with the calculated value.

g. Obtain plots for the voltage across the inductor in Discovery Board. Compare your results to part c.

h. Simulate the original parallel RL circuit with a current source in PSpice (include your small probe resistor). Use IPULSE as your source (the component description is similar to VPULSE, with currents instead of voltages). Again compare your results.