RL High Pass Filter Quandary: Part 1

Physics 251

Spring 2025

In this lab, you will study a high pass RL filter and compare it to your previous work with a high pass RC filter. You will find weird behavior that you will have to explain! Part II will be where you test your predicted solution.

Part 1: Simple high pass RL filter.

This lab is in two parts. In this first part, you'll build a simple high pass RL filter and measure it's frequency response. The RL filter you will build is shown in Figure 1.

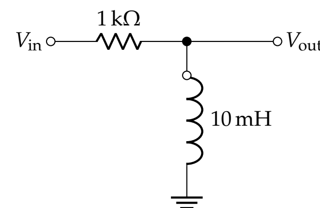

Figure 1: A basic high pass RL filter.

Theory

Before building the circuit, compute the magnitude of the frequency dependent gain, $G = |V_{\text{out}}/V_{\text{in}}|$, of the circuit using your knowledge of the complex impedances for the resistor and capacitor. Then, make a plot of

$$20 \log \left\| \frac{V_{\text{out}}}{V_{\text{in}}} \right\|$$

vs frequency, f, with the the horizontal frequency axis plotted logarithmically. Have the plot be for frequencies from 10 Hz to 10 MHz.

Experiment

Now, build the circuit, and measure the frequency response as you have done in previous labs. Take log-spaced values from 10 Hz to 10 MHz, and add these data points to your theoretical plot.

The problem

Now, looking at your final plot, you will see a disagreement between theory and experiment. Explain in a few sentences what the disagreement is, and then come up with at least two possible reasons for this discrepency. Do you trust the theory or the experiment? When you finish with your write-up, I will give you part 2 of this lab.

Part 2: The quandary solved

Before embarking on the solution, it's highly worth pointing out the *the true test of theory is experiment.* Theoretical physics is wonderful, but if the result it predicts is not borne out in experiment, then either the theory is incorrect, or the experiment is flawed.

When I did this experiment and observed the disagreement with theory, I first modeled the oscilloscope (which has an input impedance of 1 MΩ and 13 pF) coupled with the probe's impedance. The scope coupled with the probe form a roughly frequency independent 10:1 voltage divider. It turns out that this was not the issue—theoretically adding this to the circuit response calculation did not account for the measured behavior.

The soltion to this theoretical/experimental discrepancy is that an inductor is not just an inductor. It has an intrinsic resistance, and a parasitic capacitance. The resistance is easy to understand, as the inductor is made of non-superconducting wire, so you can model the resistance as being in series with the inductance. The parasitic capacitance is due to the fact that the inductor is composed of a coil of wire, and the individual coils have a small capacitance relative to each neighboring coil. This is much more challenging to measure, but to model it, you place a small capacitance in parallel with the inductor. Hence, the actual circuit you have in front of you is better modeled by Figure 2.

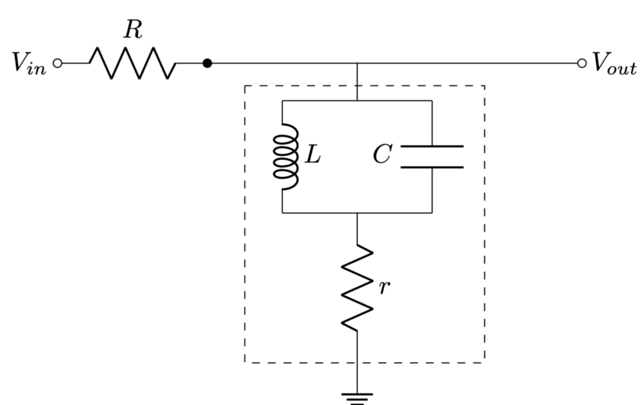

Figure 2: A better model for a realistic high pass RL filter. The dotted box encloses the effective content of the real physical inductor.

New theoretical model

In this section, you will compute a new theoretical model for the frequency response. Redo your calculation based on the more realistic model of our circuit shown in Figure 2. Use the algebraic values $R, L, C,$ and r in your calculation.

You may find it useful to perform the sequence of steps outlined below:

1. Compute the impedance (as a function of ω) for the effective inductor (the dotted box in Figure 2).
2. Now, you have a voltage divider! Compute the new magnitude of the frequency dependent filter gain.
3. Finally, figure out how to get an experimental value for r, the inductor's intrinsic resistance.
4. The parasitic capacitance will likely be on the order of a few 10's of pF.
5. Now create a function to plot the theoretical curve. The function depend on R, L, C, r, and f.
6. Plot your theoretical curve along with your data points. You will have to adjust the values of r and C to best fit your data.

Now that you (should) have a good theoretical model with your best guess for r and C, answer the following questions:

1. Of the two inductor parameters, r and C, which explains the low frequency correction, and which the high frequency correction?
2. How does your *phenomenological* value for r compare to your attampt to measure r?