Experiment 3

RLC Circuits

1. Introduction

You have studied the behavior of capacitors and inductors in simple direct-current (DC) circuits. In alternating current (AC) circuits, these elements act somewhat like resistors to limit current flow. The term used for the resistance these elements offer to current flow in AC circuits is *reactance*. The general term for the sum of all the resistance and reactance (both *capacitive* and *inductive*) in a circuit is *impedance.*

The reactance for a particular capacitor or inductor varies with the frequency of the circuit. Capacitors store energy in electric fields. When fully charged, they will not let current flow in a DC circuit. However, in AC circuits, as the frequency increases, their resistance to the flow of charge decreases. Inductors store energy in magnetic fields. In DC circuits, an ideal inductor has no resistance, but in AC circuits, its resistance increases with the frequency.

In this experiment, you will examine the behavior of an AC circuit containing a capacitor (C), an AC circuit containing a resistor and an inductor (RL), and an AC circuit containing all three elements (RLC).

2. Objectives

In this experiment, you will

a) Learn the terms capacitive reactance, inductive reactance, and impedance.
b) Determine the relationship between the reactance and frequency for
c) Determine the relationship between the impedance and frequency of
d) Determine the resonant frequency of an RLC circuit.
e) Experiment with resonance and energy transfer in an RLC circuit.

3. Apparatus/ Materials

1) Computer
2) Vernier board circuit

3) Power Amplifier

4) Vernier current sensor

5) Vernier Voltage sensor

4. Procedure

Part 1. A Capasitor in a circuit

a. Set up the circuit with a 10 µF capacitor in series with a current probe, as shown in Figures 2 and 3. The Voltage Probe will measure the potential difference across the capacitor plates.

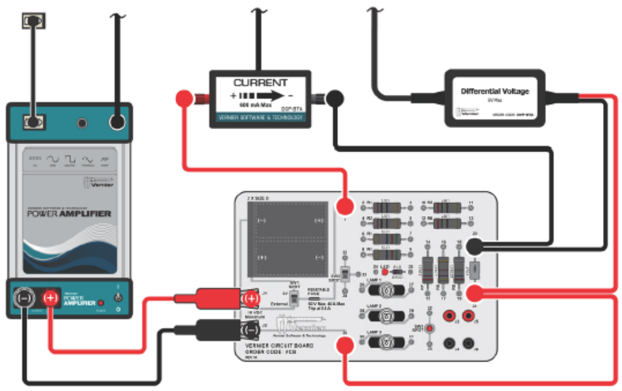


Figure 2

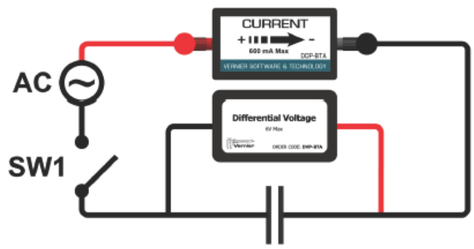


Figure 3

b. Choose one of the following options to drive the Power Amplifier.

LabQuest with Logger Pro

1) Use the mini stereo cable that came with the amplifier to connect the Speaker Out port on LabQuest and the Audio In port on the amplifier.

2) In Logger *Pro*, choose Set Up Sensors ► Show All Interfaces from the Experiment menu.

3) From the Sensor Setup dialog box, click Power Amplifier. In the Waveform list, click Sine.

4) The default value of 2.0 V is suitable, but change the initial frequency to 100 Hz. Use the up and down arrows to adjust the frequency, or use the parameter box to enter the desired value.

5) Click Start.

LabQuest as a standalone device

1) Use the mini stereo cable that came with the amplifier to connect the Speaker Out port on LabQuest and the Audio In port on the amplifier.
2) Launch Power Amplifier from the Home screen. The default setting of 2.0 VAC is suitable, but reduce the frequency to 100 Hz.
3) Tap Start. Use the up and down arrows to adjust the frequency or enter the value in the
4) parameter field.

Power Amplifier computer program and the computer's audio output

Use this option if using LabQuest Mini or LabPro for data collection.

1) Use the mini stereo cable that came with the Power Amplifier to connect the Speaker Out port on your computer and the Audio In port on the amplifier.
2) Set the computer's sound output on and at maximum volume.
3) Start the Vernier Power Amplifier computer program.
4) The default value of 2.0 V is suitable, but set the initial frequency to 100 Hz. To adjust the frequency, use the up and down arrows, or use in the parameter box to enter the desired value.
5) Click Start.

c. Connect the voltage and current probes to the interface and start the data-collection program. Two graphs, potential *vs.* time and current *vs.* time, will be displayed. Change the datacollection rate to 10,000 samples/second and the duration to 0.02 seconds.

d. Start the power amplifier output using a sine wave output with the frequency set to 100 Hz and an amplitude of 2.0 volts. Close the switch to complete the circuit.

e. From your Pre-Lab Investigation, consider how the circuit you have constructed *should* behave. Now that you have connected this circuit to an AC voltage source, would you expect the current to be greater at low or high frequencies?

f. To test your prediction, start data collection. When data collection stops, choose Statistics from the Analyze menu to determine the maximum value of the potential and the current for the run; record these values in your notebook.

g. Continue collecting data in this way until you have potential and current values for 6–7 frequencies ranging up to 1000 Hz.

Evaluation of Data

a. For each of your runs, the maximum voltage should have remained roughly the same. How did the maximum current in the circuit vary with frequency? Write a statement that describes the relationship you found.
b. For each frequency, determine the capacitive reactance (Xc) of the capacitor by dividing the maximum value of the potential by the maximum value of the current. From what you know about Ohm’s law, determine the units of capacitive reactance.
c. Disconnect the probes from the interface and choose New from the File menu. In the table, manually enter values so as to produce a graph of capacitive reactance vs. frequency. Instead of Hz, use 1/s as the units for frequency. Write a statement that describes the relationship between the capacitive reactance and frequency.
d. If your graph of capacitive reactance vs. frequency is not linear, take steps to modify a column so as to produce a linear relationship. When you have done so, save your file and (if possible) print a copy of your original and then linearized graph.
e. Write the equation of the line that best fits your linearized graph. Examine the units of the slope of the line.
f. The textbook definition of capacitive reactance is

$$X_c = \frac{1}{(2\pi f.C)}$$

Rearrange this equation so that it has the same form as the one you recorded in Step 5. Compare the slope (value and units) of the equation for your linearized graph to the constant of proportionality in this equation. From the units for f and C, show that the unit of capacitive reactance is the ohm.
g. Many capacitors have a tolerance of 10%. This means that their capacitance is only guaranteed to be within 10% of their labeled value. Would your data indicate that your capacitor is within its specification?

Part 2. An RL Circuit

a. Set up the circuit with a 10 Ohm resistor in series with a current probe and a 5.0 mH inductor. As shown in Figures 4 and 5.

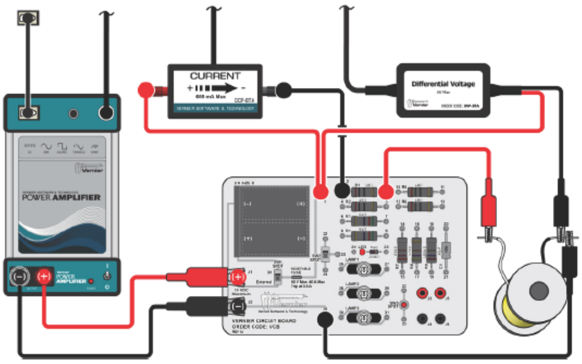


Figure 4

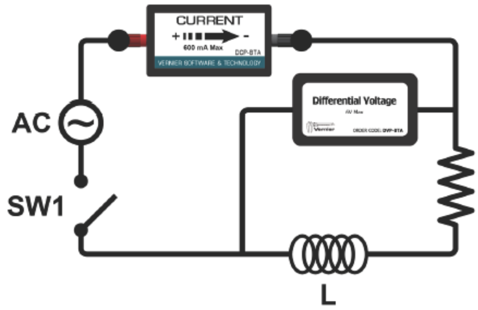


Figure 5

b. Connect the voltage and current probes to the interface and start the data-collection program. Change the data-collection rate to 10,000 samples/second and the duration to 0.02 seconds.

c. Start the power amplifier output using a sine wave output with the frequency set to 100 Hz and an amplitude of 2.0 volts.

d. From your Pre-Lab Investigation, consider how the circuit you have constructed *should* behave. Now that you have connected this circuit to an AC voltage source, would you expect the current to be greater at low or high frequencies?

e. Close the switch and begin collecting data. When data collection stops, use the Statistics tool to determine the maximum value of the potential and the current for the run; record these values in your notebook.

f. Continue collecting data in this way until you have potential and current values for 6–7 frequencies ranging up to 1000 Hz.

Evaluation of Data

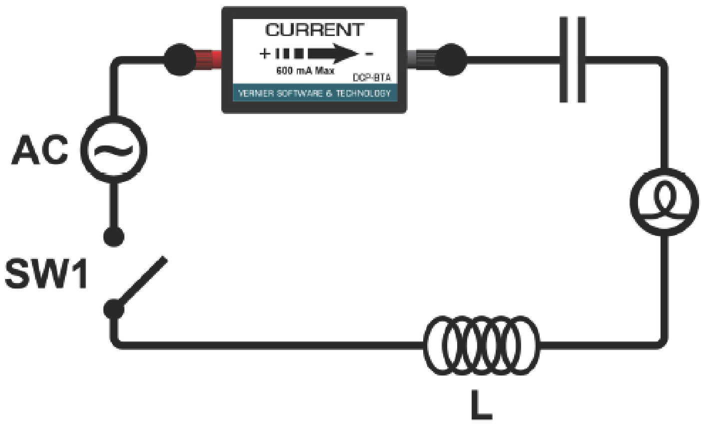
a. For each of your runs, the maximum voltage should have remained roughly the same. How did the maximum current in the circuit vary with frequency? Write a statement that describes the relationship you found.

b. Impedance is the general term for the opposition to the current due to the resistance and reactance of circuit elements. In this step, you will determine how the impedance varies with the frequency. For each frequency, determine the value and units of the impedance of the circuit by dividing the maximum value of the potential by the maximum value of the current.

c. Disconnect the probes from the interface and choose New from the File menu. In the table, manually enter values so as to produce a graph of impedance *vs.* frequency. Instead of Hz, use 1/s as the units for frequency.
d. At first glance, the relationship between impedance and frequency might appear to be linear. Closer inspection shows that this is not the case. Rather than performing a curve fit on the data, take steps to modify one of the variables so as to produce a more linear graph. You may find it necessary to modify the variables on *both* axes to achieve this end. When you have a linear graph, record the equation of the best-fit line.
e. Relate the y-intercept of your graph to the resistance of the circuit; be sure to include the resistance of the inductor.
f. The textbook definition of inductive reactance is $X_i = 2\pi fL$. Relate this equation to the equation of your best-fit line. What does the slope of your equation indicate about your inductor?

Part 3. An RL Circuit

a. Set up the circuit as shown in Figure 6. This is an RLC circuit, containing a capacitor, an inductor, a current probe, and a mini lamp, which serves as the resistor.



b. Connect the current probe to the interface and start the data-collection program. Change the data-collection rate to 10,000 samples/second and the duration to 0.02 seconds.
c. Start the power amplifier output using a sine wave output with the frequency set to 100 Hz; increase the amplitude to 5.0 volts. Close the switch to complete the circuit.

d. Collect data and, as you have done before, determine the maximum current. Record this value in your lab notebook.
e. Repeat Step 4 until you have data for at least eight frequencies ranging up to 1300 Hz.
f. Disconnect the probe from the interface and choose New from the File menu. In the table, manually enter values so as to produce a graph of current *vs.* frequency. Examine your graph and determine the frequency at which the current in your circuit was greatest.
g. Use the frequency controls of the program you used to control the power amplifier to try different frequencies while watching the lamp. Focus your investigation in the region where the current was highest. Find the frequency that causes the lamp to glow most brightly. This is the resonant frequency of your RLC circuit.
h. Once you have determined the resonant frequency of your circuit, place the powdered iron core inside the coil of your inductor. Note the effect this has on the brightness of the bulb. Check to see if the resonance frequency has changed.

EVALUATION OF DATA

a. An RLC circuit can be considered to be analogous to a damped spring/mass combination moving in simple harmonic motion. Like the spring/mass combination, it has a resonant frequency at which it absorbs outside energy most readily. In this part of the experiment, you found this resonant frequency for your RLC circuit. Resonance occurs when the impedance of the circuit is a minimum. For RLC circuits, impedance is defined as

$$Z = \sqrt{R^2 + (X_i^{\ 2} - X_c^{\ 2})}$$

The value of impedance reaches a minimum when the inductive reactance and the capacitive reactance are equal. Using the equations for capacitive and inductive reactance, derive an equation to calculate the resonant frequency for an RLC circuit.
b. Using the labeled values for the capacitor and inductor you used, calculate the expected resonant frequency for your circuit.
c. How does your measured resonant frequency compare with the calculated value? What factors could explain any difference?

d. Can you explain the change in the bulb brightness when you placed the metal core into the coil of the inductor?

SOURCE:

http://vernier.com