PHY 112L Activity 8

Series RLC Circuit – 2: Resonance

Name: _____ ID #:_____

Section: _____ Date: _____

Lab Partners: _____ TA initials: _____

Objectives

1. Introduce the various characteristics of series RLC circuit at its resonant frequency
2. Determine the resonant frequency by measuring current and voltages and compare (lab report)

Materials & Resources

1. Computer with DataStudio and Pasco interface, 2 voltage sensors, and a current sensor
2. Multimeter and RLC circuit module

Introduction

Recall from last week's lab that, for a series AC circuit, Ohm's law still applies, but in order to describe the circuit properly, *impedance* must be used in place of the resistance. This results in the following restatement of Ohm's Law:

$$\boldsymbol{V = IZ = I\sqrt{R^2 + (X_L - X_C)^2}}$$

Examining this restatement of Ohm's law, it becomes apparent that when $X_L = X_C$, these terms cancel, and Ohm's law then reduces to its original form, V = IR. Then, the only resistance limiting the current through the circuit is that of the resistor. Since these quantities are always positive, cancellation of the X_L and X_C terms has the effect of minimizing the impedance in the circuit as seen in Figure 1. To determine how the AC source should change so that $X_L = X_C$, substitute in their definitions:

$$X_L = 2\pi fL \quad and \quad X_C = {}^{1}/_{2\pi fC}$$

and then solve for f. The minimization of impedance of the circuit is then seen to be frequency dependent, and the frequency at which the minimum occurs is known as the *resonant frequency*, which is given by

$$f_R = \frac{1}{2\pi\sqrt{LC}}$$

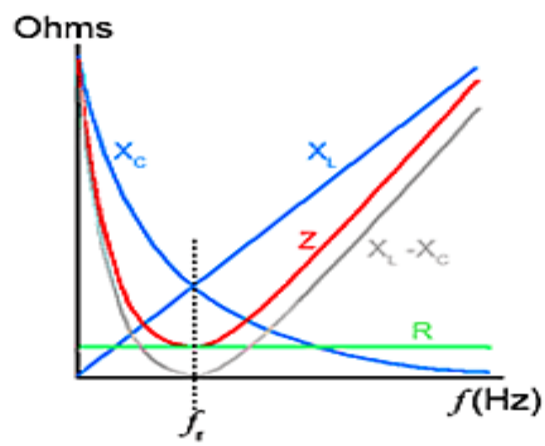

Figure 1

When rearranging Ohm's law to get $I = {}^{V}/_{Z}$, it also becomes apparent that *minimizing the impedance* in the circuit also has the effect of *maximizing the current* through the circuit. In addition to the current through a series RLC circuit exhibiting specific behaviors at resonance, the voltages across the inductor and capacitor also exhibit very specific behaviors. When the circuit is tuned to the resonant frequency f_R, the voltage across the inductor (V_L) *leads* the current by 90°, and the voltage across the capacitor (V_C) *lags* the current by 90°, as shown in Figure 2 to the right. This has the effect that the two voltages are 180° out of phase at resonance, which means that when the voltage on one is at a maximum, the voltage on the other is at a minimum. And since $X_L = X_C$ at resonance, by Ohm's law the magnitudes of the voltages V_L and V_C are also equal at the resonant frequency, this means that the two voltages are always *equal and opposite* at the resonant frequency.

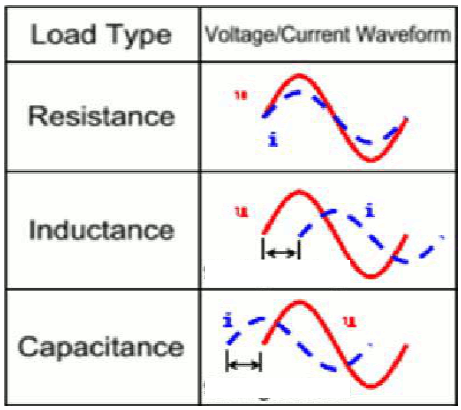

Figure 2

1. *Determining Resonant Frequency using Current*

Procedure:

1) Connect a multimeter across the resistor as shown in Figure 3 and set the multimeter to resistance mode. Measure and record the resistance below. This value will be used for calculations later in the experiment.

R_E = _____ ( )

2) Connect the voltage source, multimeter and 2 voltage sensors to the RLC module and Pasco interface as shown in Figure 4.
3) Create an appropriate experiment in DataStudio. Use a Sine Wave with a 5 V amplitude and a 4000 Hz frequency.
4) In order to find the resonant frequency manually, set the step size in the Signal Generator to 100 Hz, increase the frequency in steps of 100 Hz until you pass a maximum value for the current reading by one step, and record this frequency and the maximum observed current in the table below.
5) Next, reset the frequency to a value 100 Hz below what was just recorded, as shown in Figure 5, and reduce the step size to 10 Hz. Repeat the process of overshooting the frequency at which the current is a maximum by 10 Hz, and then record this frequency and the maximum observed current in the table.
6) Finally, reset the frequency to a value 10 Hz below what was just recorded and reduce the step size to 1 Hz. Repeat the process of overshooting the maximum current frequency by 1 Hz; record this frequency and the maximum current in the table below. *Note*: when the step size is 1 Hz, the current may be at its maximum value for multiple frequency values. If this happens, estimate the resonant frequency by identifying the frequency at which the current begins to drop on both sides of the peak and use the average value of those two frequency values; record your results in the table below.

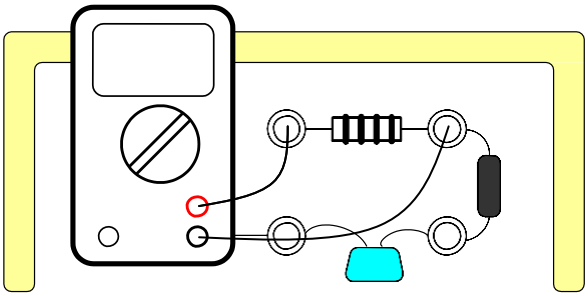

Figure 3

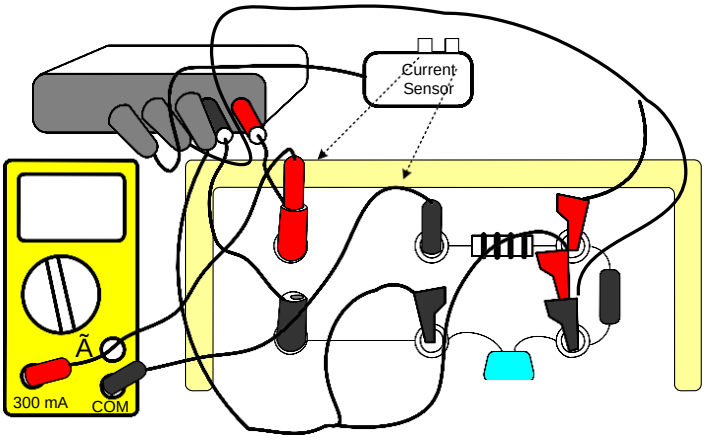

Figure 4

Step size	Frequency	Max. *I*
100 Hz		
10 Hz		
1 Hz		

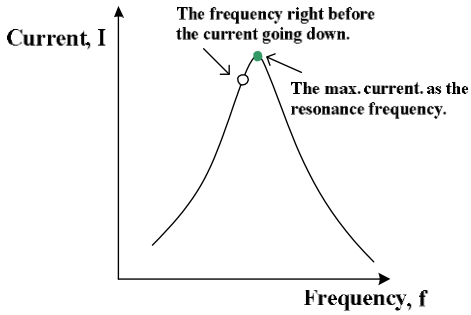

Figure 5

7) AC current measurements given by the multimeter are RMS values. Convert the maximum current found at the resonant frequency to its peak value I_{P1} as shown below. Use Ohm's law to calculate the theoretical resistance R_T of the circuit at its resonance frequency. Calculate the % difference between this R_T and R_E above.

$I_{P1} = \sqrt{2} * I_{RMS}$ = _____ ( ) $R_T = V_P / I_{P1}$ = _____ ( ) $\%\, difference = \frac{|R_T - R_E|}{\frac{1}{2}(R_T + R_E)} \times 100$ = _____ %

Questions:

1) Is your calculated value for R_T higher or lower (circle one) than your value for R_E measured in part 1 above?
2) How is the method for finding R_T physically different from that used to measure R_E above?

3) Briefly explain the expected difference in your results for R_E and R_T based on the physical difference of the methods.

2. *Determining Resonant Frequency using Inductor and Capacitor Voltages (Lab Report)*

Procedure:

1) Double click on "Scope" under Display to add an oscilloscope view of the current to your DataStudio experiment, add the voltage sensors on channels B and C to the scope display, as in Figure 4. Set both of the voltages to the same vertical scale.
2) Verify that the amplitude is still 5V and reset the frequency to 4000 Hz. Start the experiment, turn on the signal source, and then verify that the outputs look similar to that of Figure 5.
3) Verify that the voltage across the inductor *leads* the current signal, that the voltage across the capacitor *lags* the current signal, and that the 2 voltage signals are 180° out of phase so that one voltage is at its maximum at the same time that the other is at its minimum. As the circuit is tuned to resonance, the magnitudes of the voltages will become equal in magnitude but remain opposite in sign. Instead of measuring the positive and negative voltage peaks directly, the resonant frequency can be determined by simply noticing at what frequency the positive voltage peaks are the *same height* on the graph.
4) Adjust the frequency until the peak values for the voltages across the inductor and the capacitor are the same height by starting with a large step size and then fine tuning the circuit with smaller step sizes until you find the frequency at which they are *precisely* equal and opposite. Record f_E below, print the graph, and then label the signals for the capacitor (V_C) and inductor (V_L) on the graph.

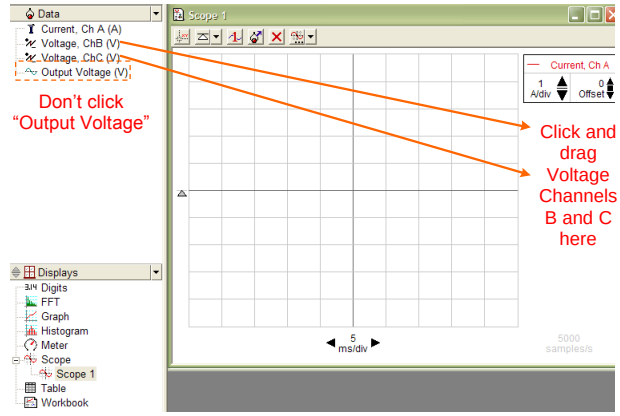

Figure 4

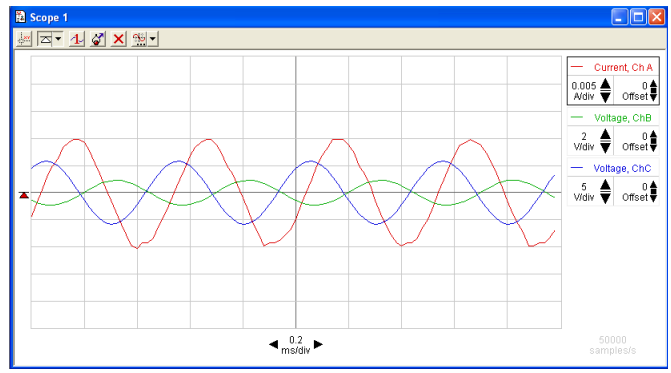

Figure 5

f_E = _____ ( )

5) Select channel A on the scope, use the "Smart Tool" to measure the peak current at this frequency, record your value for I_{P2} below, and then calculate a percent difference between I_{P1} and I_{P2} in the space below.

I_{P2} = _____ ( ) $\% \, difference = \frac{|I_{P1}-I_{P2}|}{\frac{1}{2}(I_{P1}+I_{P2})} \times 100 =$ _____ %

6) Use the theoretical values for the inductor ($L = 10\ mH$) and the capacitor ($C = 0.1\ \mu F$) to calculate the resonant frequency f_T, record below with correct significant figures and units, and then calculate the % error between f_T and f_E.

$f_T = \frac{1}{2\pi\sqrt{LC}} =$ _____ ( ) $\% \, error = \frac{|f_T - f_E|}{(f_T)} \times 100 =$ _____ %

Questions:

1) Is your measured value for I_{P1} from part 1 *very* similar to your measured value for I_{P2} here, yes or no (circle one)?
2) Which method is more reliable for determining the current of a series RLC circuit at resonance? Justify your answer.

3) In part 2, is the measured value for f_E higher or lower (circle one) than the theoretical value calculated for f_T?
4) What experimental factors would account for the discrepancy between your measured and theoretical results for the resonant frequency? List all relevant factors and explain how they are *physically* consistent with your results below.