

RLC Series Resonance

Object: The purpose of this laboratory activity is to study resonance in a resistor-inductor-capacitor (RLC) circuit by examining the current through the circuit as a function of the frequency of the applied voltage.

Apparatus: Power Amplifier, voltage sensor, capacitor (100 μ F), inductor coil and iron core, resistor (10.0 Ω), hook up wires, PASCO Interface, computer and Data Studio Software

FOREWORD

The amplitude of the AC current (I_o) in a series LRC circuit is dependent on the amplitude of the applied voltage (V_o) and the impedance (Z).

(1)
$$I_o = \frac{V_o}{Z}$$

Since the impedance depends on frequency, the current varies with frequency:

(2)
$$Z = \sqrt{(X_L - X_C)^2 + R^2}$$

where

(3)
$$X_L = \omega L = \text{inductive reactance,}$$

(4)
$$X_C = 1/\omega C = \text{capacitive reactance,}$$

$$R = \text{resistance,}$$

(5)
$$\omega = 2\pi f = \text{angular frequency, and}$$

$$f = \text{linear frequency.}$$

The current will be maximum when the circuit is driven at its resonant frequency

(6)
$$\omega_{res} = \frac{1}{\sqrt{LC}}$$

One can show that, at resonance, $X_L = X_C$ and thus the impedance (Z) is equal to R . At resonance, the impedance is the lowest value possible and the current will be the largest value possible.

PROCEDURE

In this activity the Power Amplifier produces an alternating current through the RLC circuit. The amplitude of the current depends on the impedance in the circuit, which varies with frequency. The Signal Generator controls the frequency. If the current is a maximum at the resonant frequency and is less than maximum for greater or lesser frequencies, the current should peak at the resonant frequency. The current can be determined from the ratio of the resistor voltage to the resistance. The Voltage Sensor measures the voltage drop (potential difference) across the resistor in the circuit.

You will use the Signal Generator to change the frequency of the applied voltage. You will investigate the phase relationship between the applied voltage and the resistor voltage as you vary the frequency. You will also determine the amplitude of the current through the resistor and then plot current vs. frequency. The Data Studio program collects and displays both the applied voltage and the resistor voltage.

You will compare the theoretical resonant frequency to your measured resonant frequency.



Part I. Determination of Resonant Frequency

Initial Data Collection

1. Use a multimeter to determine the resistance of the 10 Ohm resistor on the circuit board and record the value on the data sheet.
2. Record the value of the inductance that is printed on the circuit board.
3. Record the capacitance as 100 μ F.

Initial Equipment and Software Set-up



1. Start Data Studio, and select *Create Experiment*.
2. Connect the Power Amplifier to the computer via an analog port on the PASCO interface. Plug the Power Amplifier into an AC outlet, and turn the power amplifier on. Connect the power amplifier to the resistor (10 Ω), inductor, and capacitor (100 μ F) connected in series.
3. Inform the software which analog port you plugged the Power Amplifier into by selecting the Power Amplifier icon and dragging it to the appropriate analog port.
4. A signal generator box should appear. The wave pattern should be the default *Sine Wave*. Change the amplitude to 3.00V. Change the Frequency to 100Hz. The **Auto** button should already be selected. It is set to **Auto** so that the signal generator will start and stop automatically when the **Start/Stop** button is pressed.

Note: The frequency can be changed by the increment shown by clicking the   buttons, and the frequency increment amount can be changed by clicking the arrow buttons. Or, the frequency can be changed by typing the desired frequency followed by pressing the Enter key on the keyboard.

5. Connect a voltage sensor across the 10 Ω resistor, and connect it to the computer via an analog port on the PASCO interface.

6. Inform the software which analog port you plugged the voltage sensor into by selecting the voltage sensor icon and dragging it to the appropriate analog port.
7. Tell the software that you wish to monitor the output voltage from the signal generator (which is the input to RLC Circuit) and the voltage across the 10Ω resistor with the oscilloscope. Locate the icon in the Displays section (the same section where the graph icon is located) that is labeled *Scope* and drag it to the *Output Voltage*. Now drag the *Voltage* icon that represents the voltage sensor from the data section to the oscilloscope display and drop it when the entire display is outlined by a dotted box.
8. Arrange the Scope Display and the Signal Generator window so that both can be seen simultaneously.

Data Collection

1. Click the Start button to begin monitoring the data. The Signal Generator will start automatically. The scope display shows the Output Voltage from the Power Amplifier (this is the input voltage of the RLC circuit) and the Voltage Across the Resistor (V_R).
2. Click the **trigger button**  located on the oscilloscope tool bar.
3. If necessary change the V/div associated with the Output Voltage trace to an appropriate scale.
4. Change the ms/div near the bottom of the oscilloscope display such that two to five peaks are visible. A good starting point should be 5 ms/div.
5. If necessary change the V/div associated with the V_R trace to an appropriate scale.
6. While the control area associated with the V_R trace is active, click on the **smart tool** . The **smart tool** should be the same color as the V_R trace, and the **smart tool** will correspond to the V/div scale associated with the V_R trace.
7. Use the **smart tool** to determine the peak voltage of the V_R .
8. Record the peak voltage in the Data Table located on your Data Sheet.
9. Increase the frequency by 10 Hz. As you increase the frequency, you will eventually need to adjust the V/div scale of the V_R trace so that accurate measurements can be taken. You will also need to adjust the ms/div scale of the oscilloscope to maintain two to five visible peaks.
10. Repeat steps 7 through 9 as you change the frequency in 10 Hz increments from 100 Hz to 250 Hz.
11. When you have completed your Data Table, click Stop.
12. Create a graph of your data table.
 - a. First click on the *Experiment* pull down menu located near the top of the Data Studio window.
 - b. Select the *New Empty Data table ...*
 - c. You should now have a **Data Table** with an X column and a Y column.
 - d. Enter the frequencies from your data table in the X column and the corresponding calculated currents in the Y column.
 - e. Drag the graph icon to the icon labeled **Editable Data**.

- f. Use the **smart tool** to obtain a good estimate of the linear frequency where the current is at a peak. You may wish to adjust the scale of the Y axis or magnify the peak area to obtain the best estimate. The estimated frequency is the approximate resonant frequency.
 - g. Print the graph.
 - h. Manually label each axis in order to clearly identify each axis beyond the computer generated labels of X and Y. Manually provide a title for your graph.
13. To determine a more exact resonant frequency, you will take advantage of the X-Y mode of the oscilloscope. The resonant frequency occurs at the frequency that maximizes the voltage across the resistor while at the same time permitting the output voltage and resistor voltage to be in phase.
14. Delete the V_R trace from the Oscilloscope. While the control area associated with the V_R trace is active, press the Delete key on the keyboard.
15. Now drag the *Voltage* icon that represents the voltage sensor from the data section to the ms/div area of the oscilloscope display. Drop the icon when the ms/div area is outlined by a dotted box. The oscilloscope will now form a trace of Input Voltage vs. V_R .
16. Change the Signal Generator frequency to the approximate resonant frequency you found from your graph.
17. Click the Start button.
18. Adjust the V/div for each axis to enlarge the trace to an appropriate size.
19. When the voltages are in phase, the oscilloscope will display a trace in the form of a straight line. When the voltages are slightly out of phase, an oblong ellipsoid will be displayed.
20. Adjust the frequency in small increments to form a straight line. The frequency that forms a single line will be the resonant frequency.
21. Record the Resonant Frequency (linear) on your data sheet.
22. Click the stop button.

Part II. Impact of a Soft Iron Core on Inductance

1. Remove the iron core from the clips mounted on the RLC circuit board, and insert the iron core into the inductor. (Remove the nylon bolt and nut from the inductor if necessary.)
2. Click the Start Button.
3. Find the new Resonant Frequency, and use it to complete Part II of your data section.
4. Remove the iron core from the inductor and store it on the RLC circuit board using the clips mounted on the RLC circuit board. (Replace the nylon nut and bolt if it was previously removed from the inductor.)
5. Click the stop button.

Part III. Impact of Resistance on the Resonant Frequency

1. Reset the signal generator to the resonant frequency without the iron core.
2. Click the start button. Make sure the circuit is in resonance.
3. Unplug the appropriate banana wires from the 10 Ohm resistor and connect them to the 100 Ohm resistor.
4. Note any changes.
5. Click the stop button.
6. Answer the questions in Part III of the Data summary.
7. Turn off the power amplifier, and disconnect the power cord from both the AC outlet and the back of the power amplifier.
8. Disconnect the banana wires from the RLC circuit board and the power amplifier.

DATA AND CALCULATION SUMMARY

Part I.

Frequency(Hz)	V_R	$I=V_R/R$	Frequency(Hz)	V_R	$I = V_R/R$
100			180		
110			190		
120			200		
130			210		
140			220		
150			230		
160			240		
170			250		

Resistance of Resistor _____ Ω

Inductance _____ mH

Capacitance _____ μF

Measured Resonant Frequency (Linear) _____ Hz

Measured Resonant Angular Frequency _____ rad/s

Show Calculation

Theoretical Resonant Angular Frequency _____ rad/s

Show Calculation

Percent difference _____ %

Show Calculation

Part II.

Measured Resonant Frequency (Linear) w/ iron core _____ Hz

Estimated value of the inductor w/ the iron core _____ mH

Show Calculation:

Did the inductance increase or decrease?

Why did the iron core have this effect on the inductor?

Part III.

1. At resonance, the reactance of the inductor and the capacitor cancel each other so that the impedance (Z) is equal to just the resistance R . Calculate the resistance of the circuit by using the amplitude of the current at resonance in the equation $R = V/I$ (where V is the amplitude of the applied voltage.)
Is this resistance equal to the resistance of the resistor? Why or why not?
2. Does the resonant frequency depend on the resistance?
Did the resonant frequency increase, decrease, or remain the same when the resistance was changed?