

Experiment #11: LRC Circuit (Power Amplifier, Voltage Sensor)

Concept: circuits

Time: 30 m

SW Interface: 750

Windows file: RLC.SWS

EQUIPMENT NEEDED

- *Science Workshop Interface*
- Power Amplifier
- (2) Voltage Sensor
- Decade Resistance, Capacitance, and Inductance Boxes
- (3) Patch Cords

FROM AC/DC ELECTRONICS LAB*

- capacitor, 100 microfarad (100 μF)

PURPOSE

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

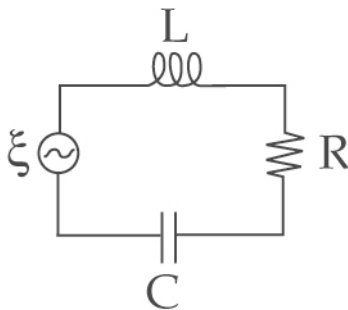


Figure 1

THEORY

The amplitude of the AC current (I_m) in a series LRC circuit is dependent on the amplitude of the applied voltage (\mathcal{E}_m) and the impedance (Z).

$$I_m = \frac{\mathcal{E}_m}{Z} \quad (1)$$

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

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

where X_L = inductive reactance = ωL , X_C = capacitive reactance = $\frac{1}{\omega C}$, R = resistance, and ω = angular frequency = $2\pi\nu$ (ν = linear frequency). The current will be maximum when the circuit is driven at its resonant frequency:

$$\omega = \frac{1}{\sqrt{LC}} \quad (3)$$

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. The phase difference ϕ between the current and the applied voltage is given by

$$\tan \phi = \frac{X_L - X_C}{R} \quad (4)$$

PROCEDURE

In this activity the Power Amplifier produces an alternating current through the LRC 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 *Science Workshop* program collects and displays both the applied voltage and the resistor voltage.

You will compare the theoretical resonant frequency to your measured resonant frequency. You will also measure the phase difference between the current and the applied voltage at different frequencies and compare that to the theoretical phase difference.

PART IA: Computer Setup

1. Connect the *Science Workshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the Power Amplifier to Analog Channel C. Plug the power cord into the back of the Power Amplifier and connect the power cord to an appropriate electrical outlet.
3. Connect the Voltage Sensors to Analog Channels A and B. The voltage measured at Analog Channel A is related to the current through the resistor by $I = \frac{V_R}{R}$.
4. Open the *Science Workshop* document titled as shown:

Windows
RLC.SWS

- The document opens with a Scope display of Voltage and the Signal Generator window which controls the Power Amplifier. The Scope display is set to show the applied (output) voltage and the resistor voltage.
 - Note: For quick reference, see the Experiment Notes window. To bring a display to the top, click on its window or select the name of the display from the list at the end of the Display menu. Change the Experiment Setup window by clicking on the **Zoom** box or the **Restore** button in the upper right hand corner of that window.)
5. The **Sampling Options...** for this experiment are: **Periodic Samples = Fast** at 2500 Hz (set by the Sweep Speed control in the Scope display).
 6. The Signal Generator is set to output 2.00 V, sine AC waveform, at 10.00 Hz.
 - The Signal Generator is set to **Auto** so it will start automatically when you click **MON** or **REC** and stop automatically when you click **STOP** or **PAUSE**.
 7. Arrange the Scope display and the Signal Generator window so you can see both of them.

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Power Amplifier or Voltage Sensor.
1. Connect the circuit as shown in Figure 1. Connect the Voltage sensor of Channel A across the resistor, and that of Channel B across either the capacitor or the inductor.

2. Connect the 100 μF capacitor instead of the Capacitance Box which you used for the previous two experiments.
3. Set the value of the inductor so that the expected resonance frequency is about 100 Hz. See relation (3) above
4. Set the resistance value at about 5 Ω

Part III: Data Recording

1. Turn on the power switch on the back of the Power Amplifier.
2. Click the **MON** button to begin monitoring data .The Signal Generator will start automatically.
3. In the Scope display, click the **Smart Cursor** button. The cursor changes to a cross-hair. Move the cursor/cross-hair to a peak of the voltage across the resistor, V_R . Record the voltage that is displayed next to the Input Menu button for Channel A. Record the voltage in the Data Table, for the frequency shown in the signal generator window.
 - a. Note the phase difference between the resistor voltage and the input voltage in the scope display. Measure it and record it. Note whether the current is leading or lagging the applied voltage. Compare it to the theoretical expression.
4. In the Signal Generator window, click on the **Up** arrow to increase the frequency by 10 Hz. Find the new frequency (20 Hz) in the Data Table. Repeat the process of using the Smart Cursor to find the new value for the resistor voltage, V_R , and record it. Again measure the phase difference, record it, and check whether the current is leading or lagging the voltage. Compare it to the theoretical expression.
5. Repeat the process until 200 Hz is reached. At the higher frequencies, change the sweep speed of the scope display to make your display convenient for measurement.
6. Look at the Data Table and determine approximately the resonant frequency (where voltage across the resistor reaches a maximum and the output voltage and resistor voltage are in phase).
7. Make fine adjustments to the frequency until the trace of voltage from Channel A is in phase with the trace of Signal Generator Voltage (Channel C). This is your resonant frequency, as determined by your experiment. Compare this with the expected value as set by you in step 3 of Part II (Equipment Setup).

Frequency Adjustment

- When using the cursor and mouse button to click on the up-down arrows next to the frequency value, the default change is 10 Hz per click. You can use modifier keys (**CTRL** and **ALT**) to increase or decrease the amount of change per click. (See the summary of Frequency Controls.)

Windows Key (s)	frequency
Shift key	100 Hz
No modifier key	10 Hz
Ctrl key	1 Hz
Alt key	0.1 Hz
Alt + Ctrl keys	0.01 Hz

8. Click the **STOP** button. Turn off the switch on the back of the Power Amplifier.

ANALYZING THE DATA

1. Calculate the current through the resistor and record the values in the Data Table. Graph the current versus the linear frequency. You can use a graphing program like Excel. (NOTE: The frequency displayed in the Signal Generator window is the linear frequency.) Similarly plot the phase shift vs. the frequency. Note that at resonance, the phase shift is zero. At lower frequencies, the circuit had a larger capacitive reactance, it behaves more like a capacitor, and the current leads the applied voltage. At higher frequencies, the circuit is more inductive, and the current lags the voltage.
2. Using the resonant frequency found from the Scope display, calculate the resonant angular frequency and record the value in the Data Table:

$$\omega_{res} = 2\pi\nu_{res}$$

3. Calculate the theoretical resonant angular frequency using the values of the inductance and capacitance and equ (3).
4. Repeat the entire experiment, but this time change the resistance to 50 or 100 Ω . See what happens to the resonant frequency, and to the shape of the resonance curve (the graph drawn by you).

DATA TABLE

Freq(Hz)	V_R	$I=V_R/R$	ϕ	$\tan \phi$
10				
20				
30				

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Item	Value
Inductance	mH
Resistance	—
Capacitance	μF
Resonant frequency (linear)	Hz
Resonant angular frequency	Hz
Theoretical resonant angular frequency	Hz

QUESTIONS

1. How does your measured value for resonant angular frequency compare to the theoretical value for resonant angular frequency?

Remember, Percent difference = $\left| \frac{\text{theoretical} - \text{actual}}{\text{theoretical}} \right| \times 100\%$

2. Is the plot of current versus frequency symmetrical about the resonant frequency? Explain.
3. At resonance, the reactances 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 $R = \frac{V}{I}$ (where V is the amplitude of the applied voltage). Is this resistance equal to the value set by you in the decade resistance box? Why not?

University Physics Students

1. Use the Voltage Sensor in Analog Channel B to measure the peak voltage across each of the components of the circuit individually. The sum of these peak voltages does not equal the applied peak voltage. Why not? Draw a phasor diagram to explain this.
2. Discuss whether the resonant frequency depends on the resistance. How about the shape of the resonance curve?