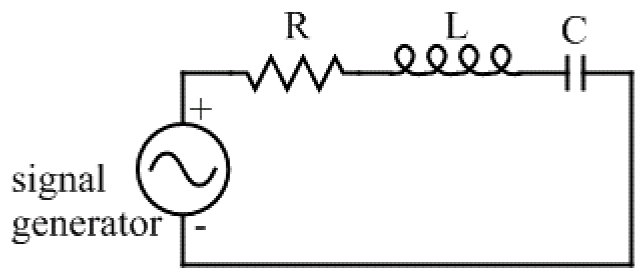
RLC Series Circuit
Microcomputer-Based Lab

In this experiment you will investigate the effects of changing inductance, capacitance, resistance, and frequency on an RLC series AC circuit.

PROCEDURE

PART I – Preliminary measurements

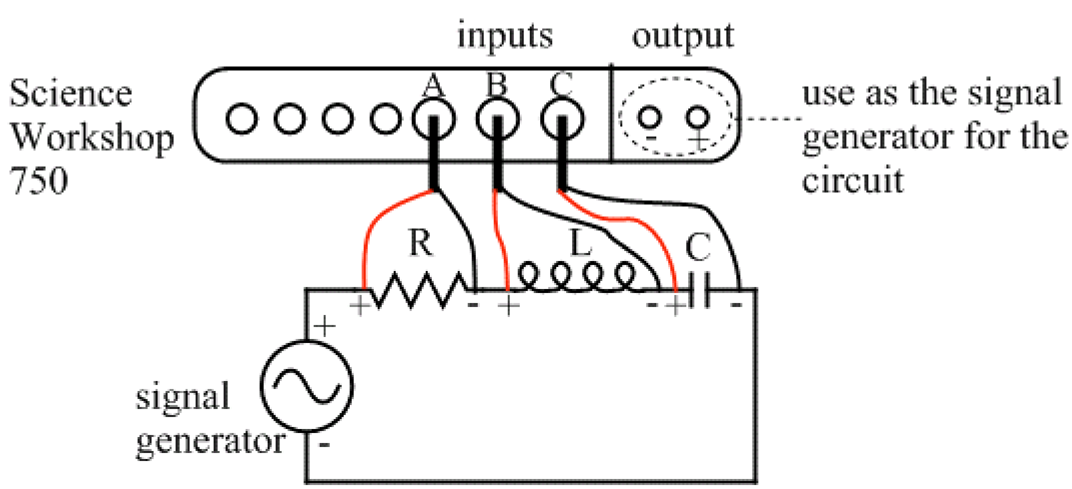


1. First, wire up the circuit as shown in the diagram above, with the resistor, inductor, and capacitor connected in series to one another and the signal generator. Use the output of the Science Workshop 750 as the signal generator.

2. Start with the following values for resistance, inductance, and capacitance:

   - R = 500 Ω; L = 100 mH = 0.1 H; C = 1 μF = 1 x 10^{-6} F

3. Throughout the experiment you will need to measure the voltage as a function of time across the resistor, the inductor, and the capacitor. To do this, connect three voltage probes from the Science Workshop to the circuit as shown below.



4. Open the DataStudio program on the computer by double-clicking on the "RLC" file in the Intro I folder. Use the "Start" button at the top of the screen to begin taking data. You should see four sinusoidally-varying signals on the screen. One shows the input voltage

from the signal generator, while the other three show the voltage across the resistor, inductor, and capacitor. You may notice that the signals have some jitter – this is perfectly normal. You can freeze the data at any time by clicking on the “Stop” button, but don’t forget to click on the “Start” button when you want to take new data.

5. Once you have data on the screen you can adjust the frequency of the signal generator and observe how the different voltage signals are affected. The signal generator window is at the bottom of the screen, and enables you to adjust the shape, amplitude, and frequency of the wave. Initially, start with a sine wave with an amplitude of 5 V and a frequency of 100 Hz. You can type in a frequency by hand or you can use the + or - buttons under the frequency display to raise or lower the frequency, respectively. With this method the frequency changes according to the frequency step size, the number under the frequency display. You can change this step size (by a factor of 10) using the left or right arrows.

6. In this experiment you are essentially using the computer in place of an oscilloscope, and the controls you have available to you on the computer are similar to the controls you would have to work with on an oscilloscope. (Don’t worry if you’ve never used an oscilloscope – this experiment will give you the basic idea about how to use one.) Familiarize yourself with these controls. For instance:

- You can adjust the vertical scale of each channel separately by clicking on the appropriate up or down arrows to the right side of the display. Initially the 4 channels should have the same vertical scale (such as 1 V/division) but make sure you understand what effect changing the vertical scale has.

- You can also adjust the horizontal scale (showing the time) by clicking the arrows on the bottom of the screen.

Question 1: With the frequency set to 100 Hz, what is the amplitude of the resistor voltage? Make a prediction – to maximize the amplitude of the resistor voltage by changing only the frequency from the signal generator, will you need to increase or decrease the frequency? What are you basing your prediction on?

7. While taking data, adjust the frequency to determine the frequency that maximizes the resistor voltage. Hint: first use a step size of 100 Hz and find the maximizing frequency to the nearest 100 Hz, then change the step size to 10 Hz and find it to the nearest 10 Hz.

Question 2: The frequency at which the resistor voltage is maximized has a name – what is the name of this particular frequency? There is also an equation that predicts what this frequency should be. What is the equation, and does the frequency given by the equation match the frequency you found in step 7?

Question 3: Does anything else special happen at this particular frequency? Do you notice anything about the voltage across the inductor compared to the voltage across the capacitor at this frequency? If so, what? What about the phase relationship between the input voltage and the three output voltages?

Question 4: State one way of changing the circuit to double the resonance frequency.

Note: check with your instructor regarding which of the following parts you should do.

PART II – Observations with a coil as the inductor

Question 5: Make a prediction – what will happen to the amplitude of the voltage across the inductor when you increase the inductance of the inductor? What do you base your prediction on?

8. First, experiment with the inductance box. Observe what happens to the amplitude of the voltage across the inductor when you increase the inductance, and what happens when you decrease the inductance.

9. Now replace the decade inductor with a coil, preferably one of the 1600-turn coils. The coil has a particular inductance.

Question 6: Estimate (or calculate or take some measurements to help you find) the value of the coil's inductance. What method did you come up with to do this?

Question 7: Predict what, if anything, will happen when you place an iron or steel rod in the center of the coil while the coil is connected in the circuit. Hint: think about whether this should increase or decrease the coil's inductance.

10. Place an iron or steel rod in the center of the coil and observe what, if any, effect there is on the amplitude of the voltage signal across the inductor. Then remove the rod.

Question 8: What does this observation tell you about what happens to the inductance of a coil when an iron or steel rod is placed in the coil? Briefly explain why this happens.

Question 9: Predict what, if anything, will happen when a copper pipe (or aluminum rod) is placed in the center of the coil while the coil is connected in the circuit.

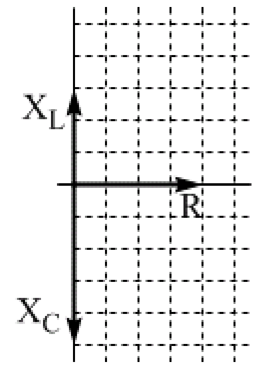
11. Now place a copper pipe (or aluminum rod) in the center of the coil. Once again observe what, if any, effect there is on the amplitude of the voltage signal across the inductor.

Question 10: What does this tell you about what happens to the inductance of a coil when a piece of copper or aluminum is placed in the coil? Briefly explain why this happens.

Question 11: The voltage across an ideal inductor should be 180˚ out of phase with the voltage across an ideal capacitor. In this experiment you should observe a phase other than 180˚ using the 1600-turn coil as the inductor – what would explain this?

PART III – Understanding the impedance triangle

When we wanted to understand a DC circuit with three resistors in series we would generally find the equivalent resistance of the circuit by simply adding the three resistance values together. The AC circuit we're using here, with three circuit elements in series, is somewhat similar. Again, it is helpful to find the equivalent resistance of the circuit – we call this the **impedance, Z**. Because of the phase relationship between the voltage and the current, however, we add the effective resistances of the different circuit elements *as vectors*.

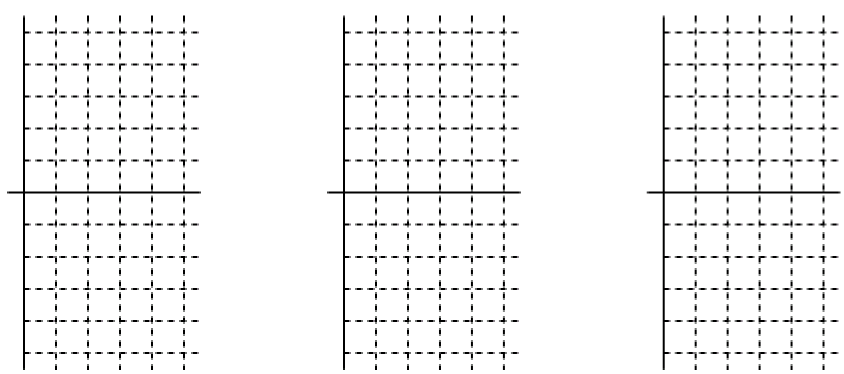


- The resistance goes on the x-axis: voltage and current are in phase for the resistor.
- The effective resistance of the inductor (the **inductive reactance** X_L) is drawn on the y-axis: voltage leads the current by 90˚ for the inductor.
- The effective resistance of the capacitor (the **capacitive reactance** X_C) is drawn on the negative y-axis: voltage lags the current by 90˚ for the capacitor.

Question 12: Add the three vectors shown above to find the impedance. The angle between the impedance and the resistance equals the phase angle between the voltage and the current in the circuit. Calculate what that angle is in the situation shown above. Does the voltage lead the current in this case or does the current lead the voltage?

Question 13: If you know the frequency and the inductance, how do you find the inductive reactance? If you know the frequency and the capacitance, how do you find the capacitive reactance?

12. Using the decade inductor, and not the 1600-turn coil, in the circuit, adjust the signal-generator frequency until you find the resonance frequency of the circuit (use the R, L, and C values from part I). Using the curves shown on the screen to help you, use the **middle graph below** to sketch, to scale, the impedance triangle corresponding to this situation.



$f = 0.5f_o$ $f = f_o$ $f = 2f_o$

Question 14: As you adjust the frequency, what do you look for on the screen to tell you that you have found the resonance frequency?

Question 15: A plot of the current as a function of time is not shown on the screen, but one of the voltage signals mirrors the current in (i.e., is in phase with) the circuit at all frequencies (not just at resonance). Which voltage signal mirrors the current?

Question 16: What does the impedance triangle tell you about how the phase of the input voltage (from the signal generator) compares to the phase of the current at resonance? Does this match what you observe on the screen?

13. Now set the frequency to half of the resonance frequency. Use the **left graph above** to sketch, to scale, the impedance triangle corresponding to this situation.

Question 17: What does the impedance triangle tell you about how the phase of the input voltage (from the signal generator) compares to the phase of the current at this frequency? Does this match what you observe on the screen?

Question 18: The maximum current in the circuit is given by $I_{\max} = \frac{V_{\max}}{Z}$**. Compare your first two impedance triangles to see how the impedance (Z) at this frequency compares to the impedance at the resonance frequency. How should the maximum currents at the two frequencies compare? Is this what you observe?**

14. Not set the frequency to twice the resonance frequency. Use the **right graph above** to sketch, to scale, the impedance triangle corresponding to this situation.

Question 19: What does the impedance triangle tell you about how the phase of the input voltage (from the signal generator) compares to the phase of the current at this frequency? Does this match what you observe on the screen?

Question 20: Now compare your three impedance triangles. At which frequency is the impedance least? At which frequency is the impedance greatest? How should the maximum currents at the three frequencies compare? Is this what you observe?

15. Sketch the impedance triangle that corresponds to a very low frequency.

Question 21: As the frequency decreases what should happen to the impedance? The maximum current? The phase between the voltage and current? Reduce the frequency in the circuit – do your observations correspond with what you stated should happen?

16. Sketch the impedance triangle that corresponds to a very high frequency.

Question 22: As the frequency increases what should happen to the impedance? The maximum current? The phase between the voltage and current? Increase the frequency – do your observations correspond with what you stated should happen? If you use a high frequency (over 1000 Hz, say) be warned that at high frequencies the computer cannot collect data fast enough to show the sine waves correctly.

PART IV – Half-power points

The half-power points are the frequencies at which the power dissipated in the circuit is exactly half of what it is at resonance. In this part of the experiment the goal is to find the half-power points for a particular circuit. At a half-power point the current is reduced by a factor of $\frac{\sqrt{2}}{2} = 0.707$ compared to its value at resonance.

Start with the following values:

- R = 200 Ω; L = 100 mH = 0.1 H; C = 1 μF = 1 x 10^{-6} F

17. For these settings determine the resonance frequency, and then the two frequencies that correspond to the half-power points.

    Theoretically, the *angular frequency* difference between the half-power points is given by:

$$\Delta\omega = \frac{R}{L}$$

Question 23: Comment on how well your experimental observations agree with the theoretical value for the frequency difference between the half-power points. Note that you control the frequency of the signal generator, while the equation relates to angular frequency.

18. Choose a different resistance (e.g., 1000 Ω) and repeat the process.

19. The sharpness of the curve of current vs. frequency is measured by the quality factor Q, which is the ratio of the resonance frequency to the width, in frequency units, between the half-power points. A high Q value is important for an RLC circuit used for tuning a radio, for instance. For our purposes we can use:

$$Q = \frac{L\omega_o}{R}$$

Question 24: Work out the quality factors for the two sets of R-L-C values you have used in this part of the experiment. To have a high Q, should the circuit have a large resistance or a small resistance?