

## ***Driven A.C. RLC Series Circuit***

Saddleback College Physics Department

**INSTRUCTOR'S NOTE:** This lab is written to take ~3 hours and will provide students with a great deal of practice analyzing driven A.C. RLC circuits.

### **Purpose:**

- (1) To examine a series RLC circuit and determine by how much the *voltage* across the *capacitor* and the *voltage* across the *inductor* lead, lag or are in phase with the *current* through the circuit, then compare these phase angles to their theoretical values.
- (2) To experimentally determine the resonance frequency of a driven alternating current RLC series circuit and compare it with the value calculated using  $\omega_0 = \frac{1}{\sqrt{LC}}$ .
- (3) To experimentally determine the phase constant,  $\phi$ , between the current and voltage of the signal generator then compare this value to that calculated using 
$$\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right).$$
- (4) To generate a graph of the current amplitude versus angular frequency and label the regions where the circuit behaves inductively and capacitively.

**\*\*NOTE:** *Since the voltage across the resistor in a driven series RLC circuit is always in phase with the current through the circuit, the plot of  $V_R$  vs. time will be used to represent the phase of the current through the circuit. UNLESS STATED OTHERWISE, for this experiment USE THE INDUCTOR WITHOUT the steel core in its center.*

### **Equipment:**

**RLC Circuit board** (PASCO Model CI-6512)

**Computer Interface System** (PASCO Series 6500)

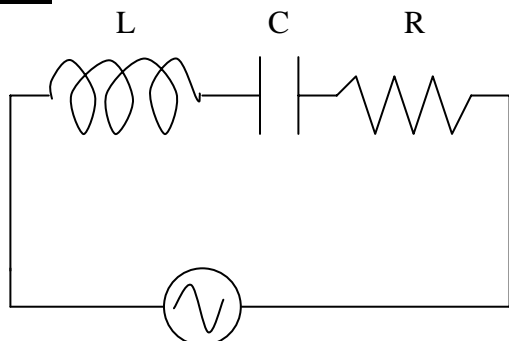
**PASCO Patch Cords** (PASCO Model SE-9750 or SE-9751)

[three, each has a red wire & a black wire connected together at one end]

**Regular Patch Cords** [two]

**Laptop Computer**

### **Schematic:**





### **Theory:**

In order to obtain the experimental phase constant(s) you will need the following ratio, where  $\delta$  represents the phase difference (between two curves) for a cycle with a period  $T$ . To calculate the phase constant  $\phi$  for a cycle with a period of  $2\pi$ , use the equation below.

$$\frac{\delta}{T} = \frac{\phi}{2\pi}$$

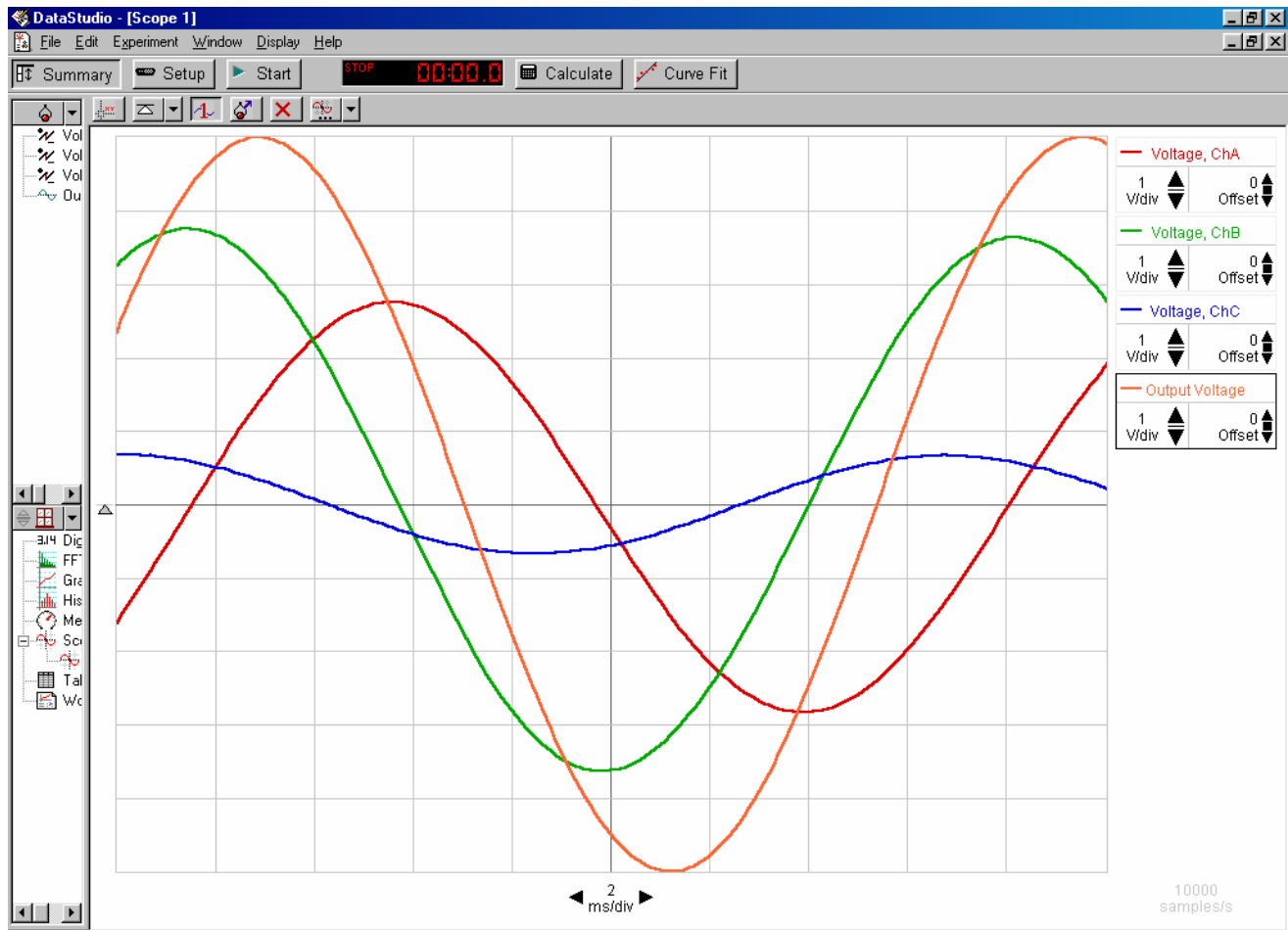
It is your job to come up with the remainder of the equations that should go in the theory.

### **Procedure:**

#### **COMPUTER SETUP**

- 1) With the computer OFF, connect the PASCO interface box to the computer via the SCZI card on the left side of the laptop, making sure that the metal side of the connecting piece is UP when you insert it into the SCZI card.
- 2) Plug the AC power cord into the interface box and plug the other end into the wall socket. Turn the interface ON using the switch on the backside.
- 3) NOW YOU MAY TURN ON YOUR LAPTOP COMPUTER and it should recognize and connect to the 750 Interface.
- 4) Obtain the PASCO RLC circuit board. Choose the R and C values you desire (it is recommended that you do not use the  $10\Omega$  resistor in your circuit).
- 5) Plug the PASCO patch cords into each of the analog channels, A, B and C of the 750 interface box.
- 6) Take the other end of the PASCO patch cords used in step 5 above and connect one set of them across the resistor, one set across the inductor and one set across the capacitor. These will measure the voltage across each component. MAKE certain that the red leads are placed at a higher electric potential than their corresponding black leads or the oscilloscope will display the wrong phase!
- 7) Plug two of the regular patch cords into the right side of the interface box that is labeled "output sockets." The interface box contains an internal signal generator or A.C. power supply, which you will use to drive your circuit.
- 8) Open the Data Studio Software (The short-cut icon should be on the desktop.)

- 9) Click on **Create Experiment**.
- 10) Click on **Experiment Setup** (near the top), unless the window is already open, and you should see a window with a list of sensors and a picture of the interface box. You are going to electronically connect the 3 voltage sensors with their corresponding channels. Click and hold on the *voltage sensor* icon then drag it to the desired channel of the interface box in the interface window. Click, hold and drag the *signal output* icon to the rightmost two holes of the interface box in the interface window.
- 11) Your instructor will walk you through how to adjust the frequency of the signal generator, open and adjust the graphs and begin recording data by using Data Studio as an oscilloscope.
- 12) A snapshot of the oscilloscope screen is shown below. In order of decreasing amplitude, the curves represent:
  - $\varepsilon$  (output voltage/orange/largest amplitude)
  - $V_R$  (voltage across resistor/green)
  - $V_C$  (voltage across capacitor/red)
  - $V_L$  (voltage across the inductor/blue/smallest amplitude)



- 13) What do you expect the phase angle to be between  $V_R$  and  $I$  in the circuit? If you need a hint, see \*\* in the purpose above.

- 14) What do you expect the phase angle to be between  $V_C$  and  $I$  in the circuit? Measure and record the experimental phase angle between  $V_C$  and  $I$  in the circuit. Compare the experimental and theoretical phase angles and in your conclusion, provide justification for any disagreement between them. Does the voltage lead or lag the current or neither?
- 15) What do you expect the phase angle to be between  $V_L$  and  $I$  in the circuit? Measure and record the experimental phase angle between  $V_L$  and  $I$  in the circuit. Compare the experimental and theoretical phase angles and in your conclusion, provide justification for any disagreement between them. Does the voltage lead or lag the current or neither?
- 16) When the circuit is in “resonance,” predict the phase constant  $\phi$  between  $\varepsilon$  and  $I$ , then test out your prediction using the apparatus and oscilloscope. Compare your experimental phase constant with the theoretical phase constant given by
- $$\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right).$$
- 17) Set the driving frequency well below resonance.
- 18) Measure the experimental phase constant. Compare this to the theoretical phase constant  $\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$ . Is the emf,  $\varepsilon$ , leading or lagging the current,  $I$ , in the circuit? How is the circuit behaving; inductively, capacitively or neither?
- 19) Now set the driving frequency well above resonance and repeat step 18.
- 20) Experimentally determine the resonance frequency of your circuit by varying the driving frequency of the signal generator to see when the current amplitude through the circuit is a MAXIMUM. Be sure to zoom-in on your graph as much as possible by changing the scale of the graph. Record the angular frequency at resonance, the amplitude of the output (signal generator) voltage, inductance and resistance in your lab book. Compare the experimental resonance angular frequency to the theoretical resonance frequency,  $\omega_o = \frac{1}{\sqrt{LC}}$ .
- 21) Do not change the amplitude of the output (signal generator) voltage from that of step 16. Record  $f$ ,  $\varepsilon$ ,  $L$ ,  $R$ ,  $C$  in an Excel spreadsheet for at least 7 different frequencies below resonance and 7 different frequencies above resonance. Repeat this process for frequencies above resonance. Use the spreadsheet to perform calculations of  $f$ ,  $\omega$ ,  $\varepsilon$ ,  $L$ ,  $R$ ,  $C$ , the impedance  $Z$ , and the current  $I$ , of the circuit. Using Excel, graph  $I$  (vertical axis) versus  $\omega$  (horizontal axis) and be sure to include the data points from resonance (step 21, above). In the plot of  $I$  vs.  $\omega$ , label where the circuit is behaving inductively, capacitively or neither.

Activities:

- 1) Observe self induced emf effects by using a digital ohmmeter across the inductor with no power supply and watch the ohm reading as you place the steel core into the center of the inductor and then do the same as you remove the steel core. Record what you observe and explain your reasoning for it.
- 3) You are to calculate the inductance,  $L_s$ , of the inductor **when the steel core is placed in the solenoid's center.** Depending on what data you record from the experiment, there are several different methods that can lead to the same answer. Make sure that at some point you try the following approach:
  - When the circuit is in resonance, take the appropriate measurements so that you can use  $\varepsilon = IZ$  to find the current, then substitute the current into  $V_L = IX_L$  and solve for your unknown inductance,  $L_s$  of the inductor when the steel core is in its center.

**Questions:** (Answer these while the apparatus is still set-up!)

- 1) Is the resonant frequency dependent on the resistance? NOTE: The equation given for the resonant frequency is an approximation. To see if the resistance makes a difference, set the scope to the resonant frequency and then replace the 100 ohm resistor with a 10 ohm resistor. Does the resonant frequency increase, decrease, or stay the same?
- 2) Is the plot of *current (amplitude) vs. angular frequency* symmetrical about the resonant frequency? Explain. Provide justification for why you labeled (in procedure #18 and #21) the circuit as behaving capacitively, inductively or neither at particular values of  $\omega$ .
- 3) What do you expect to happen to the inductance of the inductor when you place the steel core in its center? Why? Include the definition of inductance in your explanation.