Driven RLC Series Circuit

Saddleback College Physics Department

Purpose: To examine an A.C. (Alternating Current) series RLC circuit and

(1) experimentally determine the resonant frequency of an A.C. RLC series circuit and compare it with the theoretical value of $\omega_{\circ_{theor}} = \dfrac{1}{\sqrt{LC}}$.

(2) experimentally determine the phase constant, $\phi_{\exp}$, between the current, *I*, and voltage of the signal generator (ε), then compare it to the theoretical phase constant found from $\phi_{theor} = \tan^{-1}\left(\dfrac{X_L - X_C}{R}\right)$.

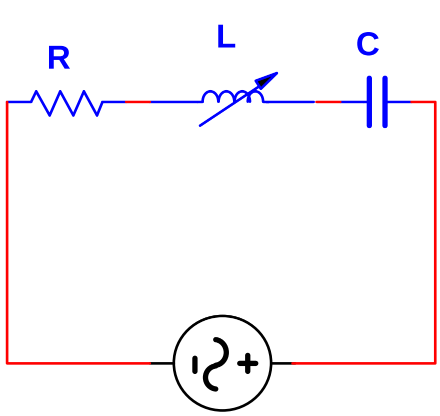
(3) determine by how much the *voltage* across the *capacitor*, the *inductor* and the *resistor*; lead, lag or are in phase with the *current* through the circuit, then compare these experimental phase differences, $\delta_{\exp}$ to the theoretical phase differences, δ_{theor}.

*****NOTE:** Since the voltage across the resistor, V_R, in a driven series RLC circuit is always in phase with the current through the circuit, I, 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 Model 750)
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
Ohmmeter

Apparatus:



Theory:

Let

ε = output voltage of signal generator (also the voltage drop across the combination of *R, L* & *C*)

V_R = voltage across the resistor

V_C = voltage across the capacitor

V_L = voltage across the inductor

I = current in the circuit

ω = angular frequency

f = linear frequency

T = period on oscilloscope curve

$\phi_{\exp}$ = the experimental phase constant between ε and ***I*** for the circuit (to be determined from the curves on the oscilloscope)

ϕ_{theor} = the theoretical phase constant between ε and ***I*** for the circuit

$\delta_{\exp}$ = experimental phase difference between either V_R, V_C or V_L and the current, ***I,*** through the circuit (to be determined from the curves on the oscilloscope)

δ_{theo} = theoretical phase difference between either V_R, V_C or V_L and the current, ***I,*** through the circuit.

Recall $\omega = 2\pi f$ and $f = \frac{1}{T}$.

Either one of the relationships seen below can be used to determine $\phi_{\exp}$.

$$\boxed{\frac{\Delta t}{T} = \frac{\phi_{\exp}}{2\pi}} \quad \text{OR} \quad \boxed{\phi_{\exp} = \omega \Delta t} \quad \text{eqn (1)}$$

Either one of the relationships seen below can be used to determine $\delta_{\exp}$.

$$\boxed{\frac{\Delta t}{T} = \frac{\delta_{\exp}}{2\pi}} \quad \text{OR} \quad \boxed{\delta_{\exp} = \omega \Delta t} \quad \text{eqn (2)}$$

The phase **constant**, $\phi_{\exp}$, and the phase **difference**, $\delta_{\exp}$, will be calculated from eqn (1) or eqn (2) above, using measurements of Δt (measured on the horizontal axis of the oscilloscope in seconds) taken between the 2 curves of interest as described in *Procedure, EXPERIMENT SET-UP, step 3*. Notice that $\delta_{\exp}$ and $\phi_{\exp}$ are measured in radians, since 2π is in radians.

It is your job to come up with the remainder of the equations & relationships that should go in the theory, based upon the lecture material and purpose.

Procedure:

COMPUTER SETUP

1) With the computer OFF, connect the PASCO interface box to the computer via the SCSI 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 SCSI 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**.

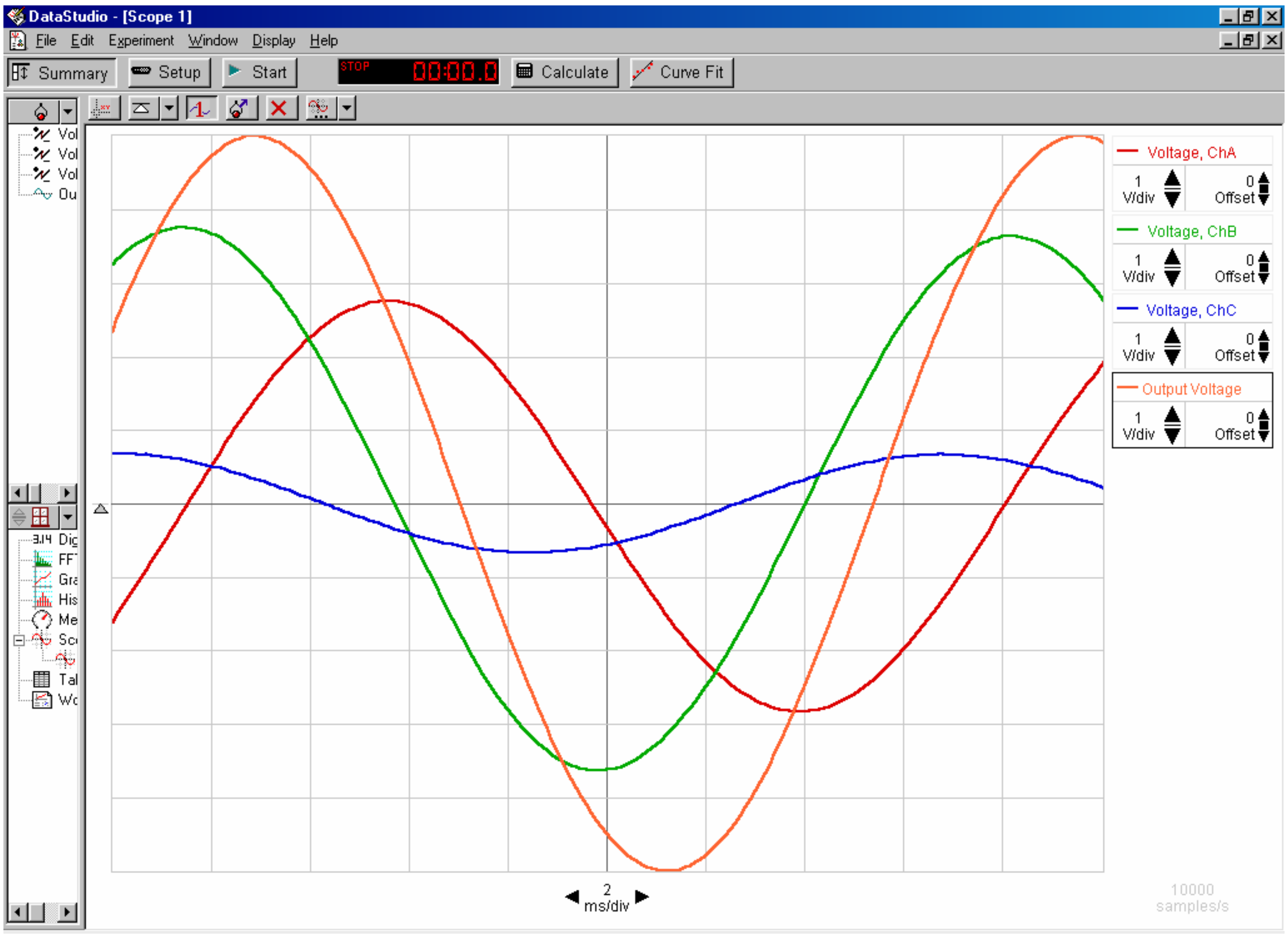
10) Click on **Experiment Setup** (near the top), unless the window is already open, and you should see a window with a list of sensors and a picture of the interface box. You are going to electronically connect the 3 voltage sensors with their corresponding channels. Click and hold on the *voltage sensor* 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.

EXPERIMENT SET-UP

1) Let your instructor know if you need help figuring out 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.

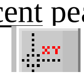
2) A snapshot of the oscilloscope screen is shown below. In order of decreasing amplitude, the curves represent:

ε (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)



3) An example of how to determine δ_{exp} (and ϕ_{exp} will be found similarly) between I and V_C is described below. Pattern all other determinations of δ_{exp} or ϕ_{exp} after this one.

a) Locate the sinusoidal curves on the oscilloscope corresponding to V_C and I.

b) The time interval, Δt, between any two adjacent peaks (or troughs, etc.) of the two curves must be determined. Use the  button on the oscilloscope to measure this time with higher precision. Record Δt and calculate δ_{exp} between I and V_C in the circuit, using eqn (2) [or eqn (1) if calculating ϕ_{exp}].

Procedure/Analysis: (Be sure you have completed "Questions" section at end of lab before disassembling your apparatus!)

1) What do you expect the phase difference δ_{theo} to be between V_R and I in the circuit? Write down your prediction and justify your answer, providing an equation if appropriate. If you need a hint, see ** in the purpose above. Does the voltage lead or lag the current, or neither?

2) What do you expect the phase difference δ_{theo} to be between V_C and I in the circuit? Determine the experimental phase difference between V_C and I in the circuit as described in "EXPERIMENT SET-UP" step 3. 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?

3) What do you expect the phase difference δ_{theo} to be between V_L and I in the circuit? Determine the experimental phase difference between V_L and I in the circuit as described in "EXPERIMENT SET-UP" step 3. 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?

4) Experimentally determine the resonance frequency of your circuit by trial and error, i.e. vary 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 following quantities: angular frequency at resonance, the amplitude of the output (signal generator) voltage, inductance in the circuit and resistance in the circuit. Compare the experimental resonance angular frequency to the theoretical resonance frequency, $\omega_{\circ_{theor}} = \dfrac{1}{\sqrt{LC}}$.

5) When the circuit is in "resonance," predict the phase constant $\phi_{\exp}$ between ε and I, then test out your prediction by determining the experimental phase constant from the oscilloscope plot as described in "EXPERIMENT SET-UP" step 3. Compare your experimental phase constant with the theoretical phase constant given by $\phi_{theor} = \tan^{-1}\left(\dfrac{X_L - X_C}{R}\right)$.

6) Set the driving frequency well below resonance.

7) Measure the experimental phase constant $\phi_{\exp}$ (See "EXPERIMENT SET-UP" step 3.) Compare this to the theorectical phase constant $\phi_{theor} = \tan^{-1}\left(\dfrac{X_L - X_C}{R}\right)$. Is the emf, ε, leading or lagging the current, I, in the circuit? How is the circuit behaving; inductively, capacitively or neither?

8) Now set the driving frequency well above resonance and repeat step 7.

9) Magnetize the steel core of the inductor by placing it inside the hole of the inductor while current is passing through the circuit. Despite the fluctuating B-field inside the inductor, when the steel core is removed it will most likely be magnetized in one direction or another. Now, observe self induced emf effects by using a digital ohmmeter across the inductor with no power supply (i.e. disconnect the signal generator which is in the interface box) and watch the ohm reading as you place the steel core (which must already be magnetized) 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.

10) Use the ohmmeter to determine the resistance of the inductor, record this resistance. Determine if your results for steps 5, 7 and 8 would be better if you had factored in the resistance of the inductor. Be sure to show a sample calculation and to discuss these results in your conclusion.

11) 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:

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) What do you expect will 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.

3) Measure the resistance of the coil/inductor. What effect does the resistance of the coil/inductor have on this experiment?