

**PHYS 2426**  
**Engineering Physics II**  
 (Revised July 7, 2011)

**AC CIRCUITS: RLC SERIES CIRCUIT**

**INTRODUCTION**

The objective of this experiment is to study the behavior of an RLC series circuit subject to an AC input voltage. The student will measure the circuit current, the voltages across the resistor and the generator. The phase angle that the generator voltage makes with respect to the electric current will also be measured. This will be done for several frequencies both above and below the resonance frequency. This lab features a high frequency and a low frequency approach. You will be told which one to do by your instructor.

**APPARATUS**

Pasco AC/DC Electronics Lab	Banana plug cables (8)
Function Generator	Coax to Banana (male) transitions (3)
Oscilloscope	Coaxial cables (3)
Inductance / Capacitance meter	• Function Generator - 1 cable
Digital Multimeter (2)	• Oscilloscope - 2 cables

	<b>HIGH Frequency</b>	<b>LOW Frequency</b>	<b>LOW Frequency</b>
	<b>North Ridge</b>	<b>Cypress</b>	<b>Rio Grande</b>
Capacitor	<b>C = 20nF</b>	<b>C = 2μF</b>	<b>C = 1.91μF</b>
Inductor Coil	<b>L = 8.2 mH; R<sub>L</sub> = 5.5Ω</b>	<b>L = 8.2 mH; R<sub>L</sub> = 5.5Ω</b>	<b>L = 14.9 mH; R<sub>L</sub> = 31.5Ω</b>
Resistance Box	<b>R = 50 Ω</b>	<b>R = 10 Ω</b>	<b>R = 10 Ω</b>
Q-Factor	11.0	4.1	2.1

**EQUIPMENT PROCEDURE**

**Notation**

The references to  $V_{meas}$  and  $I_{meas}$  are general. The specifics are shown below.

<b>HIGH Frequency</b>	<b>LOW Frequency</b>
All voltages ( $V_p$ ) and currents ( $I_p$ ) are assumed to be peak values unless otherwise indicated.	The digital multimeters read average rectified values. $V_{avg} = 0.637 V_p$ . All voltages are assumed to be average values unless otherwise indicated.

**Components**

The components for this lab need to be selected specifically for this experiment. The three components consist of an inductor coil, a capacitor and a decade resistance box. These values have been chosen so that the resonant frequency of the series RLC circuit will be about **12,000 Hz** in the HIGH frequency version and **1100 Hz** in the LOW

frequency version. The circuit component values have been specifically chosen to enhance the resonance effect on the peaking of the current and to make it easier to measure the phase angle and to avoid certain equipment limitations.

### Setting Up The Circuit

Connect the circuit as shown in Figure 1., with the exception that you will not be using an ammeter in either frequency approach. If the physical layout of the circuit elements matches the schematic diagram, as closely as possible, it will be easier to understand what is going on during this experiment. See APPENDIX 1 for details of setting up the PASCO AC/DC Electronics Lab circuit board..

### Polarity

The point of the circuit where the resistor connects to the Function Generator (point “b” (GND)) will be considered the common ground connection for this experiment. Each coaxial cable that you will be using will utilize a Coax to Banana Plug Transition. There are two banana plug connectors on each transition. The side of the banana plug connector that is electrically connected to the coax ground shield will have a raised plastic tab with the letters GND embossed on it. Make sure you are consistent with the polarity shown in the circuit schematic when wiring your circuit.

### Function Generator

Set the Function generator to the Sine Wave mode. Select the correct frequency range. Maintain this voltage ( $V_g$ ) constant throughout the lab. You may have to adjust the voltage, to keep it constant, each time the frequency is changed.

HIGH Frequency	LOW Frequency
HIGH frequency: 12kHz Set the amplitude (peak voltage) of the generator Voltage ( $V_g$ ) to 2.0 V.	LOW frequency: 1100Hz Set the amplitude (average voltage) of the generator Voltage ( $V_g$ ) to 2.0 V. As read on the digital multimeter.

### The Oscilloscope

We will be using both Channel 1 and Channel 2 on the oscilloscope. Channel 1 will measure the voltage across the resistor ( $V_R$ ) in your circuit. Channel 2 will measure the input voltage from the Function Generator,  $V_g$ , (point “a”). The oscilloscope will be triggered by the signal on Channel 1. Under the “Trigger Menu” make sure the selected Trigger Source is Channel 1.

### Circuit Current $I_{meas}$

HIGH Frequency	LOW Frequency
The signal on Channel 1 ( $V_R$ ) will be used to determine the circuit current ( $I_{meas}$ ). $I = V_R/R = V_R(p-p)/(2*R) = V_R(p-p)/(2*50) = V_R(p-p)/100$ This is due to our choice of $R = 50$ ohms. In effect you	A digital multimeter will read the voltage across the decade resistance box ( $10 \Omega$ ). $I_{meas} = V_R/10$

only need to move the decimal two places to the left in $V_R(p-p)$ to get the value of the current $I_{meas}$	
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## EXPERIMENTAL PROCEDURE

### Component Measurements and Calculations

1. Use the inductance meter to measure the inductance of the coil ( $L$ ) and record the value in your Data Table.
2. Use the capacitance meter to measure the capacitance of the capacitor ( $C$ ) and record the value in your Data Table.
3. Use the Ohm scale of your multimeter to measure the resistance of the inductor coil ( $R_L$ ) and the resistance setting of the decade resistor box ( $R$ ) in your circuit. Record these resistance values in your Data Table. **Note:** When you do the calculations below these two resistance values will be added together and used as a single resistance value.
4. Calculate the resonance frequency of the circuit.

$$\omega_{res} = 1/\sqrt{LC}$$

$$f_{res} = \omega_{res}/(2\pi)$$

5. Calculate the circuit parameters:  $X_L$ ,  $X_C$ ,  $Z$ ,  $I_{calc}$  and  $\Theta$ ; for seven different frequencies. The spacing of these frequencies are in increments of approximately 10% of  $f_{res}$ . Three of these frequencies should be below the resonance frequency and three should be above the resonance frequency.

You will be taking quite a few measurements during this lab and it is a very good idea to check your measured values against your calculated values to make sure that if a mistake is made and an erroneous measurement results it can be corrected and not repeated for all of the other frequencies.

### Experimental Measurements

HIGH Frequency	LOW Frequency
All Oscilloscope measurements will be peak-peak. These will need to be divided by 2 to get the peak values that we want.	All voltages are measured with the digital multimeters are average rectified values unless otherwise indicated.

### Set Up Check

With the circuit assembled, function generator and oscilloscope connected and turned on you should have  $V_R$  on Channel 1 and  $V_g$  on Channel 2. Set the frequency of the function generator to your resonance frequency. This should give you the maximum value for  $V_R$  (and the circuit current  $I_{meas}$ ). As you adjust the frequency both above and below

resonance the  $V_R$  value should decrease in both directions and the  $V_g$  display should shift LEFT and RIGHT relative to  $V_R$ .

To establish a measurement pattern follow this sequence: (1) Set the frequency, (2) Adjust  $V_g$ , if necessary, (3) Measure  $V_g$ , (4) Measure  $V_R$ , (5) Measure  $I_{meas}$ .

HIGH Frequency	LOW Frequency
6.) Using Channel 2, measure the generator voltage $V_g$ , ( <b>point “a”</b> ). Enter the value into your Data Table. Determine the value of the current $I_{meas}$ , from the $V_R$ signal on Channel 1. Enter the value in your Data Table. The largest value of the current should occur at the resonance frequency.	6.) Using digital multimeter, measure the generator voltage $V_g$ , ( <b>point “a”</b> ). Enter the value into your Data Table. Determine the value of the current $I_{meas}$ , from the $V_R$ signal across the decade resistance box divided by $10\Omega$ . Enter the value in your Data Table. The largest value of the current should occur at the resonance frequency.
7.) Calculate the experimental value of the impedance $Z_{exp} = V_g/I_{meas}$ . Keep an eye on the theoretical impedance values that you have already calculated. The experimental values of the impedance should be reasonably close.	

Repeat steps (6) and (7) for the other six frequencies. Remember to keep the generator voltage ( $V_g$ ) constant.

Don't measure the phase angle until ALL the voltage and current measurements are complete.

### Phase Angle - Both HIGH frequency and LOW frequency

The phase angle will change with frequency. At resonance the phase angle is zero and therefore it will be difficult to measure this angle at frequencies that are very close to resonance. Above resonance the impedance is more **inductive** than capacitive and the Current will **LAG** the Voltage. Below resonance the impedance is more **capacitive** than inductive and the Current will **LEAD** the Voltage. You will be measuring this phase angle using the phase shift between  $V_R$  and  $V_g$  as displayed on the oscilloscope.

### Set Up Check

With  $V_R$  on Channel 1 and  $V_g$  on Channel 2, shift the position of the Channel 2 waveform upward on the display so that it slightly overlaps the Channel 1 waveform, but not so close that you cannot distinguish the two different waveforms from each other. Set the Function Generator to the resonance frequency. The peaks of the two waveforms on the oscilloscope should line up vertically. As the frequency is changed above and below the resonance frequency, the  $V_g$  waveform (Channel 2) will shift LEFT or RIGHT relative to the  $V_R$  waveform (Channel 1).

If the frequency is decreased below the resonance frequency  $V_g$  will LAG  $V_R$ . On the oscilloscope the  $V_g$  waveform (Channel 2) should move to the RIGHT relative to the stationary  $V_R$  waveform (Channel 1). These phase angles are NEGATIVE.

If the frequency is increased above the resonance frequency,  $V_g$  will LEAD  $V_R$ . On the oscilloscope the  $V_g$  waveform (Channel 2) should move to the LEFT relative to the stationary  $V_R$  waveform (Channel 1). These phase angles are POSITIVE.

### **Phase Angle Measurement Procedure**

If the  $V_g$  waveform (Channel 2) shifted in the correct directions during the Set Up Check, when you changed the frequency, then you are ready to start taking phase angle measurements. If you did not observe the correct circuit behavior consult with your instructor.

Determine the horizontal distance, in time units, between the peaks in the  $V_g$  waveform (Channel 2) and the  $V_R$  waveform (Channel 1). The large block of 5 tick marks is called a square. The time scale at the bottom of the oscilloscope screen shows the time value of one of these squares. Say it is  $10\mu\text{s}$ . Then each tick mark is worth  $2.0\mu\text{s}$ . If the distance between the two waveform peaks is 6.0 ticks, then this distance represents  $6.0 \times 2.0\mu\text{s}$  or  $12\mu\text{s}$ . To turn this into radians multiply by the angular frequency  $\omega$ . If  $f = 20.0\text{kHz}$  then  $\omega = 1.25\text{E}+03 \text{ rad/s}$ . The  $12\mu\text{s}$  time interval when multiplied by  $\omega$  becomes 1.50 radians. There are 3.14 radians in  $180^\circ$ . Therefore the  $12\mu\text{s}$  time difference represents a phase shift of  $86.0^\circ$ .

For each of your frequencies, on both sides of the resonant frequency, measure the phase angles in time units and record them in your Data Table. Calculate the phase angles in degrees and record them in your Data Table.

## ANALYSIS

1. For all the frequencies, using the measured values of the current,  $I_{\text{meas}}$ , calculate the voltages across each of the three components.  $V_R = I_{\text{meas}}R$ ,  $V_L = I_{\text{meas}}X_L$ ,  $V_C = I_{\text{meas}}X_C$ . Also calculate the generator voltage  $V_g = \text{SQRT}(V_R^2 + (V_L - V_C)^2)$ . Enter your values in the Data Table. Remember that the value of  $R$  used above includes the coil resistance  $R_L$ .
2. Calculate the % difference for the calculated and measured values of  $V_g$  and  $Z$  and enter the results in your Data Table.
3. Calculate the % difference between the calculated and the experimental values of the phase angles and enter the results in your Data Table.
4. For three frequencies, the smallest, largest and the resonance frequency, draw vector diagrams using the calculated voltages. These diagrams must be drawn to scale. Pick an appropriate length scale to represent the voltages. Use a protractor to measure the phase angle from these diagrams. Are the results of these vector diagrams in agreement with the measured values?
5. On a second graph, plot the theoretical values of  $X_L$ ,  $X_C$  and the experimental value of  $Z_{\text{exp}}$  on the vertical axis and the frequency on the horizontal axis. Mark the location of the resonance frequency on this graph.
6. On a third graph, plot the experimental current  $I_{\text{meas}}$  and the theoretical current  $I_{\text{calc}}$  on the vertical axis and the frequency on the horizontal axis. Mark the location of the resonance frequency on this graph.
7. On a fourth graph, plot the experimental and theoretical values of the phase angle as a function of frequency. Mark the location of the resonance frequency on this graph.

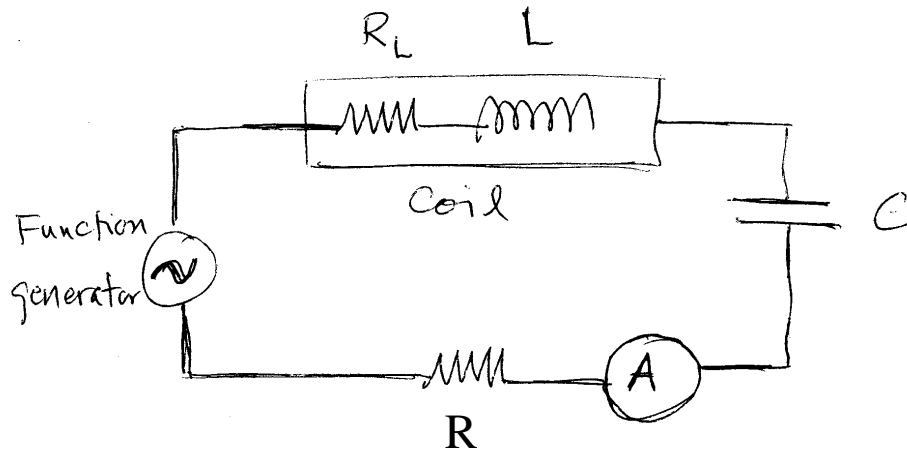


Fig. (1)

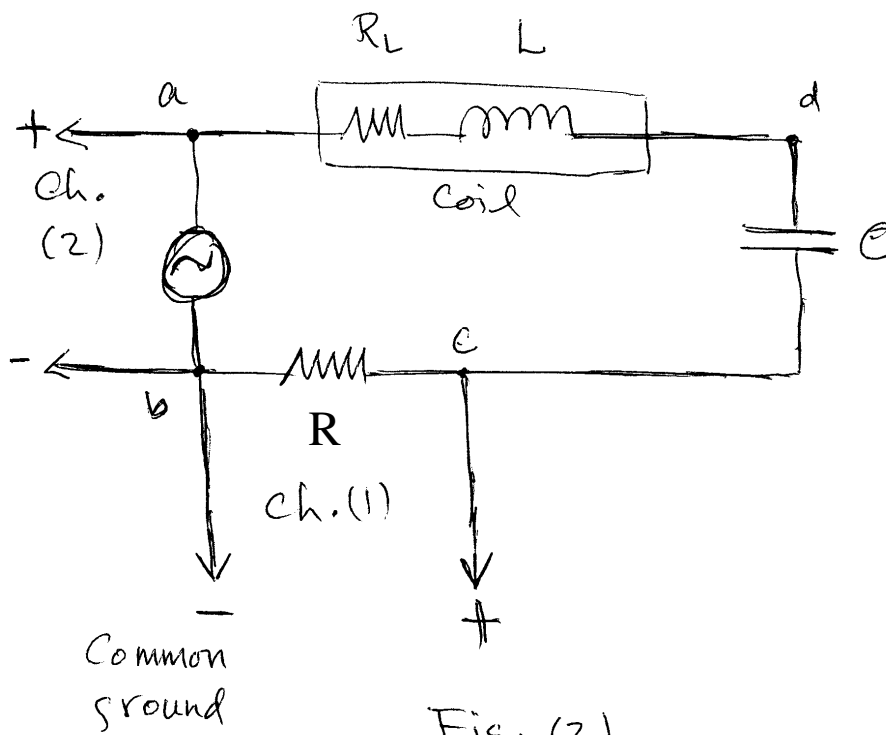


Fig. (2)

**Data Table**

Name	Value	Name	Value
Inductance L (H)		Resonant Freq $\omega_0$ (Rad/sec)	
Coil Resistance $R_L$ ( $\Omega$ )		Resonant Freq. $f_0$ (Hz)	
Capacitance C (F)		Generator Voltage $V_g$ (V)	
Resistance R ( $\Omega$ )			

**Calculated Theoretical Values**

Freq (Hz)	Angular Freq (Rad/sec)	$X_L$ ( $\Omega$ )	$X_C$ ( $\Omega$ )	$Z_{calc}$ ( $\Omega$ )	$I_{calc}$ (A) = $V_g / Z_{calc}$	$\Theta_{calc}$ (degrees)
$f_0$						

**Experimental Values**

Freq (Hz)	Angular Freq (Rad/sec)	$V_g$ (V) (Adjust to keep constant)	$V_R$ (V)	$I_{meas}$ (A)	$Z_{exp}$ ( $\Omega$ ) = $V_g / I_{meas}$	$\Theta_{exp}$ ( $\mu$ s)	$\Theta_{exp}$ (degrees)	$\Theta_{calc} - \Theta_{exp}$ (degrees) % Diff
$f_0$								

**Measured Value Calculations (Using measured  $I_{meas}$ )**

Freq (Hz)	Angular Freq (Rad/sec)	$V_R$ (V)	$V_L$ (V)	$V_C$ (V)	$V_g$ (V)	$V_g$ (V) %Diff	$Z_{calc} - Z_{exp}$ % Diff
$f_0$							



## APPENDIX 1 - Setting Up The Circuit. (Pasco AC/DC Electronics Laboratory)

### 1. Components

Place the components on the prototype board with the input voltage plugs oriented in the upper left hand corner - batteries on the right (See Figure 3.). Lay the components out to resemble the schematic diagram, (see Figure 2.).

### 2. Input Voltage

Using the coax cable, the transition (coax to banana plug) and two banana plug wires connect the OUTPUT of the Function Generator to the input plugs on the prototype board. Use red for the positive connections and place the positive plug at points “a” and the negative connection at point “b” (GND). Point “b” is the common ground connection for all signals.

### 3. Trigger Signal

Use the “Trigger Menu” to ensure that Ch 1 has been selected as the Trigger Source.

### 4. Channel 1

Using a coax cable, a transition (coax to banana plug) and two banana plug wires connect the Ch 1 input on the oscilloscope to points “b” (GND) and “c” on the prototype board. Watch the polarity. For the connection at point “c” it will be easier if you put one of the alligator clips over the banana plug.

### 5. Channel 2

Using a coax cable, a transition (coax to banana plug) and two banana plug wires connect the Ch 2 input on the oscilloscope between points “a” and “b” (GND) on the prototype board. For the connection at point “a” it will be easier if you put one of the alligator clips over the banana plug.

### 6. Current Measurement

HIGH Frequency	LOW Frequency
The Channel 1 voltage $V_R$ will be used to determine the circuit current $I_{meas}$ .	The current $I_{meas}$ , will be determined from the measured $V_R$ signal across the decade resistance box divided by $10\Omega$ .

### 7. Power Up

Turn on the Oscilloscope and the Function Generator. On the upper right hand corner of the oscilloscope press the “Auto Set Up” button. [Only on the Tektronix scopes]. Two sine waves should be displayed on the screen of the oscilloscope. Ch 1 ( $V_R$ ) should be on the top and below it is Ch 2 ( $V_g$ ). Press the “Ch1 Menu” button and ensure that the Probe signal is at “1X.” Perform a similar check on Ch 2. Note: The signal frequency is shown in the lower right hand corner of the display, if you have a digital oscilloscope. Follow the remaining steps in the Equipment Procedure section.

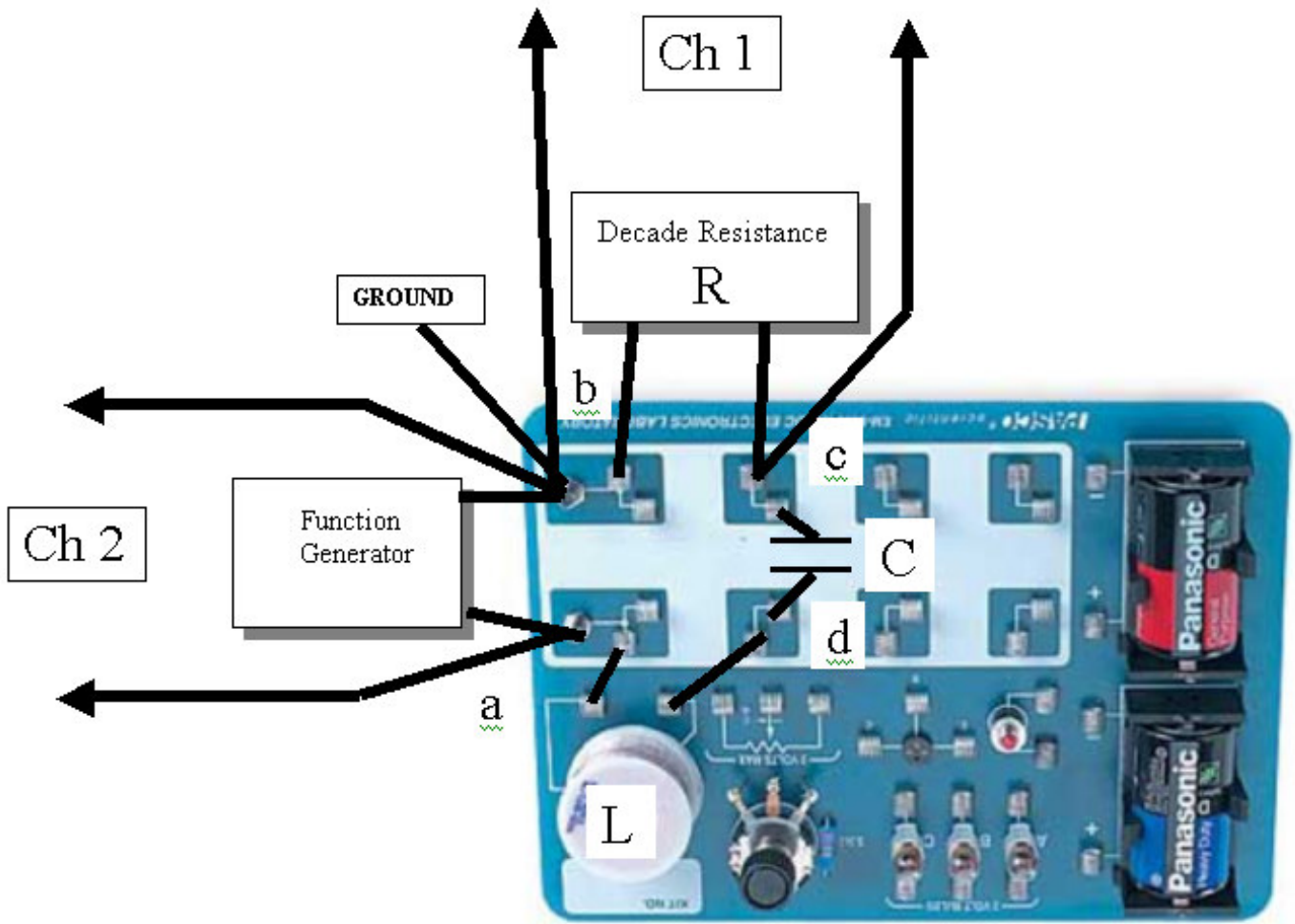


Figure 3. The RLC Series circuit setup on the PASCO AC/DC Electronics Lab