# Lab 7: AC Circuits

Experiment for Physics 212 Lab at CSUF

What You Need To Know:

The Physics

All of the circuit labs you've been dealing with in this lab course have been using *direct current* or DC. DC implies that the current has a constant value and it flows in only one direction through a circuit. In today's lab we will be using *alternating current* or AC. AC implies that the current has a value that is constantly changing, like a sine wave. See *Figure 1*. The current flows both forwards and backwards through a circuit. Associated with any wave is a frequency. The frequency, *f*, is the number of cycles that occur per second. Shown in *Figure 1* is one complete cycle of current.

Figure 1 - Current vs. Time graph
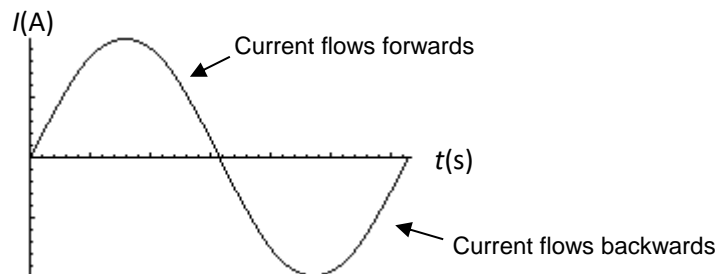
You should be familiar with the following circuit elements: power sources, resistors, and capacitors. Today you will learn about a new circuit element called an *inductor*. An inductor is basically a small coil of wire that is very much like the solenoid you worked with in the lab Magnetic Fields. An inductor's job, like a capacitor, is to store energy. However, while a capacitor stores energy in the form of an electric field between its plates, an inductor stores its energy in the form of a magnetic field inside the coil.

Compared to DC circuits, inductors and capacitors act differently in AC circuits. For today's lab you will be mainly dealing with only one of these differences. When capacitors and inductors are in an AC circuit they act like they have a resistance. For a capacitor this "resistance" is called a *capacitive reactance*. The capacitive reactance is defined by the following equation 1...

$$X_C = \frac{1}{2\pi f C}$$

X_C is the capacitive reactance (in ohms, Ω)

f is the frequency (in hertz, Hz)

C is the capacitance (in farads, F)

Equation 1 – Capacitive Reactance

Since X_C acts as a resistance, you can use a form of Ohm's Law to find the voltage across the capacitor …

$$V_C = IX_C$$

V_C is the voltage across the capacitor (in volts, V)	*Equation 2 – Ohm's Law with Capacitor*
I is the apparent current through the capacitor (in amps, A)	
X_C is the capacitive reactance (in ohms, Ω)	

An inductor's resistance in an AC Circuit is called an *inductive reactance*. The inductive reactance is defined by the following equation 3 …

$$X_L = 2\pi f L$$

X_L is the inductive reactance (in ohms, Ω)	*Equation 3 – Inductive Reactance*
f is the frequency (in hertz, Hz)	
L is the inductance (in henrys, H)	

Since X_L acts as a resistance, you can use a form of Ohm's Law to find the voltage across the inductor …

$$V_L = IX_L$$

V_L is the voltage across the inductor (in volts, V)	*Equation 4 – Ohm's Law with Inductor*
I is the current through the inductor (in amps, A)	
X_L is the inductive reactance (in ohms, Ω)	

In DC circuits, you used Kirchhoff's Loop Law to analyze circuits. This will not work for AC circuits because the current and voltage for capacitors and inductors are out of phase. Instead, you will use the following equation 5 …

$$V_S = \sqrt{V_R^2 + (V_L - V_C)^2}$$

V_S is the voltage across the source (in volts, V)	*Equation 5 – AC Voltage*
V_R is the voltage across the resistor (in volts, V)	
V_L is the voltage across the inductor (in volts, V)	
V_C is the voltage across the capacitor (in volts, V)	

There is one more idea that you need to be introduced to before you begin the lab. At a very specific frequency of current, the capacitive reactance will be equal to the inductive reactance, **$X_C = X_L$**. This frequency is called the resonance frequency. This idea will be discussed more thoroughly while you do the last part of the lab.

The main idea of this lab is basically the same as in the Series and Parallel Resistors lab. You are going to use all the above information to analyze an AC Circuit and then compare a calculated final value to the known value.

The Equipment

You will be using a new piece of equipment for the lab today. It is called a function generator. This will serve as your AC voltage source for your circuit. Your TA will demonstrate how to use this device.

What You Need To Do:

The Setup

The circuit should already be hooked up for you. If not, then just take two cables and have them go from the power supply to the circuit board. Hook them up so they are across the resistor-capacitor circuit (the top line). The other two cables should come from the voltmeter and have alligator clips on the ends.

Turn on the function generator. Make sure the 10k button is pressed in the Range area. See *Figure 2*. Also make sure that the "sine wave" button is pressed in the Function area. Next, turn on the voltmeter and set it for ACV in the 2V range.
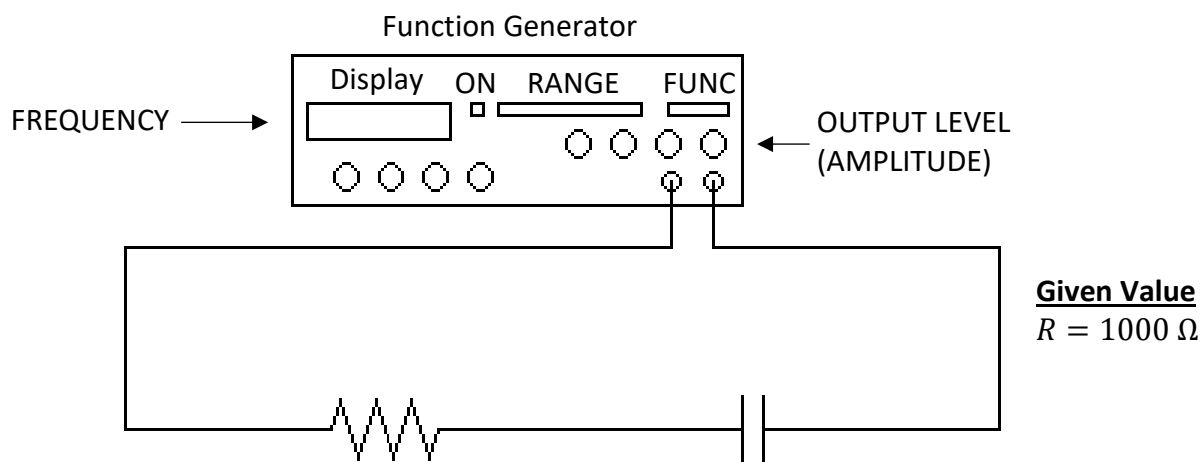

Given Value
$R = 1000 \ \Omega$

Figure 2 – Series Resistor-Capacitor Circuit

Part 1 – RC Circuit

The first circuit you will analyze is a series resistor-capacitor circuit. See *Figure 2*. The end result of analyzing this circuit is to calculate the value of the capacitor and then compare it to the real value.

Table 1 – Part 1 Data

f	$\dfrac{1}{f}$	V_S Measured	V_S Calculated	V_R	I	V_C	X_C	C
1000								
1300								
2000								
4000								
5000								

    A) Make a copy of *Table 1* in your lab report.

B) Using the frequency knobs on the function generator, set the frequency on the function generator to 1000 Hz. You can get a rough number using the COARSE knob and then fine-tune the frequency using the FINE knob.

C) Hook up the leads from the voltmeter so that the voltmeter will read the voltage across the function generator, V_S. Adjust the amplitude (OUTPUT LEVEL knob) of the function generator so that you get a reading on the voltmeter that is somewhere between 1.900 V and 1.999 V. Record this in the table as Voltage Source Measured.

D) Using the leads from the voltmeter, measure the voltage across the resistor, V_R, and measure the voltage across the capacitor, V_C. Record both of these values in the table.

E) Repeat this procedure for the following frequencies: 1300, 2000, 4000, and   5000 Hz. Place all these values in the table.

NOTE: Every time you change the frequency you will have to re-adjust the function generator so that the voltage is somewhere between 1.900 V and 1.999 V. In other words, you need to re-check VS with the voltmeter each time you change the frequency.

F) It was stated earlier that we couldn't use the Loop Law because the circuit elements are out of phase. For the 1000 Hz trial, try to apply the Loop Law to see if it works. Show your work.

G) Using the Equation 5 given in the introduction of this lab, calculate V_S. Do this for each frequency in the table. Show one sample calculation.

NOTE: There is no inductor in the circuit so VL = 0. How do these values compare to the measured values?

H) It will be left up to you to calculate the remaining values in the table. (For the **1/f** column, make sure you calculate a decimal.) Use the equations from the introduction and resistor Ohm's law.

HINT: You will also need the given resistor value (Given in).

   a. First find the current, then X_C (eq 2), and lastly the capacitance (eq 1).

   b. Show one sample calculation for each column.

NOTE: Do at least one set of calculations to get C for a single row before you move on. This is to ensure that you took your data correctly.

I) **I)** Calculate the average value of the capacitance. Also, compare the average value to the real value (2.2×10^{-8} F) by calculating a percent error. If your percent error is over 15% then you made an error somewhere. It is up to you to go back to find and correct the error.

J) **J)** Now you are going to use the **Graphical Analysis** software on the computer desktop to make a graph of X_C vs. **1/f** . On the computer screen you should see two columns labeled X and Y.

From your table, you are going to plug the **1/f** values (in decimal) into the X column and the **X_C** values into the Y column.

K) **K)** Once you have plotted all of your data push the "R=" button to find the slope. Using this value and the following equation, calculate the capacitance, **C**. Calculate a percent error with this **C** value against the average **C** value you calculated from *Table 1*.

$$m = \frac{1}{2\pi C}$$

| m is the slope value from the computer

| C is the capacitance

Equation 6 – Slope Capacitance

Question 1

Why is the above equation 6 true?

HINT: Refer back to the RC Circuits lab. In it you used a certain method to find a slope.

Part 2 – RL Circuit

This part of the lab is very similar to the last part, except now you have a resistor in series with an inductor. See *Figure 3*. The end result of analyzing this circuit is to calculate the value of the inductance and then compare it to the given value.
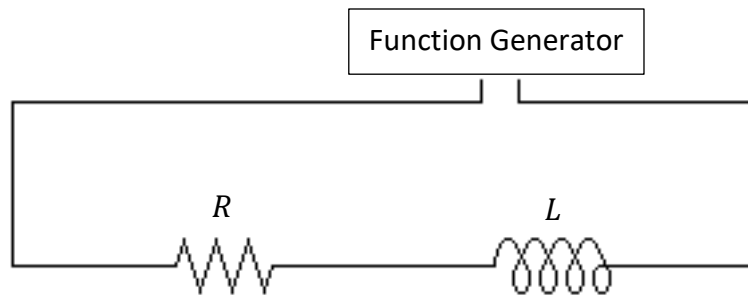
Given Value
$R = 1000\ \Omega$

Figure 3- Series Resistor-Inductor Circuit

A) Make a copy of _Table 2_ in your lab report.

Table 2 – Part 2 Data

f	V_S Measured	V_R	I	V_L	X_L	L
2000						
3000						
4000						
5000						
6000						

B) Turn off the function generator. On the circuit board, remove the wire from the side socket and place it in the next socket down. This is the RL circuit. Turn the function generator back on.

C) Use the voltmeter to find all the voltages in the table for the frequencies shown (the frequencies are slightly different from the previous part). Keep in mind the following …

   a. **When measuring the voltage across the inductor, attach the alligator clips only to the tall curly-ended pieces of wire on either side of the inductor. If you do not do this you could damage the inductor.**

   b. **Make sure that you re-set the amplitude of the voltage source every time you change the frequency.**

D) It will be left up to you to calculate the remaining values in the table.

   a. Use the same method you used in **Part 1H**.

   b. First find the current, then X_L, and lastly the inductance.

   c. Show one sample calculation for each column.

NOTE: Do at least one set of calculations to get L for a single row before you move on.

E) Calculate the average value of the inductance. The real value of the inductor is 75 mH (milli-Henri's). Also, compare the average value to the real value by calculating a percent error. If your percent error is over 15% then you made an error somewhere. It is up to you to go back to find and correct the error.

Part 3 – RLC Circuit and Resonance

It was stated earlier that resonance occurs in a circuit when $X_C = X_L$. This would imply that $V_C = V_L$ since the current for the capacitor and inductor are the same. If the voltages are equal then the $V_L - V_C$ part of the V_S equation will be zero, or at least close to zero. This corresponds to the voltage across both the capacitor and the inductor. You will use this fact to measure the resonance frequency of the circuit.
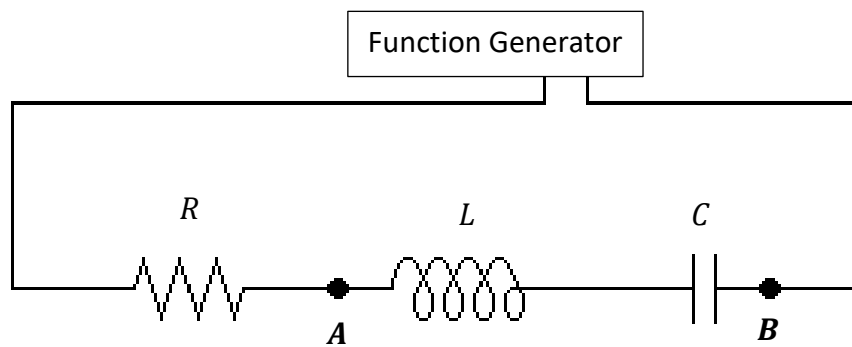

Given Value
$R = 1000\ \Omega$
$L = 75\ mH$
$C = 2.2 \times 10^{-8}\ F$

Figure 4- Series Resistor-Inductor-Capacitor Circuit

A) Make a copy of *Table 3* in your lab report.

Table 3 – Part 3 Data

f	V_{LC}
1000	
...	

B) Turn off the function generator. On the circuit board, remove the wire from the side socket and place it in the next socket down so that it corresponds with the circuit in *Figure 4*. Turn the function generator back on.

C) Open up **Graphical Analysis or Excel** from the desktop of your computer. You are going to use **Graphical Analysis or Excel** to make a graph of Voltage (across L-C) vs. Frequency. Keep a record of your data on your paper in *Table 3* and also enter the data into the computer as you go.

D) Set the function generator to 1000 Hz and adjust the amplitude of output, **V_S**, so that 1 V (as measured by the voltmeter) is being supplied to the circuit.

E) Now place the leads from the voltmeter so that they measure the voltage across BOTH the capacitor and the inductor, **V_LC**. See *Figure 4* at points A and B. Enter this value into your table and on the computer. The frequency will be X and Voltage will be Y.

F) Continue taking data using other frequencies. Change your data by using increments of 1000 Hz:

Note: Every time you change the frequency make sure that VS is still 1V before you measure VLC.

    a. Record your values in your table and also plot them on the computer as you go. You will get a relatively straight horizontal line at first but it will soon change drastically. When this happens, change the increments to 300 Hz.

    b. You can use increments of 1000 Hz after the graph levels off again.

    c. Continue taking data until you reach 10,000 Hz.

G) When you are finished, make a sketch of the graph on your paper. It does not have to be exact, just free-hand sketch it. Label on your graph at what point the circuit is in resonance. Record the resonance frequency.

Question 2

How do you know from the graph when the circuit is in resonance?

H) Calculate the resonance frequency using the following equation 7…

$$f_R = \frac{1}{2\pi\sqrt{LC}}$$

| f_R is the resonance frequency (in hertz, Hz)
| L is the calculated inductance from Part 2 (in henrys, H)
| C is the calculated capacitance from Part 1 (in farads, F)

Equation 7 – Resonant Frequency

I) Compare the calculated resonance frequency to the one you recorded from the graph by calculating a percent error.

What You Need To Turn In:

Make sure that all calculations are done in the sections which ask for them. There are no graphs to turn in except for the sketch in **Part 3G**.