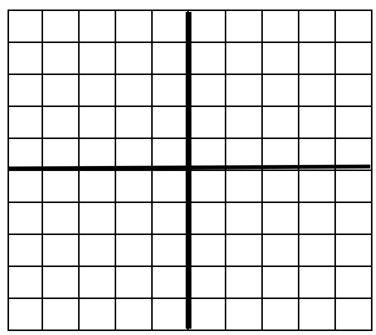
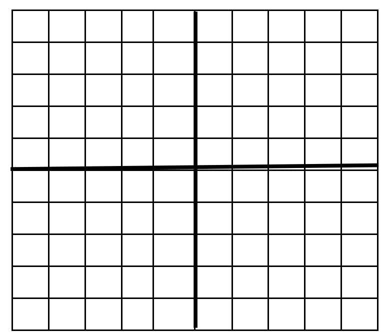
EXPERIMENT 10:
AC CIRCUITS AND PHASE CONSTANTS

When a capacitor and an inductor are present in a circuit with a resistor and an emf, the current is more complicated than $i = V/R$. This is particularly true if $V = V(t)$, as $V = V_m \sin \omega t$. In this experiment we examine the current in an RLC circuit with an emf of variable frequency.

ADVANCE STUDY ASSIGNMENT

1. One way to understand the relation between two quantities is to plot them on a graph. To understand the relation between $V = V_m \sin \omega t$, and $i = I \sin (\omega t - \varphi)$, you are to plot them for set values of t, with i on the y-axis and V on the x-axis. (This type of plotting is called parametric plotting, where we plot y vs x, although we do not have y as a function of x.) For values of t = 0, 1/8 T, 2/8 T 3/8 T, … T plot i vs V when $\varphi = 0$, using (and labeling) the left graph below.





2. Repeat the plot of i vs V, this time for a phase constant $\varphi = 45°$ on the right graph above.

BACKGROUND

Refer to chapter 31 and equations $V = V_m \sin \omega t$, and $i = I \sin (\omega t - \varphi)$. We are interested to test the expressions found in chapter 31 for the values of I and φ. These values depend on V_m, R, L, C, and also on ω. Review the formulas for I, Z and φ in chapter 31.

PROCEDURE A

1. Turn on the black interface box first, then the computer.
2. Open Data Studio. Plug the actual power amplifier box into channel A on the interface. In Experiment Setup window, double-click on power amplifier (also called signal generator – or SG – for this experiment), under the list of sensors. Move the SG window near the bottom of the monitor.
3. Again, on Experiment Setup window, double-click on voltage sensor (for Analog Channel B).
4. Drag the icon for oscilloscope (or scope) from the Displays window onto the icon for the power amplifier Experiment Setup window. You should now have three windows on the Data Studio window on your computer monitor: the experiment window, the signal generator window and the scope window. Note that only one is active at a time, and in order to do anything on any window, you need to first click once on that window to make it active. Make the Signal Generator window active, and then select on the list, Sine Wave, if not already selected.
5. Make the scope window active (by clicking anywhere on it). At the right of this window should be a small box which is called the Trace Control Area. It should now be labeled "Current Ch A" from the Power Amplifier. This is for trace A on the scope. Now click on the Voltage, Ch B line under the Data window at the left of the Data Studio window, and drag this onto the scope window. This opens a new trace control box, and will add a trace to the oscilloscope for the Voltage sensor. The traces will have different colors, as indicated by the titles of the Trace Control areas.

6. To see how the traces work, connect the voltage sensor (watch polarity) to the output of the power amplifier, and turn on the amplifier and click On on the SG window (You may have to click the Auto button first, below the ON/Off buttons.) Click Start on the Data Studio window.
7. Note the buttons for the horizontal time sweep rate below the scope display, suitable for displaying higher or lower frequencies. Experiment changing these, using the arrows pointing right or left. Note the change of horizontal scale (e. g., 10 ms/div). Also practice with the buttons showing different amplitude scales on the Trace A and Trace B control areas to the right of the scope display. Also practice controlling the voltage of the signal generator on its window, and also the frequency. Note you can change either by using the plus or minus signs, or by highlighting the numbers and typing in the desired value. If you use the plus or minus signs, the arrows can change the quantity of the jump with each click. Note that the current trace will be a straight line, because the voltage sensor is high resistance, and does not draw significant current.
8. Next, practice with the smart cursor button which is labeled with an x-y axis, and is just left of the triangle w/ balance (for trigger) button. Clicking on the smart cursor button gives a moveable x-y axis, and note you can read the values of time and voltage below and to the right of the scope window, respectively. Note the horizontal scale starts at 0 at the left end, not in the middle.

PROCEDURE B

9. After this quick review of the computerized oscilloscope, you are ready to proceed with the experiment. Connect the power amplifier (or signal generator) to the RLC circuit board by plugging two banana plug connectors, one into the end of the 33Ω resistor away from the coil, and the other wire into the end of the 100 μF capacitor, also away from the coil. Now plug the wires into the power amplifier. (Always make the power amp connections last, and break them first; this prevents accidental shorting of leads -- and blowing of fuse -- if the wires touch while they are plugged into the power amp.) Trace out with your finger the series RLC circuit you have just established, with four elements: signal generator, capacitor, inductor and resistor.
10. Plug the voltage sensor into either end of the resistor, but be sure to observe polarity. If the positive end of the signal generator (red) is connected to one end of the resistor, the positive terminal (red) of the voltage sensor should be connected to the same side of the resistor. Note that the banana plug of the voltage sensor can have another plug stacked on top of it, useful when more than one banana plug is to be connected to the same point in the circuit. One trace (for voltage sensor) on the scope window will now display the voltage across the resistor. Note that this is proportional to the current in the resistor, and the phase of the voltage across the resistor is always the same as the phase of the current in the resistor (and in the circuit at large). Click on the Trace Control area for current of output and delete it. Now drag the words Output Voltage from Data window onto the scope, and you will have a new trace, showing applied voltage.
11. Set V of the signal generator to 3.00 V, and f to 20 Hz. Click Start on the Experiment Setup window. Clicking the box with “1” on it will freeze the trace so you can use the Smart Cursor. With the smart cursor read the peak voltage on the resistor (the color indicated by the Voltage Ch B in the Trace Control area) and record it in data table B, as V_r . Line up the vertical line of the smart cursor with the peaks of the two curves, and read t_r and t_S for the resistor voltage and applied SG voltage, respectively. Now calculate $\Delta t = t_r - t_S$ and $\Delta\varphi = \Delta t\ \omega$. (Recall $\omega = 2\pi f$.)
12. Repeat procedure 11 for each frequency on data table B. It will speed things if one member of your group records, while another member manipulates the mouse and reads the scope window. If there is a third group member, s/he should verify the readings the mouse manipulator makes, because it is easy to read the wrong number on the scope display.
13. When all readings are complete, plot a graph of i vs f, using the fact that $i = V/R$. (The actual graphing may be delayed to a later time, while you continue doing the experiment.) Now identify f_o as the value of the frequency where the current has maximum value. This is the resonant frequency.

PROCEDURE C

14. For an alternate method to find f_o, click stop on the scope window, and switch the oscilloscope to x-y mode. To do this, first click on and delete the output voltage in the Trace Control area. Then drag the words Output Voltage from the Data window box onto the horizontal scale of the oscilloscope window. This replaces the time sweep with the output of the signal generator ($V_m \sin \omega t$). As you saw in ASA 1 and

2, at resonance (when $\varphi = 0$) the graph of i vs V will be a straight line. At any other value of φ, there will be an ellipse (or circle, a special case of ellipse). To find resonance, change the frequency, either by clicking or by highlighting and typing in numbers. Recall the options given for clicking in procedure 7. Adjust the frequency, at least to the nearest whole number value of f, and perhaps to a decimal value, until you have a thin straight line. Record this as f_{oC} (C for from curve analysis).

15. Next, we will use this method to find the value of the inductance of the coil when the steel cylinder is inserted into the coil. Since the steel will become magnetized, this will change the value of B within the coil when there is a current, and since $L = N\Phi/i$, the presence of the steel changes $\Phi$and L as well. Place the steel cylinder in the coil. It is easier to slide the cylinder out of its holder, rather than pulling directly up.
16. Now repeat procedure 14 to find the new resonant frequency, and use $\omega = \frac{1}{\sqrt{LC}}$ to find the new value of L' with the steel cylinder present. Don't forget to express angular frequency in rad/s.

PROCEDURE D

17. Next, return the oscilloscope to the configuration described in Procedure B. This is most easily done by clicking on the horizontal scale and then pressing delete on the key board. Then drag the words Voltage Ch B onto the vertical scale in the Trace Control area, followed by Output Voltage to the same Trace Control area. Note the steel cylinder is still in the coil.
18. On the SG window, select the square wave (by using the triangular arrow immediately to the right of the words sine wave. To see the damped LC circuit (with small R) we need a value of R smaller than the smallest resistor on the RLC circuit board. Use a banana plug after the coil to connect a decade resistance box into the circuit, instead of the resistors on the RLC board. Make sure you do not turn the resistance to 0 while you are turning the knobs. Set the resistance to 10 Ω. You may want to change the vertical scales to see the largest trace possible of the V_R .
19. Try various frequencies to get the best graph on the oscilloscope of a damped LC oscillation. You may also want to change the resistance, but be sure not to select 0 Ω. Sketch the display on the axes on data table D, and list the value of the square wave frequency you use. Using the smart cursor, determine the frequency of the damped oscillation (by reading the time between two peaks of the oscillation, and recalling $T = 1/f$). Does this f match the predicted frequency of the damped oscillation (the same formula as in procedure 16, since $R/(2L)$ is small)? Remember you will need to use the value L' for the resonant frequency. Fill in all parts of data table D.

PROCEDURE E

20. Now remove the steel cylinder from the coil, return the signal generator to sine wave output, and select the frequency to be 300 Hz. Also return to the 33 Ω resistor. Determine the phase difference between i and V (by the method outlined in procedure 11).
21. Next, with the voltage probes, measure the peak voltages on the resistor, coil, capacitor and signal generator (power amplifier) by using the smart cursor. To do this you will need to move the connectors for the Voltage Sensor to each of the three elements in turn. Be sure to observe correct polarity. Record in data table E.
22. Measure also instantaneous values of v_R, v_L, v_C at a time when $V_{emf} = +V_m$. Note instantaneous values may be positive or negative, while maximum (peak) values are always positive. Line up the smart sensor so that you record each voltage at the time when the $V_{emf} = +V_m$, the peak voltage.

QUESTIONS

1. Do the two frequencies f_0 and f_{0C} (Procedure 12 and 14, respectively) match? What is the percent difference between them?
2. How close was f' (Procedure 16) to f_{exp} (Procedure 19). Can you explain any differences?
3. Add V_R, V_L and V_C (maximum values) and compare to V_m (max emf value). Explain.
4. Add v_R, v_L and v_C and compare to V (= V_m). Comment.

5. Is the circuit in procedure E inductive, or capacitive? Explain using $\tan\varphi = \dfrac{X_L - X_C}{R}$ and ELI the ICE man.

DATA TABLE B

f (Hz)	V_R (V)	t_S (ms)	t_r (ms)	Δt (ms)	$\Delta\varphi$ (rad)
20					
40					
60					
80					
100					
120					
140					
160					
180					
200					
220					
240					
260					
280					
300					
320					
340					
360					
380					
400					

DATA TABLE C

Alternate method for resonance

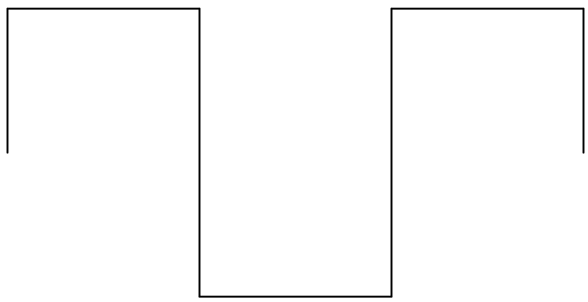
f_{oC}	.

Resonance with steel cylinder

f_o’	

Calculation for L’

DATA TABLE D



R_{decade} ________________

t_1 ________________

t_2 ________________

$\Delta t = t_2 - t_1$ ________________

$f_{exp} = \frac{1}{T} =$ ________________

DATA TABLE E

Δt	
t_S	
t_r	
$\Delta\varphi$	

V_L	
V_m	
V_R	
V_C	

Maximum values

v_L	
$V=V_m$	
v_R	
v_C	

Instantaneous values