How Do We Sense, Think, and Move? -- Lab #10
~ AC DC ~

Important Equipment Warnings for Today's Lesson

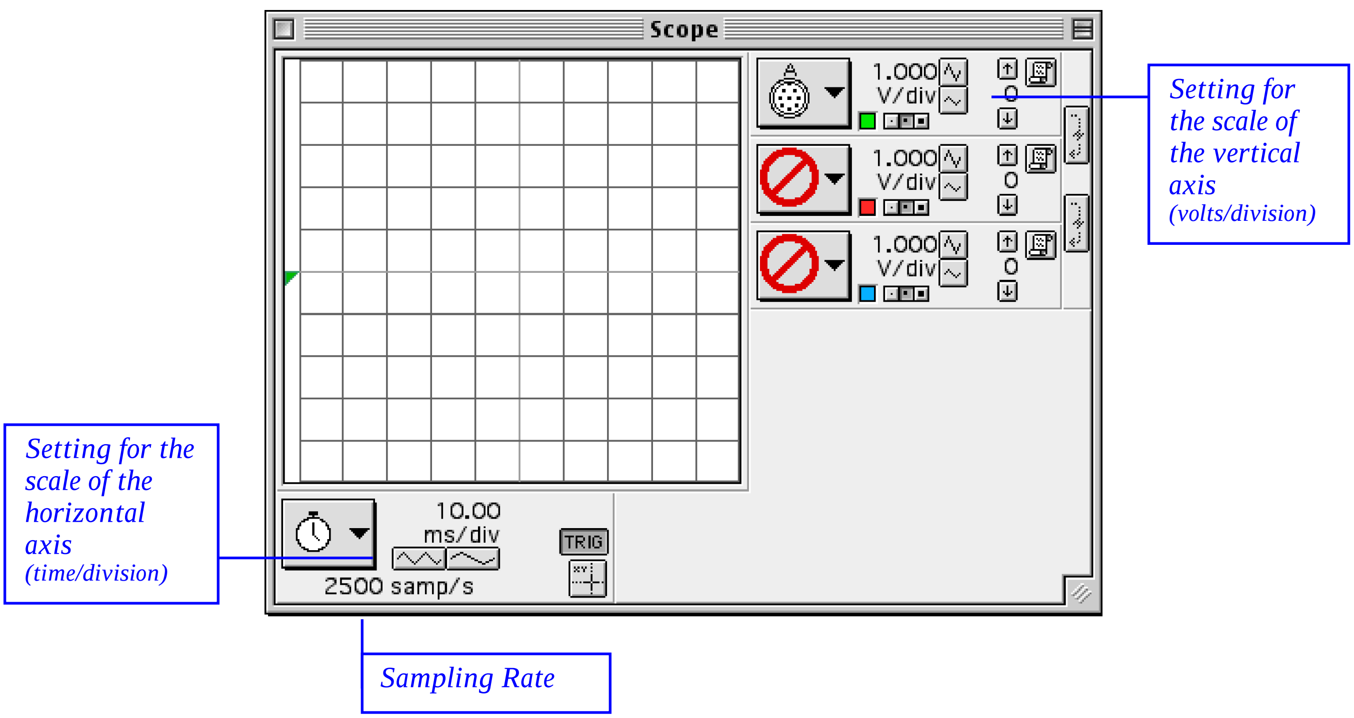
- The interface should not be used to measure any voltage greater than ± 10 V. If you see that the signal from the interface is being saturated, then immediately disconnect the circuit (i.e., open the key switch).
- The ammeter should not be used to measure any current greater than ± 5 A. If you see that the needle of the ammeter is pinned at maximum, then immediately disconnect the circuit (i.e., open the key switch).

Task #1 - Measuring AC Voltages Using an Oscilloscope Display

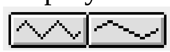
Oscilloscopes are one of the most common instruments used in science, medical technology, and industry and it is important that you gain experience in interpreting information from such a display.

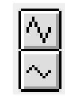
The oscilloscope has the advantage that it can collect data at a very high rate. For example, you can collect up to 250,000 samples/s when using the interface in oscilloscope mode. This makes it ideal for signals that are changing rapidly in time.

Open the file *Lab #10 MBL - Scope Display*. You should be looking at the following display.



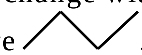
When you monitor data, you will notice that the data constantly updates on the screen instead of scrolling off to the right. This makes it easier to analyze certain kinds of signals.

Time is being displayed along the horizontal axis. You can adjust the amount of time per division with the  buttons. The scale currently being used will be displayed above the buttons. Likewise, you can adjust the amount of voltage per division along the vertical direction with the pictured buttons.



Keep in mind that when you change the scale on the oscilloscope display, you are only changing the way the signal is displayed, but you cannot change the actual signal with these settings.

Experiment #1 – Oscilloscope display; Function generator

The function generator can produce output signals of various voltages that change with time in different ways (square wave , sine wave , and triangular wave .)

- Check that you have a cable with a BNC connector at one end and a double-banana plug at the other connected to the 50 Ω output.
- Plug the double-banana plug into the plastic circuit block.
- Set the amplitude button so that it is closer to MIN than to MAX.
- Set the waveform so that the generator will produce a signal with a sine-wave shape.

- Using the voltage sensor connected to Channel A of the interface, set up a circuit so that you can measure the potential difference across the double-banana plug. Be sure to note which side of the double-banana plug is ground!

- *Monitor* the data (do not *record* data at this time!) when you have everything set.
- You will probably need a faster sampling rate (20,000 samples/s or more!) to study the signal from the function generator.

Using this circuit, discuss the answers to the following questions about the scope display with your partners. You do not need to actually write down your answers in your logbook.

(a) How does the displayed signal change if you increase the V/div setting?
(b) How does the displayed signal change if you decrease the V/div setting?
(c) How does the displayed signal change if you increase the time/div setting?
(d) How does the displayed signal change if you decrease the time/div setting?

Using this circuit, discuss the answers to the following questions about the output of the function generator with your partners. You do not need to actually write down your answers in your logbook.

(a) How does the signal change if you increase or decrease the setting of the frequency knob on the generator?
(b) How does the signal change if you increase or decrease the value of the depressed scale button?
(c) How does the signal change if you increase or decrease the setting of the amplitude knob? (Be sure to keep the amplitude less than 10 V!)

- As a group, select a number between 99 and 9,999. Record this number in your logbook.
- Set the frequency to equal the recorded number. This is accomplished by setting the frequency knob (.2 to 2.0) and the frequency multiplier factor (given in Hz). The actual output frequency should be the product of these two settings.

Adjust the oscilloscope settings so you are viewing about 5 cycles of the signal and the signal covers at least one half of the graph. Stop monitoring the data. Print a copy of the display for each member of your group. Identify the following settings on your printout: V / div, time / div, and sampling rate.

1. Using this circuit, your graph, and the cursor tool, answer the following questions about the measured signal:

   (a) What is the amplitude of this signal? Identify it on your graph and state the measured value.

   (b) What is the period of this signal (time for one complete cycle)? Identify one period on your graph and state the measured value.

   (c) What is the frequency of this signal in Hz? (Recall, 1 Hz = 1 cycle / s)

   (d) How does this calculated frequency compare to the value you set on the frequency generator? Does the knob on the frequency generator seem to be very accurate?

Task #2 - Examining the Behavior of AC circuits with single components

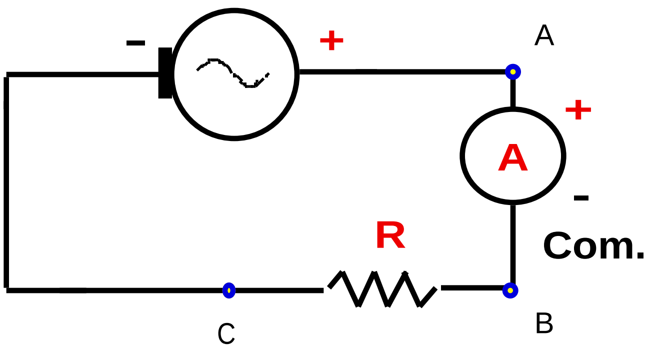
Equipment: Signal generator, Plastic circuit block, Resistor, Banana leads, Ammeter (AC setting), MBL voltage sensors, Digital multimeter

Experiment #2 – R Circuit; AC Signal

Build the following circuit.

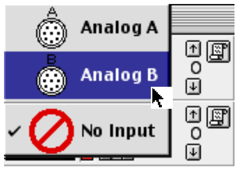
V = Signal Generator

R ≈ 220 Ω



- **Be careful to place the ammeter in the circuit with the (-) and (+) in the correct orientation!**

- Set the ammeter to the AC scale. The ammeter will give you the "root mean square" value of the current (I_{rms}) passing through the circuit.
- Hook up the Channel A MBL Voltage sensor to measure the voltage across the function generator, $V_{CA} = V_{Signal}$.
- Hook up the Channel B MBL Voltage sensor to measure the voltage across the resistor, $V_{CB} = V_R$.
- Adjust the Scope display on the software so that you can display a signal for Channels A and B.



- Set the amplitude of the signal from the function generator so that it is near the MIN value (say at 9:00 if the dial were a clock face).
- Set the frequency of the signal from the function generator so that it is small (~ 50 Hz).

Draw a picture of the circuit in your logbook. Include the voltage sensors connected to measure V_{Signal} and V_R in your drawing. Clearly label all relevant quantities.

Data Collection Procedure:

- Monitor the data with the Scope display.
- Adjust the axes of the display so you can clearly view the behavior of the two signals.
- Adjust the amplitude of V_{Signal} so that it is about 2.0 V as displayed on the scope. This adjustment should be made using the knob on the frequency generator since you want to change the actual signal.

- Slowly vary the frequency of V_{Signal} over a large range (say 50 – 20,000 Hz).
- Adjust the amplitude knob on the generator as needed to keep the amplitude of V_{Signal} at about 2.0 V.
- **That is, you want the amplitude of V_{Signal} to remain constant as you change its frequency.**

2. In words, describe how the voltage across the resistor (V_R) changed as you varied the frequency of V_{Signal}. That is, describe how the frequency of V_R changed (or didn't change) and describe how the amplitude of V_R changed (or didn't change). If the amplitude did change, when was it largest and when was it smallest?

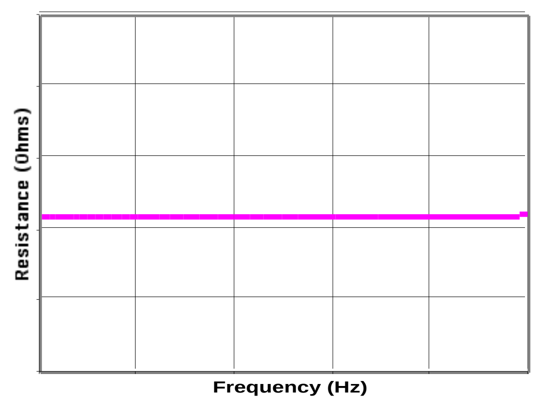
3. In words, describe how the rms current (I_{rms}) passing through the circuit changed (or didn't change) as you varied the frequency of V_{Signal}. If the current did change, when was it largest and when was it smallest?

Comparison to Theory

Chapter 23 of your textbook provides a theoretical discussion of the behavior of AC circuits. Based on this discussion, the authors predict the following behavior for a circuit with a resistor and an AC voltage supply.

$$V_{rms} = I_{rms} R$$

$$R(f) = R$$



4. Do your experimental results confirm the relation between V_{rms} and I_{rms}? Explain.
   Hint! Pick one frequency where $I_{rms} \neq 0$ A, and measure V_{rms}, I_{rms}, and R.
   Hint! You can measure V_{rms} with the digital multimeter set to AC.

5. Do your answers to questions 2-4 confirm the frequency dependence of the resistance value pictured in the graph? Explain.

6. Based on your results, sketch the rms current of this circuit as a function of frequency. Use the same frequency scale pictured in the above graph.

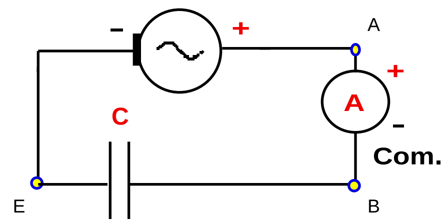
Experiment #3 – C Circuit; AC Signal

<u>Equipment</u>: Signal generator, Plastic circuit block, Capacitor, Banana leads, Ammeter (AC setting), MBL voltage sensors

Build the following circuit.

V = Signal Generator

C ≈ 0.47 μF



- Hook up the Channel A MBL Voltage sensor to measure the voltage across the function generator, $V_{EA} = V_{Signal}$.
- Hook up the Channel B MBL Voltage sensor to measure the voltage across the capacitor, $V_{EB} = V_C$.
- Set the amplitude of the signal from the function generator so that it is about 2.0 V.
- Set the frequency of the signal from the function generator so that it is small (~ 50 Hz).

Draw a picture of the circuit in your logbook. Include the voltage sensors connected to measure V_{Signal} and V_C in your drawing. Clearly label all relevant quantities.

Data Collection Procedure:

- Monitor the data with the Scope display.
- Slowly vary the frequency of V_{Signal} over a large range (say 50 – 20,000 Hz).
- Adjust the amplitude knob on the generator as needed to keep the amplitude of V_{Signal} at about 2.0 V.
- **That is, you want the amplitude of V_{Signal} to remain constant as you change its frequency.**

7. In words, describe how the voltage across the capacitor (V_C) changed as you varied the frequency of V_{Signal}. That is, describe how the frequency of V_C changed (or didn't change) and describe how the amplitude of V_C changed (or didn't change). If the amplitude did change, when was it largest and when was it smallest?

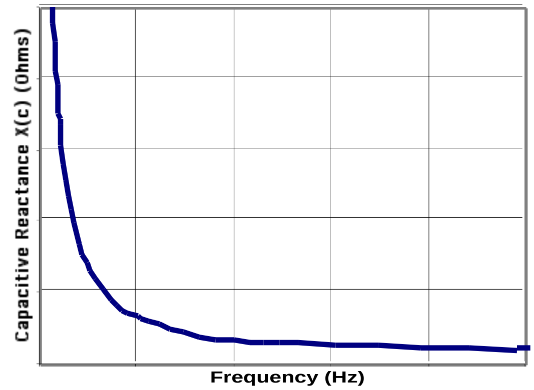
8. In words, describe how the rms current (I_{rms}) passing through the circuit changed (or didn't change) as you varied the frequency of V_{Signal}. If the current did change, when was it largest and when was it smallest?

Comparison to Theory

Based on your textbook, the authors predict the following behavior for a circuit with a capacitor and an AC voltage supply.

$$V_{rms} = I_{rms} X_C$$

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



9. Do your experimental results confirm the relation between V_{rms} and I_{rms}? Explain. *Hint*! Pick one frequency where $I_{rms} \neq 0$ A, and measure V_{rms} and I_{rms} and calculate X_C. *Hint*! You can measure V_{rms} with the digital multimeter set to AC.

10. Do your answers to questions 7-9 confirm the frequency dependence of the capacitive reactance pictured in the graph? Explain.

11. Based on your results, sketch the rms current of this circuit as a function of frequency. Use the same frequency scale pictured in the above graph.

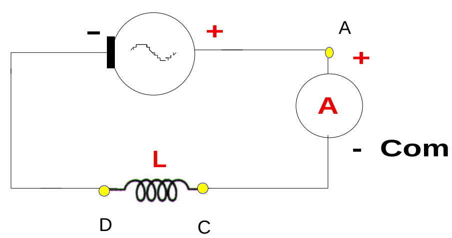
Experiment #4 – L Circuit; AC Signal

Equipment: Signal generator, Plastic circuit block, Inductor, Banana leads, Ammeter (AC setting), MBL voltage sensors

Build the following circuit.

V = Signal Generator

L ≈ 25 mH



- Hook up the Channel A MBL Voltage sensor to measure the voltage across the function generator, $V_{DA} = V_{Signal}$.
- Hook up the Channel B MBL Voltage sensor to measure the voltage across the inductor, $V_{DC} = V_L$.
- Set the amplitude of the signal from the function generator so that it is about 2.0 V.
- Set the frequency of the signal from the function generator so that it is small (~ 50 Hz).

Draw a picture of the circuit in your logbook. Include the voltage sensors connected to measure V_{Signal} and V_L in your drawing. Clearly label all relevant quantities.

Data Collection Procedure:

- Monitor the data with the Scope display.
- Slowly vary the frequency of V_{Signal} over a large range (say 50 – 20,000 Hz).
- Adjust the amplitude knob on the generator as needed to keep the amplitude of V_{Signal} at about 2.0 V.
- **That is, you want the amplitude of V_{Signal} to remain constant as you change its frequency.**

12. In words, describe how the voltage across the inductor (V_L) changed as you varied the frequency of V_{Signal}. That is, describe how the frequency of V_L changed (or didn't change) and describe how the amplitude of V_L changed (or didn't change). If the amplitude did change, when was it largest and when was it smallest?

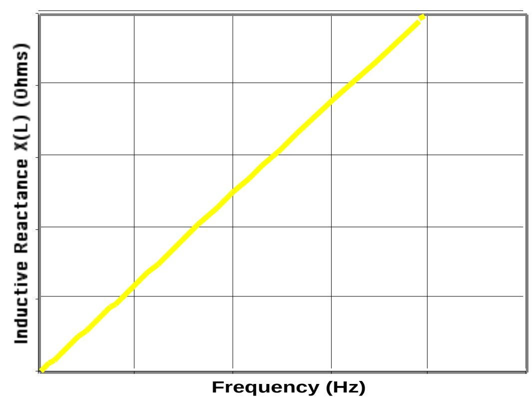
13. In words, describe how the rms current (I_{rms}) passing through the circuit changed (or didn't change) as you varied the frequency of V_{Signal}. If the current did change, when was it largest and when was it smallest?

Comparison to Theory

Based on your textbook, the authors predict the following behavior for a circuit with an inductor and an AC voltage supply.

$$V_{rms} = I_{rms} X_L$$

$$X_L = 2\pi f L = \textit{Inductive Reactance}$$



14. Do your experimental results confirm the relation between V_{rms} and I_{rms}? Explain. *Hint*! Pick one frequency where $I_{rms} \neq 0$ A, and measure V_{rms} and I_{rms} and calculate X_L. *Hint*! You can measure V_{rms} with the digital multimeter set to AC.

15. Do your answers to questions 12-14 confirm the frequency dependence of the inductive reactance pictured in the graph? Explain.

16. Based on your results, sketch the rms current of this circuit as a function of frequency. Use the same frequency scale pictured in the above graph.

Task #3 - Examining the Behavior of an RLC circuit with an AC Signal

Equipment: Signal generator, Plastic circuit block, Resistor, Capacitor, Inductor, Banana leads, Ammeter (AC setting), MBL voltage sensors

Experiment #5 – RLC Circuit; AC Signal

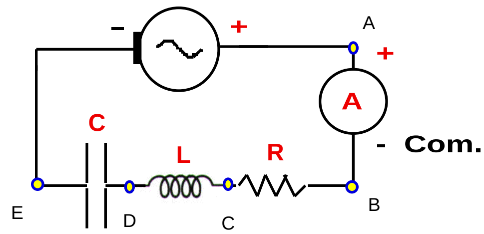
Build the following circuit.

V = Signal Generator

R ≈ 220 Ω

C ≈ 0.47 μF

L ≈ 25 mH



- Hook up the Channel A MBL Voltage sensor to measure the voltage across the function generator, $V_{EA} = V_{Signal}$.
- Hook up the Channel B MBL Voltage sensor to measure the voltage across the resistor, $V_{BC} = V_R$.
- Set the amplitude of the signal from the function generator so that it is about 2.0 V.
- Set the frequency of the signal from the function generator so that it is small (~ 50 Hz).

Draw a picture of the circuit in your logbook. Include the voltage sensors connected to measure V_{Signal} and V_R in your drawing. Clearly label all relevant quantities.

Data Collection Procedure:

- Monitor the data with the Scope display.
- Slowly vary the frequency of V_{Signal} over a large range (say 50 – 20,000 Hz).
- Adjust the amplitude knob on the generator as needed to keep the amplitude of V_{Signal} at about 2.0 V.
- **That is, you want the amplitude of V_{Signal} to remain constant as you change its frequency.**

17. In words, describe how the voltage across the resistor (V_R) changed as you varied the frequency of V_{Signal}. That is, describe how the frequency of V_R changed (or didn't change) and describe how the amplitude of V_R changed (or didn't change). If the amplitude did change, when was it largest and when was it smallest?

18. In words, describe how the rms current (I_{rms}) passing through the circuit changed (or didn't change) as you varied the frequency of V_{Signal}. If the current did change, when was it largest and when was it smallest?

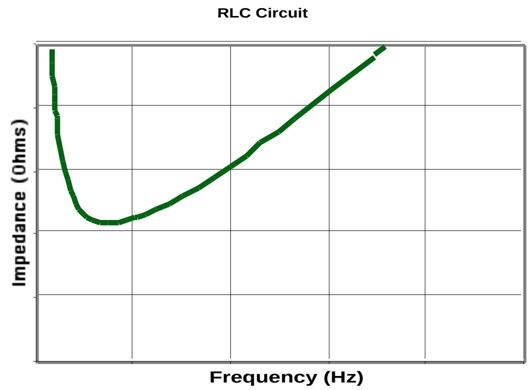
Comparison to Theory

Based on your textbook, the authors predict the following behavior for a circuit with a resistor, capacitor, and inductor in series with an AC voltage supply.

$$V_{rms} = I_{rms} Z$$

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = Impedance$$

$$\text{where } Z_{Minimum} \text{ occurs when } f = f_0 = \frac{1}{2\pi\sqrt{LC}}$$



19. Use the given formula to predict at what frequency Z will be a minimum for your circuit. Compare your prediction to an experimental value. Explain how you are able to experimentally determine the frequency where Z is a minimum. Print a copy of your graph showing V_{Signal} and V_R when Z is a minimum.

20. Do your experimental results confirm the relation between V_{rms} and I_{rms}? Explain. *Hint*! Pick $f = f_0$ (with the amplitude of V_{Signal} set to 2.0 V) and measure V_{rms} and I_{rms} and calculate $Z_{Minimum}$.

21. Do your answers to questions 17-20 confirm the frequency dependence of the impedance pictured in the graph? Explain.

22. Based on your results, sketch the rms current of this circuit as a function of frequency. Use the same frequency scale pictured in the above graph.

23. If someone asked you, "Does the frequency of an AC signal matter in a circuit?" How would you answer? What examples could you give?

<u>End of Lab Cleanup</u>

- Turn off the multimeter and the function generator.
- Unplug all banana leads.
- Return the circuit components (R, L, and C) to the box provided at your station.