

University of Utah
Electrical & Computer Engineering Department
 ECE 2210 Lab 7
Phases and Filters

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Objectives

- 1.) Observe the phase relationships of current and voltage in a capacitor and an inductor.
- 2.) Make some simple filters and plot their frequency response curves.

Equipment and materials to be checked out from stockroom:

- ECE 2210 kit (if available)

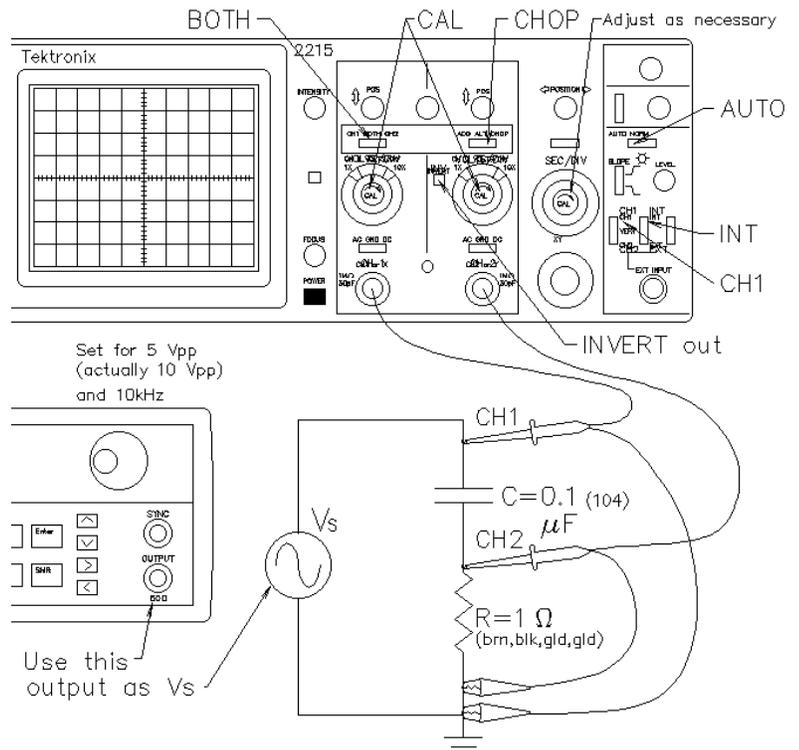
Parts:

These items may be bought from stockroom or may be in the ECE 2210 kit.

- 1 Ω , 100 Ω , and 1 k Ω resistors
- 0.1 μF (104) & 0.01 μF (103) capacitors
- Inductor, 2 to 4 mH

Experiment 1, Current / Voltage phase shifts

Set up the scope and wire the circuit shown at right (scope probes are hanging up at several locations in the lab). Set the signal generator amplitude to 5 Vpp (which will actually give 10 Vpp) and its frequency to about 10kHz.



Measure both voltage and current with scope:

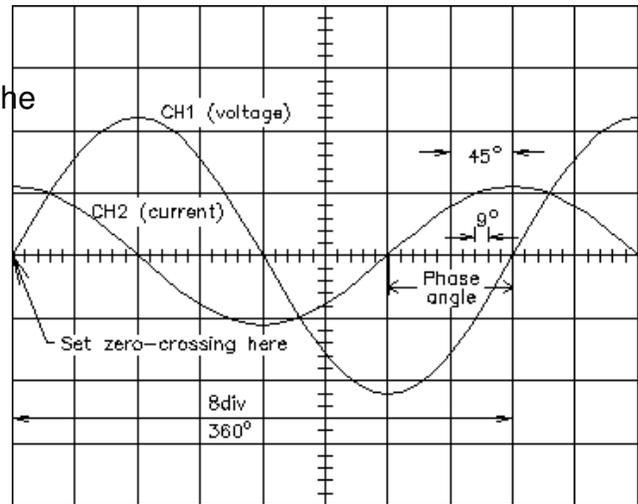
Notice the small value of the resistor in this circuit (1 Ω). This value will have very little effect on the CH1 signal, but will allow the CH2 signal to effectively display the current through the capacitor. Think of the CH2 trace as a measure of the capacitor current. (It may not always look like a nice sinusoid due to noise and scope/circuit irregularities, but try to ignore that in this lab.)

Note the phase difference of the two traces. Is the current (CH2) leading (to the left of) the voltage? If not, check the INVERT switch on your scope. It should be in the non-invert position.

Phase angle Measurement

Adjust scope: Adjust both VOLTS/DIV knobs on the scope to get two good, big traces. This may not always be possible, but do the best you can. Switch each of the AC GND DC switches (right under the VOLTS/DIV knobs) to GND and use the vertical position knobs to adjust both horizontal traces to center of the screen, right along the center horizontal grid line. This “zeroes” the scope. Switch the AC GND DC switches back to AC.

Refer to the figure at right. Use the HORZ POSITION knob and/or the TRIGGER LEVEL knob to make the CH1 trace cross the zero line (the center horizontal grid line) just at the leftmost line on the scope screen. Use the TIME/DIV knob and its little red, inner CAL (or VAR) knob so that the full cycle occupies 8 divisions. You may have to readjust the position. Now each scope division represents 45° of phase angle.



Phase angle: Measure the phase angle between the voltage and current waveforms. Is this 90° as expected? Return the TIME/DIV CAL (or VAR) knob to its calibrated (click-stop) position.

Circle: Turn the TIME/DIV knob fully CCW, to the x-y position. In this position the left-right movement of the scope beam is controlled by CH1 rather than scope sweep circuits. CH2 works as normal, making the beam move up and down. If the CH1 and CH2 are both sine waves and are truly 90° out of phase, then you should be able to adjust the VOLTS/DIV knobs to get a perfect circle. You may also have to adjust one of the little red, inner CAL (or VAR) knobs. Sketch this in your notebook and explain why it's (almost) a circle. Restore your scope to its normal operation and return the CAL (or VAR) knob to its calibrated (click-stop) position.

Other frequencies: Adjust the function generator frequency down to 1 kHz. Does the phase angle change? Check again at 30 kHz. Also note that the current magnitude does change with frequency. Considering that the impedance of a capacitor is inversely proportional to the frequency, is it changing as expected? Return your frequency to 10 kHz.

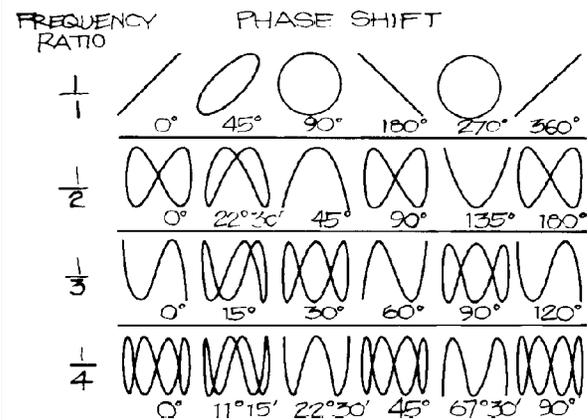
Repeat with Inductor: Replace the capacitor with your inductor and repeat this entire section, including the detailed phase angle measurement at 10 kHz. Note that the current now lags the voltage by 90° . (You don't need to explain the circle again, but do everything else including the other frequencies.)

Experiment 2, Simple Filters

The impedance of an inductor is proportional to frequency and the impedance of a capacitor is inversely proportional to frequency. These characteristics can be used to select or reject certain frequencies of an input signal. This selection and rejection of frequencies is called *filtering*, and a circuit which does this is called a *filter*. The bass and treble controls on your

Lissajous (LEE-za-shu) Figures

These figures are generated on the scope screen when two sine waves are used to manipulate the x and y positions of the beam. If the two sine waves have a integer frequency ratio then you'll see a stable figure like one of these:



stereo are frequency filters. So are the tuners in TVs and radios.

You've already made a simple filter in the Capacitors lab. We called it a frequency-dependent voltage divider. Almost any circuit where a capacitor or an inductor is part of a voltage divider is a filter. The magnitude of the output voltage is a function of frequency. Look back at the frequency response curve you made in the Capacitors lab.

If a filter passes high frequencies and rejects low frequencies, then it is a *high-pass* filter. Conversely, if it passes low frequencies and rejects high ones, it is a *low-pass* filter. A filter that passes a range or *band* of frequencies and rejects frequencies lower or higher than that band, is a *band-pass* filter. The opposite of this is a *band-rejection* filter, or if the band is narrow, a *notch* filter or *trap*. What type of filter did you make in the Capacitors lab? How about the Resonance lab (look at the frequency response curve)?

Filters, like most things, aren't perfect. They don't absolutely pass some frequencies and absolutely reject others. In fact there are large gray areas between pass and reject that make it somewhat arbitrary to say just what *is* and what *isn't* passed. For filters, you measure the pass and reject areas by using a constant magnitude of input signal and varying its frequency. A frequency is considered passed if it's magnitude (voltage amplitude) is within 70% of the maximum amplitude passed, and rejected otherwise. The 70% frequencies are known as *half-power* points, *3-dB-down* points, or *roll-off* points. (Square 0.7 on your calculator to see why they're called half-power points).

For RC (resistor-capacitor) filters, roll-off is where:

$$R = \frac{1}{\omega_c C}$$

$$\omega_c = \frac{1}{RC}$$

$$f_c = \frac{1}{2\pi RC}$$

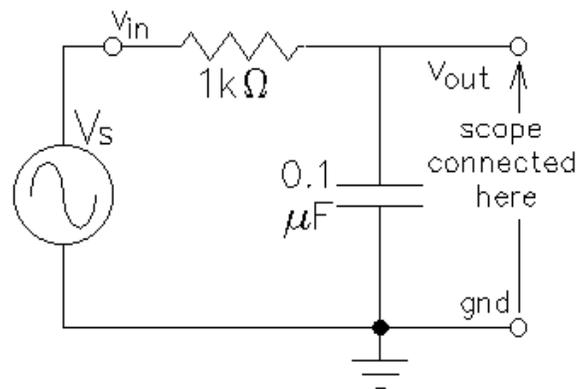
For RL (resistor-inductor) filters, roll-off is where:

$$R = \omega_c L$$

$$\omega_c = \frac{R}{L}$$

$$f_c = \frac{R}{2\pi L}$$

RC low-pass: The filter shown at right is the same one that you built in the Capacitors lab. Look back at that lab now and find the frequency response curve for this filter. Determine what the roll-off frequency (f_c) was from this curve (the frequency where $v_o/v_{in} = .70$).

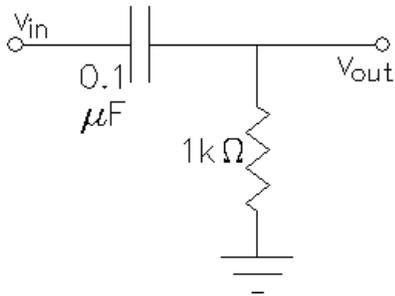


Calculate the theoretical roll-off frequency for this filter and compare this to what you found from the frequency response curve.

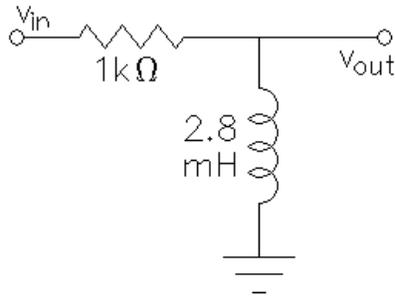
Frequency response curves: Calculate the roll-off points for the three filters shown on the next page. You may want to measure the actual value of your inductor and use that value in your calculations instead of 2.8 mH. Your lab TA can show you how to use the HP LCR meter to measure your inductor. If you don't measure your inductor, remember that it probably isn't exactly 2.8 mH when you compare calculations to measurements.

Make one of the RC or RL filters shown on the next page. Use the signal generator to supply v_{in} , and the scope to observe both v_o and v_{in} . This should result in a circuit that looks like the

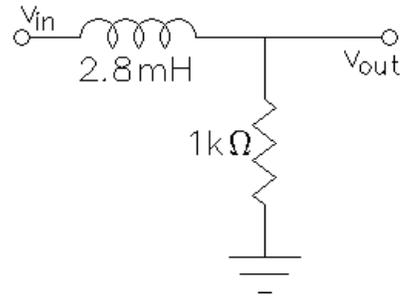
one on the first page of this lab, although the parts will be different. Measure the frequency response of your filter and plot the results on a log plot. You can make your log plot (frequency response curve) in several different ways; use a 1, 3, 10,... pattern of frequencies like you did in the Capacitors lab, use a \log_2 pattern like you did in the Resonance lab, use log paper, or use a computer program. In the last two cases you'll tape or paste the plot in your notebook. Be sure to find the roll-off point and compare it to your calculated roll-off frequency.



High-pass RC



High-pass RL



Low-Pass RL

Make one of the other two filters. Confirm that it is high-pass or low-pass as advertised. Find its roll-off point and compare that to your calculated roll-off. You **don't** need to make another curve.

Repeat for the last filter. Again, just confirm that it is high-pass or low-pass as advertised. Find its roll-off point, compare it to your calculation, and **don't** make another curve.

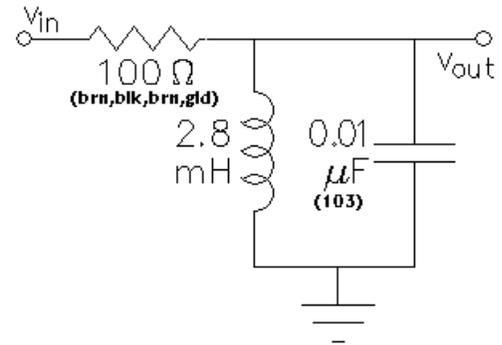
Band-pass filter: Make the band-pass filter shown below. Measure its frequency response and plot the results on a log plot, you'll need quite a few data points. This will be your second curve for this lab. Find the two roll-off point(s) for each, and compare to calculations.

Low frequency roll-off:

$$f_L = \frac{R}{2\pi L}$$

High frequency roll-off:

$$f_H = \frac{1}{2\pi RC}$$



Conclude

As always, check off and write a conclusion.

