Capacitors and inductors

This week, we play a bit around with capacitors and inductors. Bring a flash drive for recording oscilloscope traces.

1. **LCR meter**

   Sometime during lab, take your inductors and a few capacitors to the LCR meter (located on the bench near the door in Rm. 2014) and measure their values. You can also use a breadboard to try connecting some components in series and parallel to confirm the series/parallel rules for capacitors and inductors.

   Also, while measuring the inductors, use the ohm-meter to measure their series resistance. It is important to note that it is not zero! This non-ideal effect can have a significant impact in some applications.

   When using capacitors and inductors in future labs, you should get in the habit of measuring them before using them. Using the wrong values has caused many (MANY!) problems problems for past students.

2. **Capacitor charge storage**

   Insert a 1-μF capacitor into your breadboard. Turn on the triple output supply, but keep the voltages set to zero initially. Use leads to attach the 25-V supply to the capacitor.

   Mind the polarity: Electrolytic capacitors are *polarized* and must have the correct DC polarity applied across them. The negative side of the capacitor is labeled on the package with something that looks like a negative sign and the lead on the negative side is shorter than the lead for the positive. If the DC polarity of an electrolytic is backwards, the capacitor may fail, perhaps catastrophically with a tiny explosion.

   Ramp up the supply voltage to 15 V. Confirm the DC voltage across the capacitor with the voltmeter. Calculate the charge stored on each plate and the energy stored in the capacitor with v_C = 15 V.

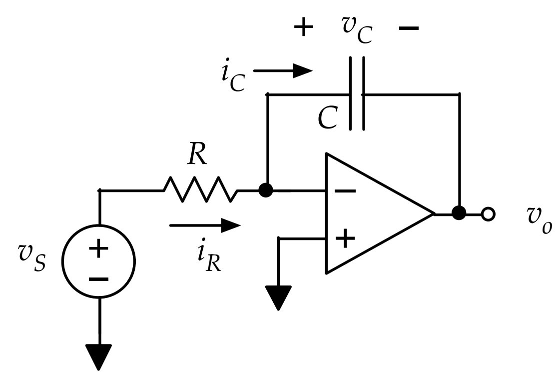
   Now remove the leads connecting the capacitor to the voltage supply, but leave the voltmeter connected to the capacitor. Observe the capacitor voltage for next few seconds – the capacitor voltage falls to zero! But shouldn’t the capacitor store the charge on its plates? It must have dissipated – can you explain what happened to it?

   Repeat the experiment, but use a 10-μF capacitor. Note any similarities or differences. Then try one more time with a 100 μF capacitor.

3. **Capacitor current-voltage relationship**

Observing the current-voltage relationship of capacitors and inductors requires a slightly different approach from what we have used with our previous devices. The derivative relationship means that we need to look at currents and voltages as functions of time — we can't make a simple graph of i versus v or plot a transfer characteristic as we did with op amps. Instead, we will use the oscilloscope to observe the behavior of waveforms in a circuit and see how those arise from the derivative nature of capacitors and inductors.

Op amps provide a useful means for observing capacitor/inductor currents and voltages. Consider the circuit at right. It is essentially an inverting op amp circuit with the feedback resistor replaced by a capacitor. (In the class notes, we saw that this was an integrating circuit — the output was the integral over time of the input.)

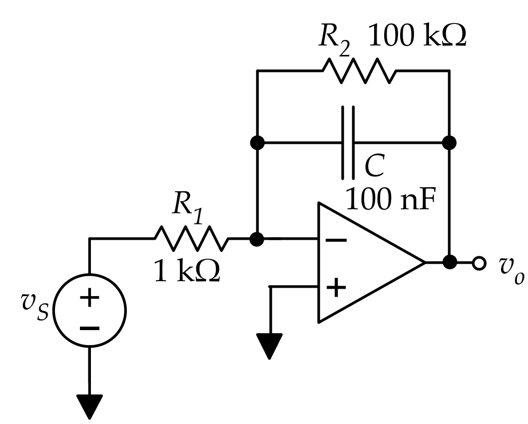


In this case, we note that the input voltage is the same as the resistor voltage, $v_S = v_R = i_R R$. And, the output voltage is the negative of the capacitor voltage, $v_O = -v_C$. Also, the resistor current is the same as the capacitor current, $i_R = i_C$. So by observing the input and the output together on the oscilloscope, we can, in effect, see the capacitor current and voltage simultaneously,

$$i_C = i_R = v_S / R \text{ and } v_C = -v_O.$$

By choosing R = 1 kΩ and using the "invert" option on the oscilloscope channel that is connected to the output, the traces will be nearly identical to the actual capacitor current and voltage. (It is not necessary to use a 1-kΩ resistor or to invert the output voltage channel — these are just conveniences in doing the measurement.)

Build the circuit shown at right using LM324 op amp with ±10 V power supplies. The extra resistor in parallel with the capacitor is useful to minimize errors that can occur in this type of circuit. (As we know, a capacitor is an open circuit at DC, meaning that the DC gain of the amp with a capacitor serving as the feedback component will be infinity! If there are any DC voltages present at the input, they will see an infinite gain, which is definitely not good. As you will learn in EE 230, there are *always* small DC voltages present at the input of an op amp. By putting a large resistor in parallel with the capacitor, the DC gain is kept finite. As long as the resistor is large, it will have minimal effect on the integrating action of the circuit.)

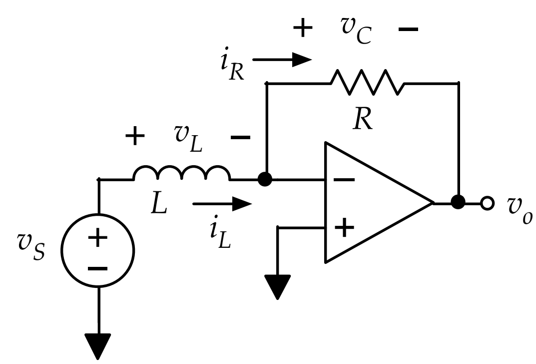


a. Apply a sinusoidal input: V_m = 1 V (= 2 V peak-to-peak = 0.707 V_{RMS}) and ω = 10,000 rad/s (f = 1560 Hz). Use the oscilloscope to observe the input voltage (i.e. capacitor current) and output voltage (i.e. capacitor voltage) simultaneously. Note the amplitude of the capacitor current. Confirm that it matches the expected value from the capacitor *i-v* relation. Note the 90° phase shift between the voltage and current. Save a copy of the traces for your report.

Add a second 100-nF capacitor in parallel with the first and note any changes in the in the amplitude or phase of the capacitor voltage. Then move the second capacitor in series with the first and note any changes in the waveforms.

b. Change the source to a square wave with a frequency of 1-kHz and and amplitude of 1 V (2-V peak-to-peak). Repeat the measurements of part a. Note in particular the slope of the ramping capacitor voltage as the equivalent capacitance is changed. Save a copy of the traces for your report.

4. **Inductor current-voltage relationship**



Now observe the inductor current - voltage relationships with the help of an op amp. Build the circuit at right, using a 1-kΩ resistor and a 15-mH inductor (available from your instructor). Note that in the circuit, $v_L = v_S$ and $i_L = i_R$. So once again we can use the input and output voltages as proxies for the inductor voltage and current.

Apply a sinusoidal input: V_m = 1 V (= 2 V peak-to-peak = 0.707 V_{RMS}) and ω = 10,000 rad/s (f = 1560 Hz). Use the oscilloscope to observe the input voltage (i.e. inductor voltage) and output voltage (i.e. inductor current) simultaneously. Note the amplitude of the inductor current. Confirm that it matches expected value from the inductor *i-v* relation. Note the 90° phase shift between the voltage and current. Save a copy of the traces for your report.

Add a second 15-mH inductor in parallel with the first and note any changes to the amplitude and phase of the inductor current. Then move the second inductor in series with the first and note any changes in the waveforms. (If the output is clipping, reduce the source amplitude.)

Report

Each lab group should prepare a report for the work done in this lab. Be sure to include all of the measured data, calculated values, and the oscilloscope traces. To complete the report, add an introduction and a conclusion (about one paragraph each). The report is due in one week.