

**California State University, Fresno**  
**Department of Electrical and Computer Engineering**

ECE 90L Principles of Electrical Circuits Laboratory  
Experiment No. 10: Capacitance and Inductance

**Objective**

The objective of this experiment is to investigate the properties of the capacitor and the inductor.

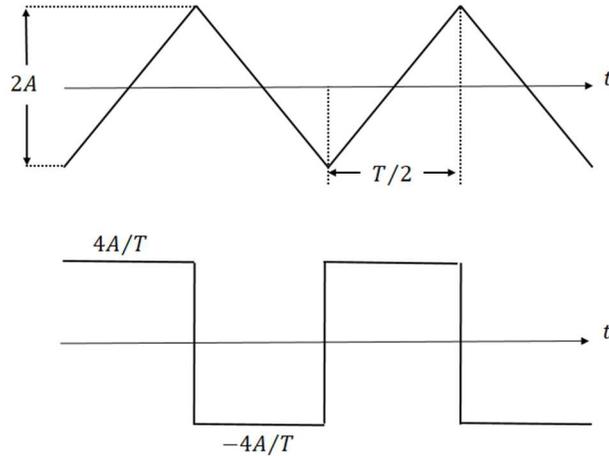
**Prelab**

*Some Math*

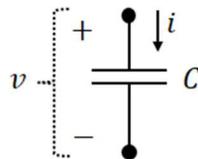
The derivative of a triangle-wave is a square-wave. The illustration below shows a triangle-wave having an amplitude  $A$  and a period  $T$ . On a line segment with a positive slope, the triangle-wave value changes by  $2A$  (peak to peak) over a time span of  $T/2$ . The slope is  $4A/T$ . This is also the derivative for this line segment (with the positive slope). For a line segment with a negative slope, the derivative is  $-4A/T$ . The derivative of this triangle-wave is therefore the square-wave shown in Figure 1. (We won't worry about the derivative at the peaks of the triangle-wave.)

*Capacitance*

Figure 2 shows the polarity convention for a capacitor. For many capacitors and all the capacitors that we will use in this laboratory, we can regard either terminal as positive. Once the positive terminal is chosen, positive current is defined as current entering the capacitor through this positive terminal (and leaving through the negative terminal). In a circuit, if the current actually flows in the opposite direction, it will have a negative value. (As an exception to the remarks above about capacitors, electrolytic capacitors have permanently marked positive and negative terminals. Electrolytic capacitors will not be used in this laboratory.)



**Figure 1:** Illustration demonstrating that the derivative of a triangle-wave is a rectangular-wave. The peak amplitude is given by  $2A/(T/2) = 4A/T$ .



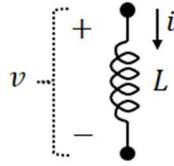
**Figure 2:** Voltage across and current through a capacitor. An electrical current only flows in a complete circuit. The entire circuit is not shown in this figure, but the fact that we define a current here implies that there is a complete circuit.

In a capacitor  $v$  and  $i$  are related by

$$i = C \frac{dv}{dt}$$

where  $C$  is the capacitance in farads,  $v$  is in volts and  $i$  is in amperes. In the special case where  $v$  is a constant (DC), then  $i$  is 0: no current flows when the voltage across a capacitor is DC. In other words, a capacitor looks like an open circuit to DC.

We wish to know the current  $i$  through a capacitor (having capacitance  $C$ ) if the voltage  $v$  across it is a triangle-wave having amplitude  $A$  and period  $T$ . We can take advantage of the math given above. The derivative  $dv/dt$  is a square-wave with amplitude  $4A/T$ . Therefore,  $i$  is a square-wave with amplitude  $4AC/T$ .



**Figure 3:** Voltage across and current through an inductor. An electrical current only flows in a complete circuit. The entire circuit is not shown in this figure, but the fact that we define a current here implies that there is a complete circuit.

**Exercise:** A triangle-wave voltage with amplitude 2 V and frequency 1 kHz is applied across a capacitor. The capacitance is 0.1  $\mu\text{F}$ . Based on the mathematics discussed above, we can say that the current will be a square-wave. What is the amplitude of the square-wave current?

**Exercise:** A sinewave voltage with amplitude 2 V and frequency 1 kHz is applied across a capacitor. The capacitance is 0.1  $\mu\text{F}$ . What is the amplitude of the current?

### *Inductance*

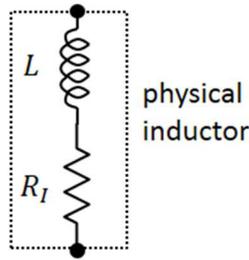
Figure 3 shows the polarity convention for an inductor. We can regard either terminal as positive. Once the positive terminal is chosen, positive current is defined as current entering the inductor through this positive terminal (and leaving through the negative terminal). In a circuit, if the current actually flows in the opposite direction, it will have a negative value.

In an ideal inductor  $v$  and  $i$  are related by

$$v = L \frac{di}{dt}$$

where  $L$  is the inductance in henrys,  $v$  is in volts and  $i$  is in amperes. In the special case where  $i$  is constant (DC), there is no voltage drop across an ideal inductor. In other words, an ideal inductor looks like a short circuit to DC.

A physical (that is, real) inductor has some resistance as well as inductance. In some applications, it is important to model a physical inductor as an ideal inductor in series with a resistor. See Figure 4. A physical inductor looks like  $R_l$  to DC.



**Figure 4:** A physical inductor has some resistance  $R_l$  as well as inductance  $L$ .

We wish to know the current  $i$  through an ideal inductor (having inductance  $L$ ) if the voltage  $v$  across it is a square-wave having amplitude  $A$  and period  $T$ . We can guess that the current is a triangle-wave. If the current  $i$  is a triangle-wave with amplitude  $I$  and period  $T$ , then the derivative  $di/dt$  is a square-wave with amplitude  $4I/T$ . Therefore, it must be true that  $A = 4IL/T$ . The current  $i$  through the inductor thus has the amplitude  $I = AT/(4L)$ .

**Exercise:** A square-wave voltage with amplitude 2 V and frequency 500 Hz is applied across an ideal inductor. The inductance is 500 mH. Based on the mathematics discussed above, we can say that the current will be a triangle-wave. What is the amplitude of the triangle-wave current?

**Exercise:** A sinewave voltage with amplitude 2 V and frequency 500 Hz is applied across an ideal inductor. The inductance is 500 mH. What is the amplitude of the current?

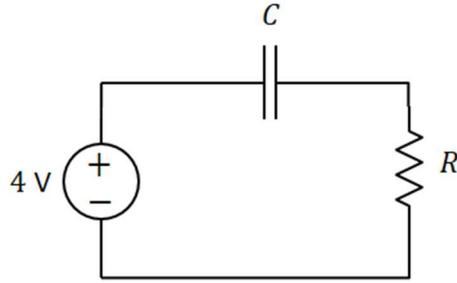
## Procedure

### Capacitance

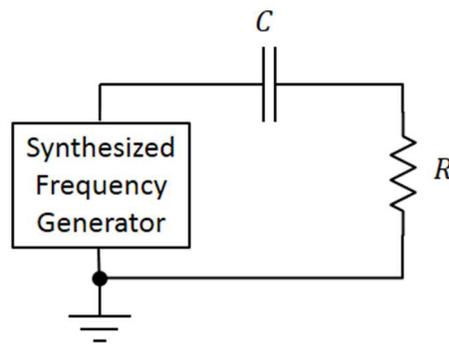
You will use a decade box for the capacitor  $C$  shown in Figures 5 and 6. Select a capacitor decade box, and set the correct value according to Table 1. You will use a decade box for the resistor  $R$ . Select a resistor decade box, set the correct value according to Table 1, measure and record the actual resistance.

**Table 1:** Component values for Figures 5 and 6

$C$	$R$
0.1 $\mu\text{F}$	100 $\Omega$



**Figure 5:** DC test of capacitor



**Figure 6:** AC test of capacitor

Construct the DC circuit of Figure 5, using CH1 of the Siglent power supply and the component values of Table 1. Set the current limit to 0.2 A. Measure the voltage across  $C$  and the voltage across  $R$ .

In the circuit of Figure 5, replace the 4-V DC source with the synthesized frequency generator, as shown in Figure 6.

Set the synthesized frequency generator to produce a 1-kHz triangle-wave with amplitude 2 V. You should minimize the DC bias of the synthesized frequency generator. You can minimize the DC bias by adjusting the Offset knob of the generator (with the knob in the pulled-out position) while observing the generator output on the oscilloscope's channel 1 (using DC coupling).

For this circuit, we want the voltage across the series combination of  $C$  and  $R$  (that is, the voltage at the generator output) connected to channel 1 of the oscilloscope. And we want the voltage across  $R$  connected to channel 2. Set the math channel of the oscilloscope to display channel 1 minus channel 2. Therefore, the math channel will display the voltage across  $C$ . You can now hide the channel-1 signal. (But don't disconnect the signal from channel 1. The math channel

needs this signal in order to complete its calculation.) Two signals should now be displayed: the voltage across  $C$  (the math channel) and the voltage across  $R$  (channel 2).

We are using  $R$  as a “test resistor” here. We are interested in the current but cannot display the current directly on the oscilloscope. But the voltage across  $R$  is proportional to the current. The value of  $R$  was chosen small enough that, for the frequency and capacitance used here, the presence of  $R$  in the circuit does not significantly affect the voltage across  $C$  or the current through  $C$ . In other words, almost all of the voltage produced by the synthesized frequency generator may be assumed to appear across the capacitor.

Call up the Acquire menu on the oscilloscope and select Average, using an average of at least 16 values. In this mode, the relatively weak channel-2 signal (the voltage across  $R$ ) will appear less noisy.

The voltage across  $R$  should look similar to a square-wave. The current in this (series) circuit equals the voltage across  $R$  divided by  $R$ . Calculate the amplitude of the square-wave current.

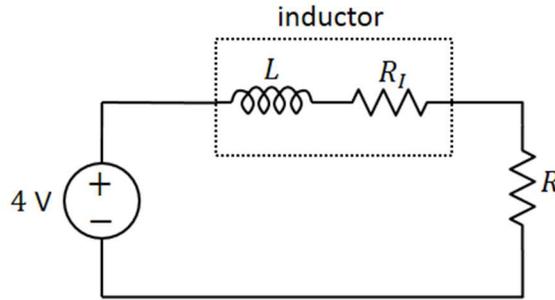
Set the synthesized frequency generator to produce a sinewave with amplitude 2 V. You will set the frequency to three different values: 1 kHz, 2 kHz, and 3 kHz. For each frequency, observe two signals on the oscilloscope: the voltage across  $C$  (the math channel) and the voltage across  $R$  (channel 2). Also, for each frequency, measure (with a voltmeter) the rms voltage across  $R$  and from this calculate the rms current.

You should find that the rms current increases with  $f$ . You should also observe that the capacitor current *leads* the capacitor voltage by approximately  $90^\circ$ . (Notice that when the capacitor voltage is at a positive-going zero crossing, the capacitor current is maximum. One-quarter period later, the capacitor voltage is maximum and the capacitor current is zero.)

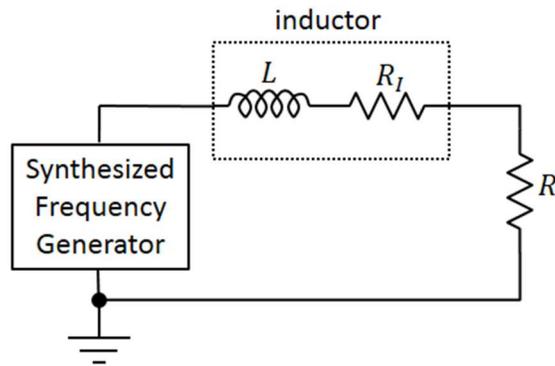
### *Inductance*

Set the adjustable inductor to every value between 100 mH and 900 mH. In every case, measure (using an ohmmeter) and record the resistance of the inductor. You should find that the resistance of the inductor depends on the inductance.

Set the inductor to 500 mH. Construct the circuit of Figure 7, using CH1 of the Siglent power supply and the component values of Table 2. Set the current limit to 0.2 A. Measure the voltage across the physical inductor (which includes both  $L$  and  $R_I$ ) and the voltage across  $R$ . Measure the current. In order to understand your results, it will be necessary for you to account for the measured value of  $R_I$ .



**Figure 7:** DC test of inductor



**Figure 8:** AC test of inductor

**Table 2:** Component values for Figures 6 and 7

$L$	$R$
500 mH	100 $\Omega$

In the circuit of Figure 7, replace the 4-V DC source with the synthesized frequency generator, as shown in Figure 8.

Set the synthesized frequency generator to produce a 500-Hz square-wave with amplitude 2 V. You should minimize the DC bias of the synthesized frequency generator. You can minimize the DC bias by adjusting the Offset knob of the generator (with the knob in the pulled-out position) while observing the generator output on the oscilloscope's channel 1 (using DC coupling).

For this circuit, we want the voltage across the series combination of the inductor and  $R$  (that is, the voltage at the generator output) connected to channel 1 of the oscilloscope. And we want the voltage across  $R$  connected to channel 2. Set the math channel of the oscilloscope to display channel 1 minus channel 2. Therefore, the math channel will display the voltage across the

inductor. You can now hide the channel-1 signal. Two signals should now be displayed: the voltage across the inductor (the math channel) and the voltage across  $R$  (channel 2). Make sure the Acquire menu is still set for an average of at least 16.

We are using  $R$  as a test resistor here. Most of the voltage produced by the synthesized frequency generator will appear across the inductor.

The voltage across  $R$  should look similar to a triangle-wave. The current in this (series) circuit equals the voltage across  $R$  divided by  $R$ . Calculate the amplitude of the triangle-wave current.

Set the synthesized frequency generator to produce a sinewave with amplitude 2 V. You will set the frequency to three different values: 500 Hz, 1 kHz, and 2 kHz. For each frequency, observe two signals on the oscilloscope: the voltage across the inductor (the math channel) and the voltage across  $R$  (channel 2). Also, for each frequency, measure (with a voltmeter) the rms voltage across  $R$  and from this calculate the rms current.

You should find that the rms current decreases with  $f$ . You should also observe that the inductor current *lags* the inductor voltage by approximately  $90^\circ$ .

## Lab Report

In your DC test of the capacitor, did the capacitor act like an open circuit for DC?

When you applied a triangle-wave voltage to the capacitor, did the current approximate a square-wave? Did it have (approximately) the expected amplitude?

With a sinewave voltage applied to the capacitor, was the current proportional to frequency?

In your DC test of the inductor, was it necessary to account for the internal resistance  $R_I$  of the inductor in order to explain the result?

When you applied a square-wave voltage to the inductor, did the current approximate a triangle-wave? Did it have (approximately) the expected amplitude?

With a sinewave voltage applied to the inductor, was the current inversely proportional to frequency?