21 Capacitive Reactance

OBJECTIVES:

After performing this experiment, you will be able to:

1. Measure the capacitive reactance of a capacitor at a specified frequency.
2. Compare the reactance of capacitors connected in series and parallel.

READING:

Floyd and Buchla, *Principles of Electric Circuits,* Sections 12–6, 12–7 and Application Activity

MATERIALS NEEDED:

Capacitors:

One of each: 0.1 μF, 0.047 μF

Resistors:

One of each: 1.0 kΩ

For Further Investigation: One 1.0 μF capacitor, one 4.7 kΩ resistor, one 10 kΩ resistor

Application Problem: One 100 kΩ resistor, one capacitor (value to be determined by student)

SUMMARY OF THEORY:

If a resistor is connected across a sine-wave generator, a current flows that is *in phase* with the applied voltage. If, instead of a resistor, we connect a capacitor across the generator, the current is not in phase with the voltage. This is illustrated in Figure 21–1. Note that the current and voltage have exactly the same frequency, but the current is *leading* the voltage by ¼ cycle.

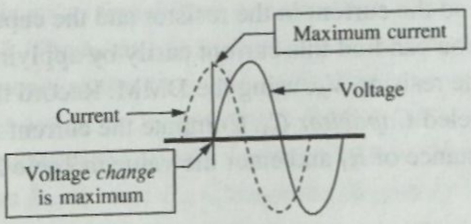

Figure 21–1 Current and voltage relationship in a capacitor.

Current in the capacitor is directly proportional to the capacitance and the rate of change of voltage. The largest current occurs when the voltage *change* is a maximum. If the capacitance is increased or the frequency is increased, there will be more current. This is why a capacitor is sometimes thought of as a high-frequency short.

Reactance is the opposition to ac current and is measured in ohms, like resistance. Capacitive reactance is written with the symbol X_C. It can be defined as

$$X_C = \frac{1}{2\pi fC}$$

where f is the generator frequency in hertz and C is the capacitance in farads.

Ohm's law can be generalized to ac circuits. For a capacitor, we find the voltage across the capacitor using the current through the capacitor and the capacitive reactance. Ohm's law for the voltage across a capacitor is written

$$V_C = I_C X_C$$

PROCEDURE:

1. Obtain two capacitors with the values shown in Table 21–1. If you have a capacitance bridge available, measure their capacitance and record in Table 21–1; otherwise record the listed value of the capacitors. Measure and record the value of resistor R_1.

2. Set up the circuit shown in Figure 21–2. Set the function generator for a 1.0 kHz sine wave with a 1.0 V_{rms} output. Measure the rms voltage with your DMM while it is connected to the circuit. Check the frequency and voltage with the oscilloscope. *Note:* 1.0 V_{rms} = 2.828 V_{pp}.

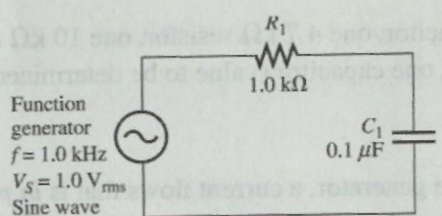

Figure 21–2

3. The circuit is a series circuit, so the current in the resistor and the capacitor are identical to the total current ($I_R = I_C = I_T$). You can find this current easily by applying Ohm's law to the resistor. Measure the voltage across the resistor, V_R, using the DMM. Record the measured voltage in Table 21–2 in the column labeled *Capacitor C_1*. Compute the current in the circuit by dividing the measured voltage by the resistance of R_1 and enter the value in Table 21–2.

4. Measure the rms voltage across the capacitor, V_C. Record this voltage in Table 21–2. Then use this voltage to compute the capacitive reactance using Ohm's law:

$$X_C = \frac{V_C}{I_T}$$

Enter this value as the capacitive reactance in Table 21–2.

5. Using the capacitive reactance found in step 4, compute the capacitance using the equation

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

Enter the computed capacitance in Table 21–2. This value should agree with the value marked on the capacitor and measured in step 1 within experimental tolerances.

6. Repeat steps 3, 4, and 5 using capacitor C_2. Enter the data in Table 21–2 in the column labeled *Capacitor* C_2.

7. Now connect C_1 in series with C_2. The equivalent capacitive reactance and capacitance can be found for the series connection by measuring across both capacitors as if they were one capacitor. Enter the data in Table 21–3 in the column labeled *Series Capacitors.* The following steps will guide you:
   (a) Check that the function generator is set to 1.0 V_{rms}. Find the current in the circuit by measuring the voltage across the resistor as before and dividing by the resistance. Enter the measured voltage and the current you found in Table 21–3.
   (b) Measure the voltage across *both* capacitors. Enter this voltage in Table 21–3.
   (c) Use Ohm's law to find the capacitive reactance of both capacitors. Use the voltage measured in step (b) and the current measured in step (a).
   (d) Compute the total capacitance by using the equation

$$C_T = \frac{1}{2\pi f X_{CT}}$$

8. Connect the capacitors in parallel and repeat step 7. Assume the parallel capacitors are one equivalent capacitor for the measurements. Enter the data in Table 21–3 in the column labeled *Parallel Capacitors.*

FOR FURTHER INVESTIGATION:

A capacitor can be used to couple an ac signal from one circuit to another. Typically, a dc voltage is also present, as shown in Figure 21–3. The ac and dc sources can be computed separately and algebraically combined as given by the superposition theorem. Use an oscilloscope to investigate this circuit by measuring the ac and dc voltages across each component. Remember to use the difference channel (CH1 − CH2) when making measurements across an ungrounded component. Show the dc and ac components of the voltage across R_1, R_2, and C_1. Change the frequency to 100 Hz and repeat the procedure. Summarize your results for both frequencies.

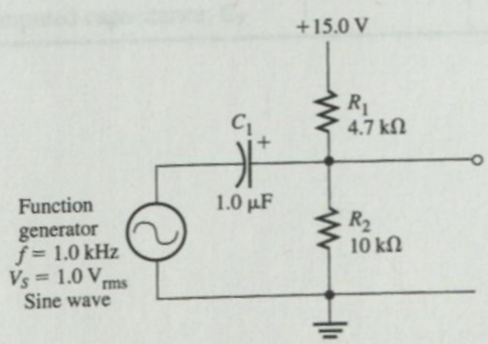

Figure 21–3

APPLICATION PROBLEM:
As illustrated in the Further Investigation, an application of capacitors is to couple an ac signal from one circuit to another while blocking any dc voltage. The capacitor is called a *coupling* capacitor. A coupling capacitor should look nearly like a short to the signal that is to be passed but appear open to the dc voltage. The basic coupling circuit is illustrated in Figure 21–4. R_{input} represents the input resistance of an amplifier and $C_{coupling}$ is the coupling capacitor.

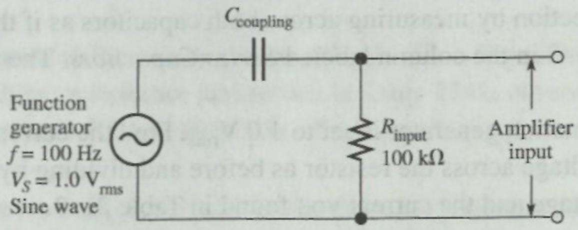

Figure 21–4

In this application, you need to find a capacitor that will allow a minimum of 90% of the generator signal to appear across R_{input} at a frequency of 100 Hz.

Compute the value of a capacitor that will meet this requirement. Construct your circuit and test it by measuring the generator voltage, the voltage drop across the capacitor, and the voltage drop across the resistor using a 100 Hz signal from the generator. Summarize your calculations and measurements in your report.

Report for Experiment 21

Name ______________
Date ______________
Class ______________

ABSTRACT:

DATA: **Table 21–1**

Component	Listed Value	Measured Value
C_1	0.1 μF	
C_2	0.047 μF	
R_1	1.0 kΩ	

Table 21–2

	Capacitor C_1	Capacitor C_2
Voltage across R_1, (V_R)		
Total current, I_T		
Voltage across C, (V_C)		
Capacitive reactance, X_C		
Computed capacitance, C		

Table 21–3

Step 7		Series Capacitors	Parallel Capacitors
(a)	Voltage across R_1, V_R		
	Total current, I_T		
(b)	Voltage across capacitors, V_C		
(c)	Capacitive reactance, X_C		
(d)	Computed capacitance, C_T		

RESULTS AND CONCLUSION:

FURTHER INVESTIGATION RESULTS:

APPLICATION PROBLEM RESULTS:

EVALUATION AND REVIEW QUESTIONS:

1. Compare the capacitive reactance of the series capacitors with the capacitive reactance of the parallel capacitors. Use your data from Table 21–3.

2. Compare the total capacitance of the series capacitors with the total capacitance of the parallel capacitors.

3. If someone had mistakenly used too small a capacitor in a circuit, what would happen to the capacitive reactance?

4. Summarize the method used in this experiment to find the value of an unknown capacitor.

5. Assume the function generator is set to a higher (but known) frequency in this experiment. Will this affect the computed capacitance in this experiment? Explain.

6. Compute the capacitive reactance for a 800 pF capacitor at a frequency of 250 kHz.