CAPACITIVE REACTANCE IN AC

Objectives

You will connect several ac circuits illustrating the characteristics of capacitance in ac and the relationship of capacitive reactance to frequency and capacitance.

In completing these projects, you will connect circuits, make measurements, perform calculations, draw conclusions, and be able to answer questions about the following items related to capacitance and capacitive reactance in ac circuits:

- Characteristic(s) of capacitance in ac circuits
- Relationship of X_C to capacitance value
- Relationship of X_C to frequency
- Total reactance of series capacitors
- Total reactance of parallel capacitors
- The X_C Formula

Project/Topic Correlation Information

PROJECT	TEXT CHAPTER	SECTION	RELATED TEXT TOPIC(S)
49 Capacitance Opposing a Change in Voltage	18	18-2	*V* and *I* Relationships in a Purely Capacitative AC Circuit
50 X_C Related to Capacitance and Frequency	18	18-4	Relationship of X_C to Capacitance Value
		18-5	Relationship of X_C to Frequency of AC
51 The X_C Formula	18	18-6	Methods to Calculate X_C

Capacitive Reactance in AC

Capacitance Opposing a Change in Voltage

PROJECT 49

Name: ______________________ Date: ____________

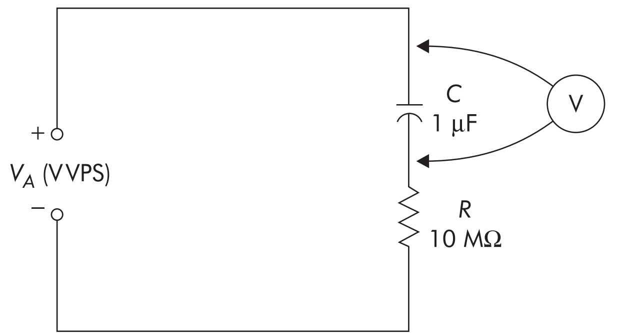


FIGURE 49-1

PROJECT PURPOSE To demonstrate the delaying effect a capacitor has on a change in voltage by varying a dc source level and observing the time it takes for the capacitor voltage to track the change in source voltage.

PARTS NEEDED

- ☐ DMM
- ☐ VVPS (dc)
- ☐ CIS
- ☐ Capacitor 1.0 µF
- ☐ Resistor: 10 MΩ

SAFETY HINTS Remember the charged capacitor warning you have seen before!

PROCEDURE

1. Connect the initial circuit as shown in Figure 49-1.
2. Temporarily remove one lead from the VVPS and then set its output voltage at 10 volts. Observe how much time it takes the capacitor to stop charging after the lead is reinserted into the VVPS by watching the voltmeter measuring V_C.

OBSERVATION Approximate time to reach a steady state for V_C was ________ seconds.

CONCLUSION V_C did not take 50 seconds to change because the (*wire, meter*) ________________ resistance formed a voltage divider with the 10-MΩ resistor.

3. Quickly turn the VVPS voltage control knob to a higher voltage setting, and note how much time it takes V_C to reach its new steady-state value.

STOP CAUTION: Do not set V_A higher than the multimeter voltage range setting.

OBSERVATION Approximate time to reach the new steady-state value was ________ seconds.

CONCLUSION It takes the voltage on the capacitor (*the same, a different*) ____________________ amount of time to change from some given value to a new value, as it does for V_C to change from zero to any steady-state value.

4. Quickly turn the VVPS voltage control knob to a lower voltage setting and observe if V_C changes instantaneously, or takes time.

OBSERVATION It (*did, didn't*) _________________ take time for V_C to decrease to its new steady-state value.

CONCLUSION From our observations, we conclude that a capacitor seems to oppose a change in (*current, voltage*) ____________________ in a similar fashion to a coil or inductor opposing a change in (*current, voltage*) ___________________.

Capacitive Reactance in AC

X_C Related to Capacitance and Frequency

PROJECT 50

Name: ______________________ Date: ______________

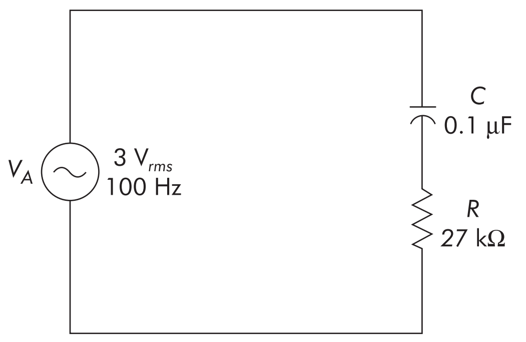
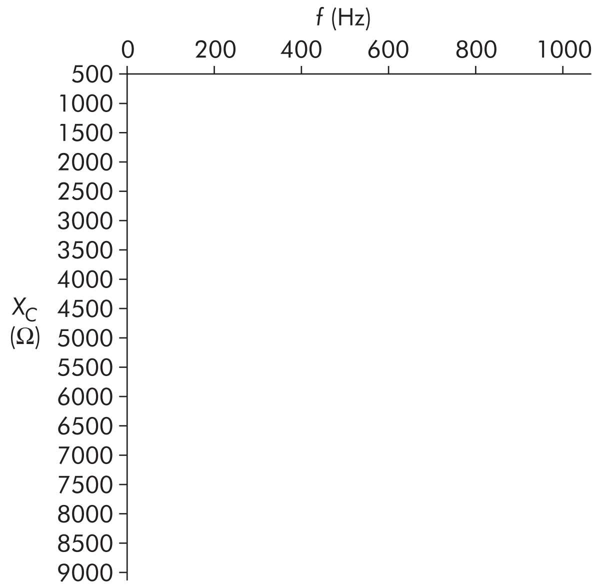


FIGURE 50-1



Use separate graph paper for drawing this graph!

FIGURE 50-2 Sample graph coordinates

PROJECT PURPOSE To verify the inverse relationship of X_C to both capacitance value and frequency by changing the values of circuit *C* and *f*, and measuring and analyzing the circuit parameter changes caused by changes in *C* and *f*.

PARTS NEEDED

- ☐ DMM
- ☐ Function generator or audio oscillator
- ☐ CIS
- ☐ Capacitors 0.1 µF 1.0 µF
- ☐ Resistor 27 kΩ

SAFETY HINTS Here's the charged capacitor warning, again! Just a reminder!

PROCEDURE

1. Connect the initial circuit as shown in Figure 50-1.
2. Set the function generator or audio oscillator to a frequency of 100 Hz and V_A to 3 volts. Measure V_R and V_C. Calculate the circuit *I* by Ohm's Law, and also calculate X_C ($X_C = V_C / I$).

OBSERVATION

V_A = ______________ V. I_T = ______________ mA.

V_R = ______________ V. X_C = ______________ Ω.

V_C = ______________ V.

CONCLUSION Since the current is the same through all parts of a series circuit and the voltage drop across R is approximately 2 times V_C, it appears that X_C must be about (*double, half*) ____________________ the value of R.

3. Change C to a 1.0-μF capacitor and repeat step 2.

OBSERVATION
V_A = ____________________ V. I_T = approximately __________ mA.
V_R = ____________________ V. X_C = approximately __________ Ω.
V_C = ____________________ V.

CONCLUSION Increasing the value of C while maintaining all other parameters the same caused X_C to (*increase, decrease*) ____________________. The X_C for the 1.0-μF capacitor was approximately (*ten times, one-tenth*) ____________________ the X_C of the 0.1-μF C. From this we conclude that X_C is (*directly, inversely*) ____________________ proportional to capacitance. This means as C decreases, X_C (*increases, decreases*) ____________________ or, if X_C has decreased, then C must have (*increased, decreased*) ____________________, all other factors being constant.

4. Keeping the 1.0-μF capacitor, change the frequency to 200 Hz and maintain 3 volts V_A. Repeat the measurements and calculations of the previous steps.

OBSERVATION
V_A = ____________________ V. I_T = approximately __________ mA.
V_R = ____________________ V. X_C = approximately __________ Ω.
V_C = ____________________ V.

CONCLUSION Increasing the frequency and keeping the C the same caused X_C to (*increase, decrease*) ____________________. If there were no voltmeter loading effects on the circuit, the indicated X_C at 200 Hz would have been (*two times, one-half*) ____________________ the X_C value at 100 Hz. From this we see that X_C is (*directly, inversely*) ____________________ proportional to frequency.

5. Keep f at 200 Hz and change C back to a 0.1-μF capacitor. Repeat the measurements and calculations of the previous steps.

OBSERVATION
V_A = ____________________ V. I_T = ____________________ mA.
V_R = ____________________ V. X_C = ____________________ Ω.
V_C = ____________________ V.

CONCLUSION Referring back to step 2 observations, does it appear that the X_C of the 0.1-μF C at 200 Hz (this step) is about one-half that at 100 Hz? ________. We conclude from the preceding that X_C is inversely proportional to ____________________ and ____________________.

6. Plot a graph of X_C versus f from 200 Hz to 1000 Hz using the 0.1-μF capacitor.

NOTE ➤ Calculate X_C for each 200 Hz change in frequency and plot with coordinates similar to those shown in Figure 50-2. Plot the graph on a separate sheet of graph paper.

OBSERVATION

X_C at 200 Hz = ____________________

X_C at 400 Hz = ____________________

X_C at 600 Hz = ____________________

X_C at 800 Hz = ____________________

X_C at 1000 Hz = ____________________

CONCLUSION Did X_C act inversely proportional to f? ________.

Capacitive Reactance in AC

The X_C Formula

PROJECT

51

Name: ______________________ Date: ______________

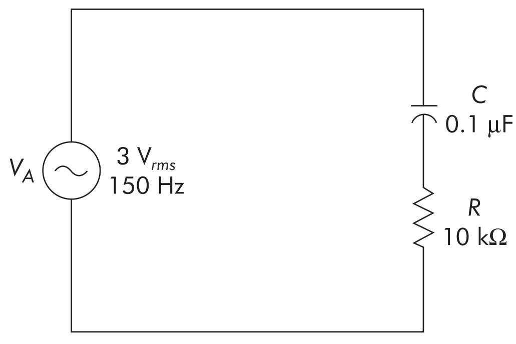


FIGURE 51-1

PROJECT PURPOSE To verify the X_C formula by changing C and f values in a simple RC circuit and making measurements and appropriate Ohm's Law calculations to see if the formula is valid.

PARTS NEEDED

- ☐ DMM
- ☐ Function generator or audio oscillator
- ☐ CIS
- ☐ Capacitors
  0.1 μF 1.0 μF
- ☐ Resistor
  10 kΩ

SPECIAL NOTE:

As shown in the previous project, the X_C of a capacitor in ohms is inversely proportional to the frequency and also to the capacitance value. This relationship is shown by the X_C formula,

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

The rationale we might use in understanding this formula is as follows. A larger C requires more charge (stored electrons) to arrive at a given difference of potential between its plates. This means that more charging (and discharging) current must flow in the circuit in order for the capacitor to "follow" the ac voltage applied to it at a given frequency than a smaller C would require under the same conditions. More current flowing for a given applied voltage indicates a lower opposition. A higher frequency also causes more charge and discharge current to flow per unit time in order for the voltage across the capacitor to follow the applied voltage.

PROCEDURE

1. Connect the initial circuit as shown in Figure 51-1.

2. Set the function generator at a frequency of 150 Hz and V_A at 3 volts. Measure V_R and then calculate I_T. Measure V_C and use the calculated I to determine X_C by Ohm's Law. Calculate X_C by the X_C formula.

OBSERVATION

V_A = ____________________________ V I = __________________________ mA.

. V_R = ____________________________ V. V_C = __________________________ V.

X_C by Ohm's Law approximately = ________ Ω.

X_C by X_C formula = ________ Ω.

CONCLUSION

Since this is a series circuit and V_C is virtually the same as V_R, it is apparent that the X_C must essentially be equal to ____________________. Was the X_C calculated by the capacitative reactance formula close to the value determined by Ohm's Law? ________.

3. Change the frequency to 75 Hz and keep V_A at 3 volts. Make the measurements and calculations described in step 2 above.

OBSERVATION

V_A = ____________________________ V. I = __________________________ mA.

V_R = ____________________________ V. V_C = ___________________________ V.

X_C by Ohm's Law approximately = ________ Ω.

X_C by X_C formula = ________ Ω.

CONCLUSION

Lowering the frequency to one-half its previous value caused the X_C to (*increase, decrease*) ____________________ to a value nearly (*double, half*) ______________ the original. Two reasons for the X_C values calculated by Ohm's Law method and X_C formula not being the same might be the resistor and capacitor __________________ and meter __________________ effects.

4. Keep the frequency at 75 Hz, but change C to 1 μF. Measure and calculate as before.

OBSERVATION

V_A = ____________________________ V. I = __________________________ mA.

V_R = ____________________________ V. V_C = ___________________________ V.

X_C by Ohm's Law approximately = ________ Ω.

X_C by X_C formula = ________ Ω.

CONCLUSION

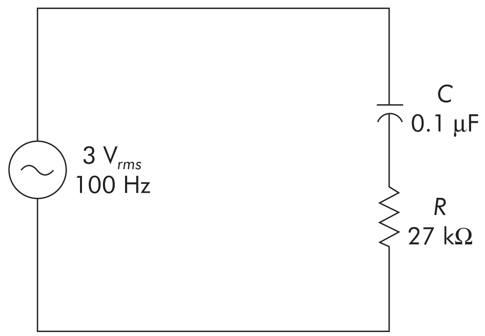
Increasing C by a factor of 10 caused the X_C to (*increase, decrease*) ______________. Did the X_C approximately change by a factor of 10? ________. From the observations we have made, does it appear that the X_C formula is functional for predicting parameters in practical circuits? ________.

PART 14

Story Behind the Numbers

Capacitive Reactance in AC

Name: ______________________________ Date: ______________



Initial Circuit

Procedure

NOTE When performing the procedure steps, you have the option of using our data collection tables and creating any requested graphs by hand; or you may use Excel for creating the required tables and create any requested graphs from the data in your Excel tables using the Excel chart feature.

1. Connect the initial circuit as shown.
2. Set the function generator (source) to a frequency of 100 Hz and V_A to 3 volts. Measure V_R and V_C. Calculate the circuit current and the value of X_C using your measurements and Ohm's Law, as appropriate. Record measured and calculated data on the Data Table, as appropriate. Disconnect one end of the circuit from the source.
3. Change the capacitor to a 1-μF capacitor. Reconnect the circuit to the source, again measure the values of V_R and V_C, and calculate circuit current and the value of X_C. Record data on the Data Table, as indicated.
4. Change the C value back to 0.1 μF, using appropriate precautions. Keep the signal frequency at 200 Hz and the input voltage set at 3 volts. Make a "frequency run" that will illustrate X_C versus f. Start at 200 Hz and incrementally change frequency by 200-hertz steps up to 1,000 Hz. (Check that V_A is still at 3 volts at each new frequency setting.) Calculate X_C for each new frequency setting, as you did before. (That is, determine circuit I value from V_R/R, then divide V_C by the I value to determine X_C.) Log all data on the Data Table, as appropriate.
5. Use the data from your frequency run and create a line graph of X_C versus frequency (f).

Data Table

Frequency Run →

Component and Parameter I.D.'s	0.1 μF @ 100 Hz	1.0 μF @ 100 Hz	f_1 0.1 μF @ 200 Hz	f_2 0.1 μF @ 400 Hz	f_3 0.1 μF @ 600 Hz	f_4 0.1 μF @ 800 Hz	f_5 0.1 μF @ 1000 Hz
V_A (V)	3	3	3	3	3	3	3
V_R measured (V_{rms})							
V_C measured (V_{rms})							
I_T (ac) calculated (mA)							
X_C calculated (kΩ)							

6. After completing the Data Table and creating the line graph, answer the Analysis Questions and develop a brief Technical Lab Report to complete the project.

Analysis Questions

1. From observing your data, define the relationship of capacitance value to capacitive reactance at any given frequency. Show a specific example of your conclusion.
2. From observing your data, define the relationship of capacitive reactance to frequency for any given capacitance value. Show at least one specific example of your conclusion.
3. From observing your graph of X_C versus frequency, does X_C change value linearly or nonlinearly with frequency change? Explain your conclusion.
4. From observing your graph of X_C versus frequency, would you say that capacitive reactance has a direct or an inverse relationship to frequency? Show a specific example of your conclusion.
5. Write the formula for finding X_C that shows these direct or inverse relationships between C, f, and capacitive reactance.
6. Show the form of the X_C formula that will allow you to find capacitance value if you know the frequency and the capacitive reactance values.

Technical Lab Report

Write a brief technical lab report summarizing the technical facts learned from this project. The report should be organized to provide the following:

1. An introductory paragraph describing the type of circuit being analyzed and the key parameters that will be discussed relating to this circuit.
2. A section describing the most important characteristics of this type of circuit that were shown via the collected data in the tables and graphs.

3. Any special facts or characteristics about this type of circuit that were highlighted in answering the Analysis Questions.
4. A practical example of how the information learned in this project might help you in operating, troubleshooting, error analysis, or adjusting a circuit of this type in your home setting, in your training program setting, or in a job setting in the real world.
5. A summary statement listing the most positive aspects of the project and any parts of the project that were difficult because of equipment problems or unclear instructions. Include areas that might be improved.

Summary

Capacitive Reactance in AC

Name: ______________________________ Date: ____________

Complete the following review questions, indicating the appropriate response by placing a check in the box next to the correct answer.

1. X_C is measured in ohms because it limits ac current to a value of
   - ☐ $0.159 \times f \times C$
   - ☐ $0.159/fC$
   - ☐ V/X_C
   - ☐ none of these

2. The formula for X_C is
   - ☐ $X_C = 2\pi/fC$
   - ☐ $X_C = fC/0.159$
   - ☐ $X_C = 1/2\pi fC$
   - ☐ none of these

3. For a given value of C, if f is increased, then X_C will
   - ☐ increase
   - ☐ remain the same
   - ☐ decrease

4. For a given value of f, if C is decreased, then X_C will
   - ☐ increase
   - ☐ remain the same
   - ☐ decrease

5. A capacitor appears to oppose a change in voltage because current must flow before a difference of potential can be established across a capacitor.
   - ☐ True
   - ☐ False

6. Since capacitors in series add like resistors in parallel, the X_C of two series capacitors will be
   - ☐ greater than either one alone
   - ☐ less than either one alone

7. Capacitive reactances in parallel add like resistances in
   - ☐ series
   - ☐ neither of these
   - ☐ parallel

8. If C and f are both doubled in a given circuit, the X_C will
   - ☐ increase two times
   - ☐ increase four times
   - ☐ decrease two times
   - ☐ decrease four times

9. If C is doubled and f is halved in a given circuit, the X_C will
   - ☐ increase
   - ☐ remain the same
   - ☐ decrease

10. What is the total capacitive reactance of two series 1-μF capacitors at a frequency of 200 Hz?

- ☐ 3180 Ω
- ☐ 15.9 Ω
- ☐ 318 Ω
- ☐ 1.59 kΩ
- ☐ 31.8 kΩ
- ☐ none of these