LAB 7

TEET 3145 Circuit Analysis II Lab
and EENG 2111 Circuit Analysis Lab

Name:______________________

[redacted] Capacitance, Capacitive Reactance, and Capacitive Impedance

Objectives

In this experiment students will:

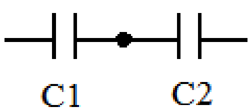
1. Confirm how capacitances add when two capacitors are connected in parallel and in series.
2. Determine the reactance of a capacitor by measuring voltage and current.
3. Draw impedance and voltage phasor diagrams for a Capacitive circuit.
4. Explain the effect of frequency on the impedance and voltage phasors for a Capacitive circuit.

Background

A capacitor is formed whenever two conductors are separated by an insulating material. Consider the simple example of two parallel conducting plates separated by a small gap that is filled with an insulating material (vacuum, air, glass, or other dielectric). If a potential difference exists between the two plates, then an electric field exists between them, and opposite electric charges will be attracted to the two plates. The ability to store that electric charge is a fundamental property of capacitors. The larger the plates, the more charge can be stored. The closer the plates, the more charge can be stored, at least until the charges leap the gap and the dielectric breaks down.

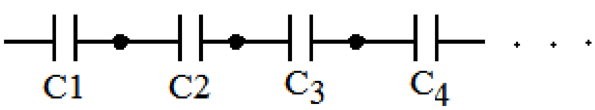
Capacitors in Series

For two capacitors in series the equivalent capacitance is:



$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} \quad or \quad C_T = \frac{C_1 C_2}{C_1 + C_2}$$

For more than 2 capacitor in series, the general formula is:



$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_4} \cdots$$

Capacitors in Parallel

Connecting capacitors in parallel is effectively the same as making a single capacitor's plates larger, and therefore able to hold more charge for a given applied voltage. This simple view is borne out if one analyzes the flow of charge through a parallel array of capacitors connected to a voltage source. The result of such analysis is that capacitances in parallel add directly:

$C_T = C_1 + C_2 + C_3 + \ldots$

Capacitive Reactance

Reactance is a characteristic exhibited by capacitors and inductors in circuits with time-varying voltages and currents, such as common sinusoidal AC circuits. Like resistance, reactance opposes the flow of electric current and is measured in ohms. Capacitive reactance X_C can be found by the equation:

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

where f is the frequency (in Hz) of the applied voltage or current and C is the capacitance in farads. As with resistance, reactance obeys Ohm's law:

$$V_C = I_C X_C \quad or \quad X_C = \frac{V_C}{I_C}$$

Impedance

Impedance (**Z**) is a measure of the overall opposition of a circuit to current, this is: how much the circuit **impedes** the flow of current.

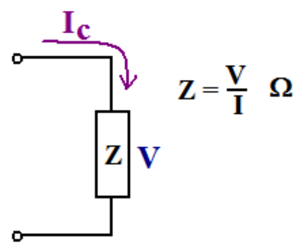


Figure 1 . Impedance concept

In general the Impedance can be split into two parts: $\mathbf{Z = R + j\,X}$

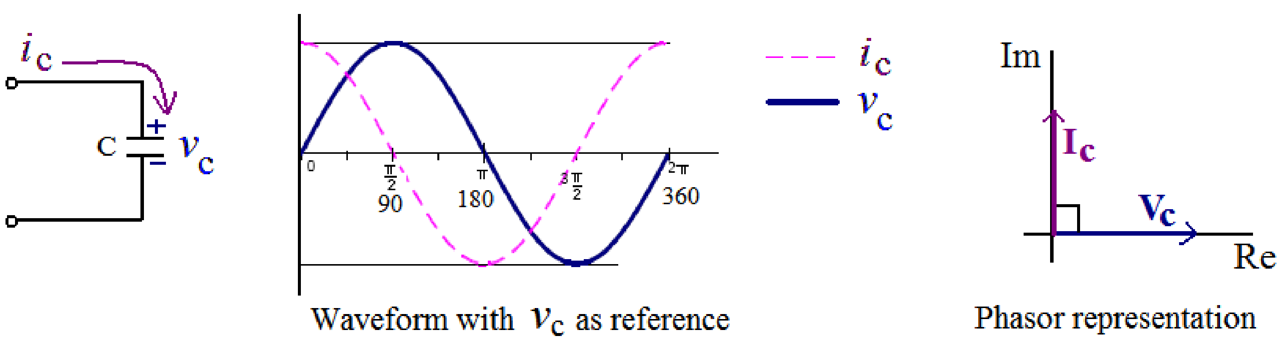
- **Resistance R** (the part which is constant regardless of frequency)
- **Reactance X** (the part which varies with frequency due to capacitance and inductance)

Note that for a pure capacitor $\mathbf{R = 0}$ and $\mathbf{Z = -\,j\,Xc}$

$$\mathbf{Z_C = -\,j\,\frac{1}{\omega C} = \frac{1}{\omega C}\ \angle -90^{o}}$$

Voltage-Current Phasor Representation in a Capacitor

If a sinusoidal voltage is applied across a *resistor*, the current through the resistor is *in phase* with the voltage. That is not true for a capacitor. If we connect a *capacitor* across a sinusoidal voltage, the maximum current flows through the capacitor when the voltage is zero (90^{o} phase); and vice versa, this is, when the voltage is at maximum the current is zero. This is shown in the following time domain and phasor domain sketches



For a capacitor the current always leads the voltage by 90^{o}

Figure 2. Time domain and Phasor representation of voltage and current in a capacitive circuit

PRE-LAB CALCULATIONS

Before going to the lab perform the following calculations.

1) Find C_T for each circuit given in Fig 3.
2) For the circuit given in Fig. 4 calculate Ic, Xc, and Z_C for f = 500 Hz and 2 kHz
3) From results in 2), sketch the time domain representation of V_C and I_C.
4) From results in 2), sketch the phasor representation of V_C and I_C.

EXPERIMENTAL PROCEDURE

1.- Calculating and Measuring Total Capacitance

A) Select 3 capacitors with nominal value 1 µF each. Measure their actual values:

$C_1 = C_2 = C_3$ (nominal value) = ____________

Actual values:

C_1 = ____________ ; C_2 = ______________ ; C_3 = ____________

B) Using the actual values and the measured values of the capacitors, calculate the equivalent capacitance for the circuits given in Fig. 3. Show below all your calculations and write your results in the corresponding spaces in Table 1.

C) Using the breadboard connect each of the three capacitor configurations given in Fig. 3 and measure their equivalent capacitance. Write your results in Table 1.

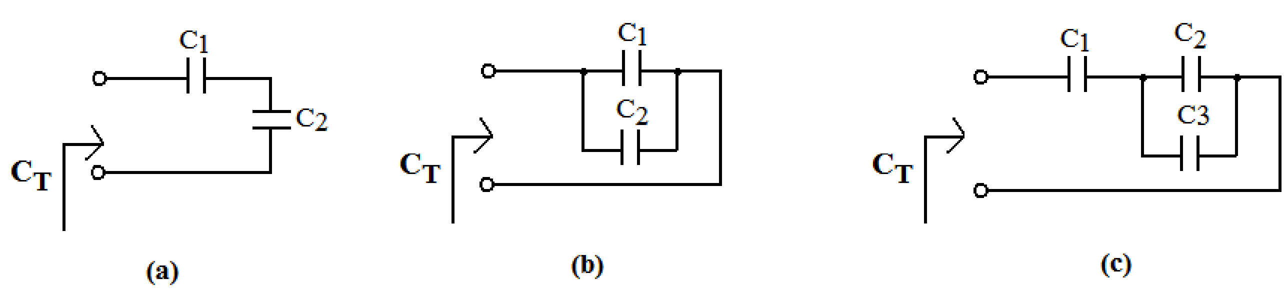


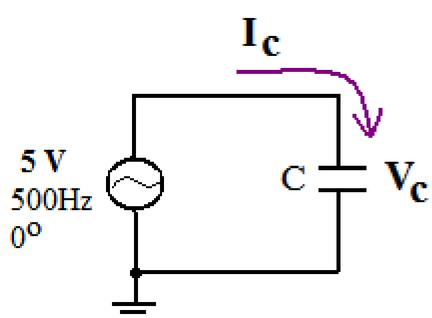
Figure 3. Capacitive Circuit Configurations

Table 1. Total Capacitance For Circuits in Fig. 3

Circuit	Total Capacitance C_T Calculated (theoretical)		Total Capacitance C_T Measured (experimental)
	Using nominal values	Using measured values	
(a)			
(b)			
(c)			

2.- Calculating and measuring capacitive reactance in an AC Circuit

The easiest way to calculate the actual capacitive reactance in a series circuit is using the Ohm's law method where the circuit voltage is divided by the circuit current. Build the circuit shown in figure 4. Select C = 2 μ F and adjust the power source to sine wave, peak value 5 volts, and frequency 500 Hz. Set the DMM to AC mode and measure the current in the series circuit. Measure the voltage across the capacitor (AC) using the DMM. Notice that the DMM readings are RMS values (RMS = Peak Values / √2).



Consider C = 2 μ F

Figure 4 Using Ohms' law to calculate Capacitive Reactance

I_C (RMS) = _______________ ; V_C (RMS) = __________________

Using the measured values I_C and V_C, calculate Xc, indicate clearly the units for Xc

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

What are the peak values for the voltage and current readings?

I (peak value) = _______________; V (peak value)= __________________

Compare the experimental reactance with the theoretical value using the equation

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

Table 2. Experimental and Theoretical Capacitive Reactance in the circuit of fig.4

Capacitive Reactance (theoretical) =	
Capacitive Reactance (experimental) =	

3.- Phase Relationships in Capacitive Circuits

In a purely capacitive circuit, the current leads the voltage by 90^{o} . In other words, the sinusoidal current that flows onto the capacitor plates will lead the voltage drop across the capacitor by 90^{o}.
In an electronic circuit with only a capacitor in the circuit, it is difficult to display this relationship. It is easy to observe the voltage across the capacitor with an oscilloscope (**an oscilloscope can only display voltage**), but is not possible to observe the current flow in the capacitor. The way to go around and observe the phase shift is to insert a very small resistor in series with the capacitor to monitor the circuit current (the current is the same through the resistor and the capacitor in a series circuit). Fig. 5 shows the circuit will be use to measure the phase shift in this experiment. Select R = 1 Ω and C = 2μ F. Set this circuit and use channel 1 to measure the voltage across the capacitor, and channel 2 to measure the voltage across the resistor.

<u>**Note:**</u> Because R = 1 Ω, and $I_R = V_R/R$; therefore ***for this particular case*** $I_R = V_R$, so if we measure the voltage in the resistor its value will be the same as the current in the series circuit, this is $V_R = I_R = I_C$

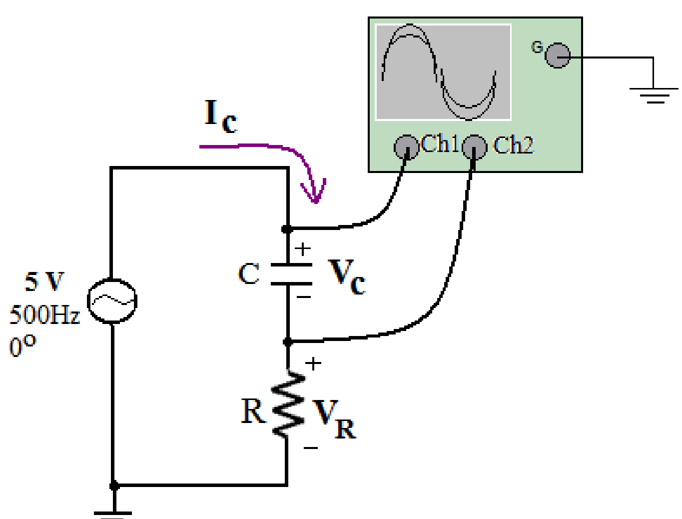


Figure 5. Circuit to Measure Phase Shift in a Capacitive Circuit
(Set R = 1 Ω and C = 2 μF)

Observe the AC signals in both channels of the oscilloscope and sketch below those signals. Answer the following questions.

a) What is the period and frequency of V_C (channel 1) : ______________________________

b) What is the frequency and period of I_C (channel 2): ______________________________

c) What is the phase shift between Vc and Ic , measure it : ____________________________

d) Write the time domain equation for V_C : ________________________________

e) Write the time domain equation for I_C : ________________________________

f) Write the Phasor equation for V_C : ________________________________

g) Write the Phasor equation for I_C : ________________________________

h) From the above Phasor equations calculate the impedance of the capacitor $Z_C = V_C / I_C$

4.- Repeat 2 and 3 changing the frequency of the voltage source to 2 KHz

5 . MultiSim. Repeat the steps in the experiment using MultiSim. Include your MultiSim results in the lab report.

In particular be sure you include 1 C), 2, and 3 (measurements in Fig.5) with the two frequencies: 500 Hz and 2 KHz. To better show you MultiSim results create tables similar to the ones given in the experiment.

Instructor Verification: ________________