# University of Jordan
# School of Engineering
# Electrical Engineering Department


## EE 374
## Electrical Engineering and Machines lab

## EXPERIMENT 4

# CAPACITIVE REACTANCES

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## OBJECTIVE

Capacitive reactance will be examined in this experiment. In particular, its relationship to the AC source frequency will be investigated, including a plot of capacitive reactance versus frequency. In addition, AC power and power factor calculations will be introduced.

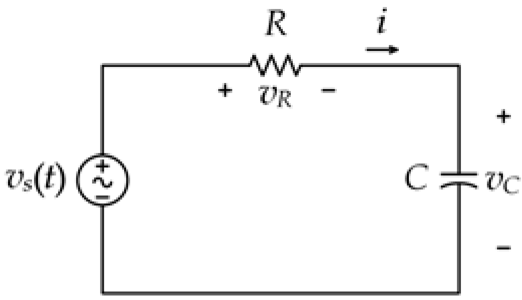
## DISCUSSION

The AC current-voltage characteristic of a capacitor, known as capacitive *reactance* $X_C$ is inversely proportional to frequency. Hence, the *impedance* of a capacitor ( Zc) (in units of Ohm) .The inverse of the impedance is *admittance* $Y = 1/Z = G + jB$, which has the real part G called *conductance*, and the imaginary part B called *susceptance*. All three quantities have units of Siemens (S).

The capacitive reactance may be determined experimentally by applying a known AC voltage across the capacitor, measuring the resulting current, and dividing the two. This process may be repeated across a range of frequencies in order to obtain a plot of capacitive reactance versus frequency.

**AC-excited series RC circuit**

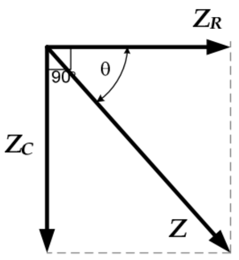
For the series RC circuit shown below, the capacitor impedance $Z_C$ changes with the frequency of the source, the total impedance Z changes with frequency as well, as shown in the following phasor diagram. Notice how the resistor impedance remains constant with frequency.



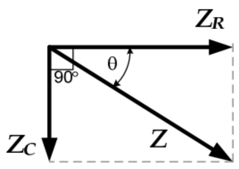

- Some important equations to find the needed quantities in the report tables:

| Quantity | Practically | Theoretically |
|---|---|---|
| Total current | $I = V_R/R = \lvert I \rvert \measuredangle I$ | $\frac{Vs}{\lvert Z \rvert \measuredangle Z}$ |
| Capacitor Reactance | $X_C = \lvert V_C \rvert / \lvert I \rvert$ | $\frac{1}{\omega C}$ |
| Total impedance magnitude | $\lvert Z \rvert = \lvert V_S \rvert / \lvert I \rvert$ | $\sqrt{R^2 + \frac{1}{(\omega C)^2}}$ |
| Total impedance phase | $\measuredangle Z = \measuredangle V_S - \measuredangle I$ | $-tan^{-1}(\frac{1}{\omega RC})$ |

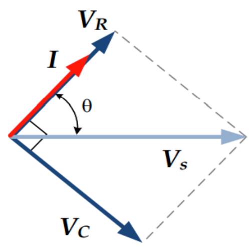
The following phasor diagram shows how the above impedance change affects the capacitor voltages ($V_C$) and resistor voltage ($V_R$), which now change with frequency for a constant $V_S$ due to the voltage divider rule. The current I also changes along with its phase shift compared to the source voltage $V_S$, but the current remains leading compared to the source voltage in case of RC circuit. Notice that complex numbers are added like vectors, not like scalars.



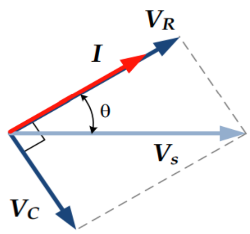

$f_1$




$f_2 > f_1$



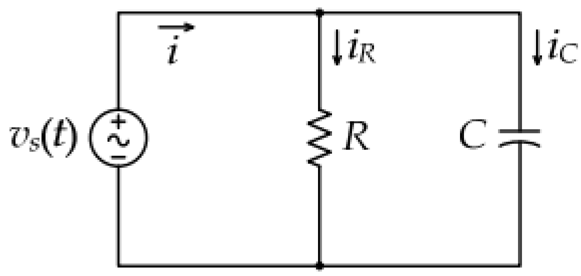

$f_1$

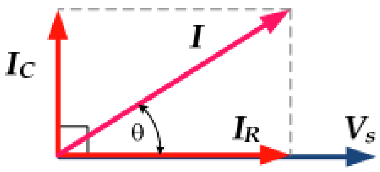



$f_2 > f_1$

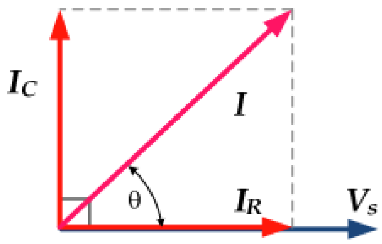
**AC-excited parallel RC circuit**

The parallel RC circuit shown below, the phasor diagram shows how the capacitive admittance change with frequency affects the capacitor current $I_C$, which increases with increasing frequency for a constant source voltage $V_S$. The resistance current $I_R$, however, stays constant, which means that the total current I changes (due to phasor addition) along with its phase shift compared to the source voltage $V_S$. Of course, the current leads the source voltage due to the capacitive load.




$f_1$




$f_2 > f_1$

- Some important equations to find the needed quantities in the tables

| Quantity | Practically | Theoretically |
|---|---|---|
| Total current | $I = V_{R'} / R' = \lvert I \rvert \measuredangle I$ | $\frac{Vs}{\lvert Z \rvert \measuredangle Z}$ |
| Resistor and Capacitor voltage | $V_R = Vs - V_{R'} = Vc = \lvert V_R \rvert \measuredangle V_R$ | $V_R = I_R * R = Vc$ |
| Resistor current | $I_R = V_R / R = \lvert I_R \rvert \measuredangle I_R$ | $I_R = V_R / R$ |
| Capacitor current | $I_C = I - I_R = \lvert I_C \rvert \measuredangle I_C$ | $I_C = Vc / Zc$ |
| Capacitor Susceptance | $B_C = \lvert I_C \rvert / \lvert V_C \rvert$ | $\omega C$ |
| Total admittance magnitude | $\lvert Y \rvert = \lvert I \rvert / \lvert V_S \rvert$ | $\sqrt{\frac{1}{R^2} + (\omega C)^2}$ |
| Total admittance phase | $\measuredangle Y = \measuredangle I - \measuredangle V_S$ | $tan^{-1}(\omega RC)$ |

**Power and Power Factor**

The average *complex power* $\boldsymbol{S}$ (units of VA) is given by the combination of the average *real power* $P$ and the average *reactive power* $Q$ as follows:

$$\boldsymbol{S} = P + jQ = V_{rms} I_{rms} \measuredangle(\measuredangle V - \measuredangle I) = \frac{1}{2} V_p I_p \measuredangle(\measuredangle V - \measuredangle I)$$

Hence, the real power $P$ (units of W) is given by:

$$P = V_{rms} I_{rms} \cos(\measuredangle V - \measuredangle I) = \frac{1}{2} V_p I_p \cos(\measuredangle V - \measuredangle I)$$

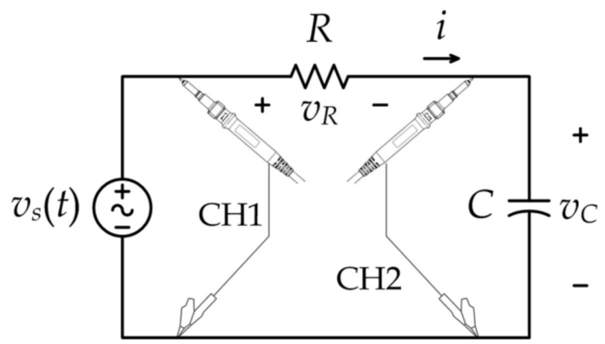
And the reactive power $Q$ (units of VAR) is given by:

$$Q = V_{rms} I_{rms} \sin(\measuredangle V - \measuredangle I) = \frac{1}{2} V_p I_p \sin(\measuredangle V - \measuredangle I)$$

where the $\cos(\measuredangle V - \measuredangle I)$ quantity is known as the *power factor* (PF), which is lagging for inductive loads, and leading for capacitive loads. Finally the *apparent power* is given by $|\boldsymbol{S}| = V_{rms} I_{rms} = 0.5 \times V_p \times I_p$.

**PROCEDURE A – AC-EXCITED SERIES RC CIRCUIT**

1. Construct the circuit shown below. Assume that $R$ **= 1200 Ω,** $C$ **= 1 μF**.




2. Set the function generator to produce a **sinusoidal** waveform (AC) with frequency of **50 Hz**, and peak to peak voltage of **$V_{p-p}$= 10 V**.

3. Use the oscilloscope to measure the **peak to peak** values of $V_C$ and $V_R$ , the phase shift of $V_C$ and $V_R$ compared to $V_S$**. R**ecord all the measurements in Table 1 in the report.

4. Measure the current in (RMS) and record the results in Table 1 in the report.

5. Can we just subtract the magnitudes of $|V_S|$ - $|V_C|$ to obtain the magnitude $|V_R|$? Why?

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6. What is the relationship between the period T of the two signals $V_S$ and $V_R$?

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7. Evaluate the reactance of the capacitor $X_C$ and the total impedance Z of the series R and C components, and record them in Table 2 in the report.

8. Evaluate the apparent power, real power, reactive power generated by the source (function generator) and power factor (PF) and state whether it is leading or lagging. Record them in Table 3 in the report.

9. Plot the following versus source frequency using the values in Table 1, 2 and 3:

(1) $X_C$ and |Z| on the same plot.

(2) ∡Z.

(3) $V_C$ and $V_R$ on the same plot.

(4) P and Q on the same plot.

10. From Table 3, at what frequency the real power P and the magnitude of the reactive power |Q| is maximum?

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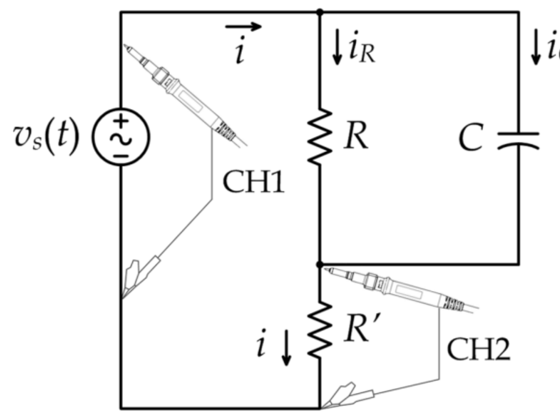
## PROCEDURE B – AC-EXCITED PARALLEL RC CIRCUIT

1. Construct the circuit shown below using ***R* = 1200 Ω, *C* = 1 μF, and *R′* = 10 Ω.** Make sure you use the correct resistor values.

2. Set the function generator to produce a **sinusoidal** waveform (AC) with frequency of **800 Hz**, and peak to peak voltage of **$V_{pp}$= 10 V**.




3. Use the oscilloscope to measure the **peak to peak** value of the voltage $V_{R'}$ and its phase shift compared to $V_S$. Record the measurements in Table 4 in the report.

4. Measure the currents in (RMS) and record the results in Table 5 in the report.

5. Evaluate phase shift and record the results in Table 5 in the report.

6. Can we just subtract the magnitudes of |I| - $|I_R|$ to obtain the magnitude $|I_C|$? Why?

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7. Evaluate the susceptance of the capacitor $B_C$ and the total admittance Y (magnitude and phase). Record them in Table 6 in the report.

8. Plot the following figures versus source frequency using the values in Table 5 and 6:
(1) $B_C$ and |Y| on the same plot.
(2) ∡Y versus source frequency.
(3) $I_C$ and $I_R$ on the same plot.

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