AC: series RC circuits (Lab 4)

More on capacitors and RC circuits

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1.0 PURPOSE

- To observe current and voltage relationships in a series RC circuit.
- To measure phase angles in a series RC circuit.

2.0 EQUIPMENT NEEDED

- (1x) desktop waveform generator.
- (3x) 4-band (1/4 watt) resistors.
- (1x) non-polarized capacitors.
- (1x) electronics breadboard.
- (1x) Keysight oscilloscope.
- (? x) BNC cables, oscilloscope accessories and others.

3.0 PRE-LAB

Prelab work

1. Refer to the circuit of Figure 1. For each value of R, calculate the theoretical values for the quantities listed in Table 1, assuming Vg is at 0°.

   For the quantity listed as “phase”, calculate the phase angle between generator current and generator voltage. If the current leads the voltage, the angle is negative, indicating the circuit is capacitive. This angle will be the same as the angle of impedance.

**Voltages represented in this table are in RMS.*

R	(1.8 kΩ)	(5.6 kΩ)	(12 kΩ)
Z	$\mathbf{8.2K\Omega}$	$\mathbf{9.7K\Omega}$	$\mathbf{14.2K\Omega}$
I_G	$\mathbf{367\mu A}$	$\mathbf{308\mu A}$	$\mathbf{211\mu A}$
V_R	$\mathbf{661mV}$	$\mathbf{1.72V}$	$\mathbf{2.534V}$
V_C	$\mathbf{2.92V}$	$\mathbf{2.45}$	$\mathbf{1.68V}$
Phase	***-77°***	***-54°***	***-32°***

Table 1: Series RC circuit calculation

Calculations on next page

Calculations:

(for 1.8kΩ)

Calculated X_C:

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

$X_C = \frac{1}{2\pi(2kHz)(10nF)}$

$\boldsymbol{X_C = 7.9k\Omega}$

Calculated Z:

$Z = \sqrt{{X_C}^2 + R^2}$

$Z = \sqrt{7.9k\Omega^2 + 1.8k\Omega^2}$

$\boldsymbol{Z = 8.2k\Omega}$

Calculated I_G:

$I_G = \frac{V_G}{Z}$

$I_G = \frac{3.0V_{RMS}}{8.2k\Omega}$

$\boldsymbol{I_G = 367\mu A}$

Calculated V_R:

$V_R = I_G * R$

$V_R = 367\mu A * 1.8k\Omega$

$\boldsymbol{V_R = 661mV_{RMS}}$

Calculated V_C:

$V_C = I_G * X_C$

$V_C = 367\mu A * 7.9k\Omega$

$\boldsymbol{V_C = 2.92V_{RMS}}$

Calculated Phase:

$Phase = tan^{-1}(\frac{X_C}{R})$

$Phase = tan^{-1}(\frac{7.9k\Omega}{1.8k\Omega})$

$\boldsymbol{Phase = -77°}$

(for 5.6kΩ)

Calculated X_C:

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

$X_C = \frac{1}{2\pi(2kHz)(10nF)}$

$\boldsymbol{X_C = 7.9k\Omega}$

Calculated Z:

$Z = \sqrt{{X_C}^2 + R^2}$

$Z = \sqrt{7.9k\Omega^2 + 5.6k\Omega^2}$

$\boldsymbol{Z = 9.7k\Omega}$

Calculated I_G:

$I_G = \frac{V_G}{Z}$

$I_G = \frac{3.0V_{RMS}}{9.7k\Omega}$

$\boldsymbol{I_G = 308\mu A}$

Calculated V_R:

$V_R = I_G * R$

$V_R = 308\mu A * 5.6k\Omega$

$\boldsymbol{V_R = 1.72V_{RMS}}$

Calculated V_C:

$V_C = I_G * X_C$

$V_C = 308\mu A * 7.9k\Omega$

$\boldsymbol{V_C = 2.45V_{RMS}}$

Calculated Phase:

$Phase = tan^{-1}(\frac{X_C}{R})$

$Phase = tan^{-1}(\frac{7.9k\Omega}{5.6k\Omega})$

$\boldsymbol{Phase = -54°}$

(for 12kΩ)

Calculated X_C:

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

$X_C = \frac{1}{2\pi(2kHz)(10nF)}$

$\boldsymbol{X_C = 7.9k\Omega}$

Calculated Z:

$Z = \sqrt{{X_C}^2 + R^2}$

$Z = \sqrt{7.9k\Omega^2 + 12k\Omega^2}$

$\boldsymbol{Z = 14.2k\Omega}$

Calculated I_G:

$I_G = \frac{V_G}{Z}$

$I_G = \frac{3.0V_{RMS}}{14.2k\Omega}$

$\boldsymbol{I_G = 211\mu A}$

Calculated V_R:

$V_R = I_G * R$

$V_R = 211\mu A * 12k\Omega$

$\boldsymbol{V_R = 2.53V_{RMS}}$

Calculated V_C:

$V_C = I_G * X_C$

$V_C = 211\mu A * 7.9k\Omega$

$\boldsymbol{V_C = 1.68V_{RMS}}$

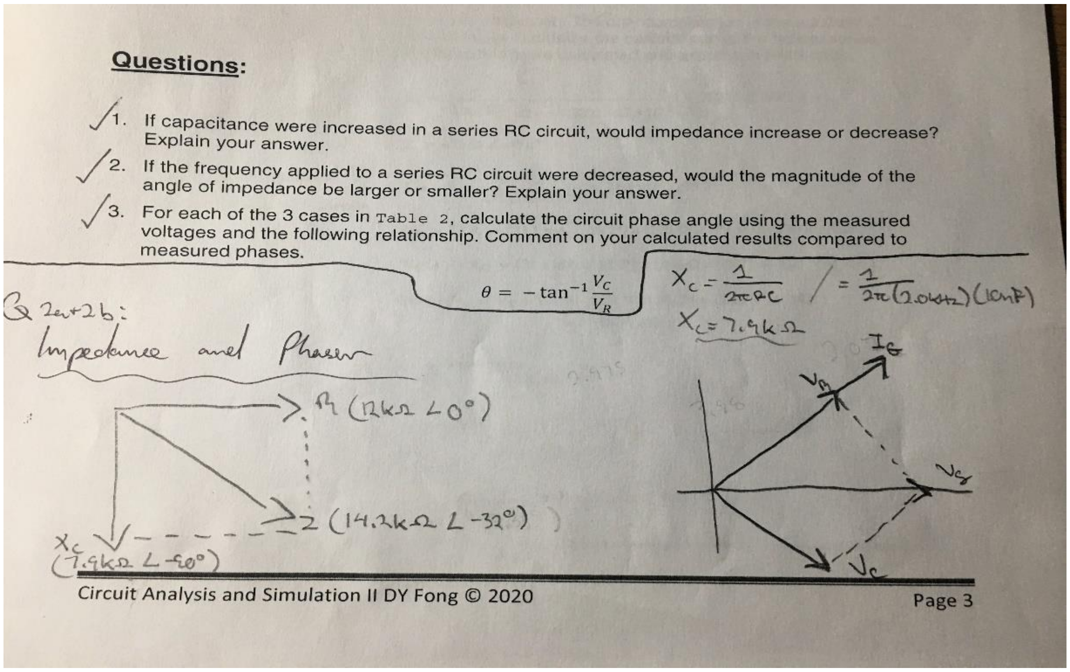
Calculated Phase:

$Phase = tan^{-1}(\frac{X_C}{R})$

$Phase = tan^{-1}(\frac{7.9k\Omega}{12k\Omega})$

$\boldsymbol{Phase = -32°}$

2a, b)



Questions:

1. If capacitance were increased in a series RC circuit, would impedance increase or decrease? Explain your answer.
2. If the frequency applied to a series RC circuit were decreased, would the magnitude of the angle of impedance be larger or smaller? Explain your answer.
3. For each of the 3 cases in `Table 2`, calculate the circuit phase angle using the measured voltages and the following relationship. Comment on your calculated results compared to measured phases.

$$\theta = -\tan^{-1}\frac{V_C}{V_R}$$

Q 2a+2b:

Impedance and Phasor

$X_C = \frac{1}{2\pi RC} = \frac{1}{2\pi(2.0kHz)(10nF)}$

$X_C = 7.9k\Omega$

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4.0

EXPERIEMNTAL RESULTS

Results from the Procedure section:

3) Connect the circuit of the following figure, using 1.8 kΩ as R. After the circuit is connected, set the generator voltage to 3.0V, at frequency of 2.0 kHz.

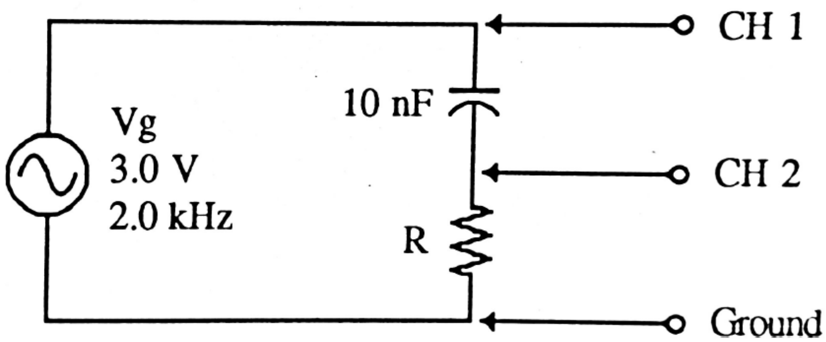


Figure 1 : Series RC measurement circuit

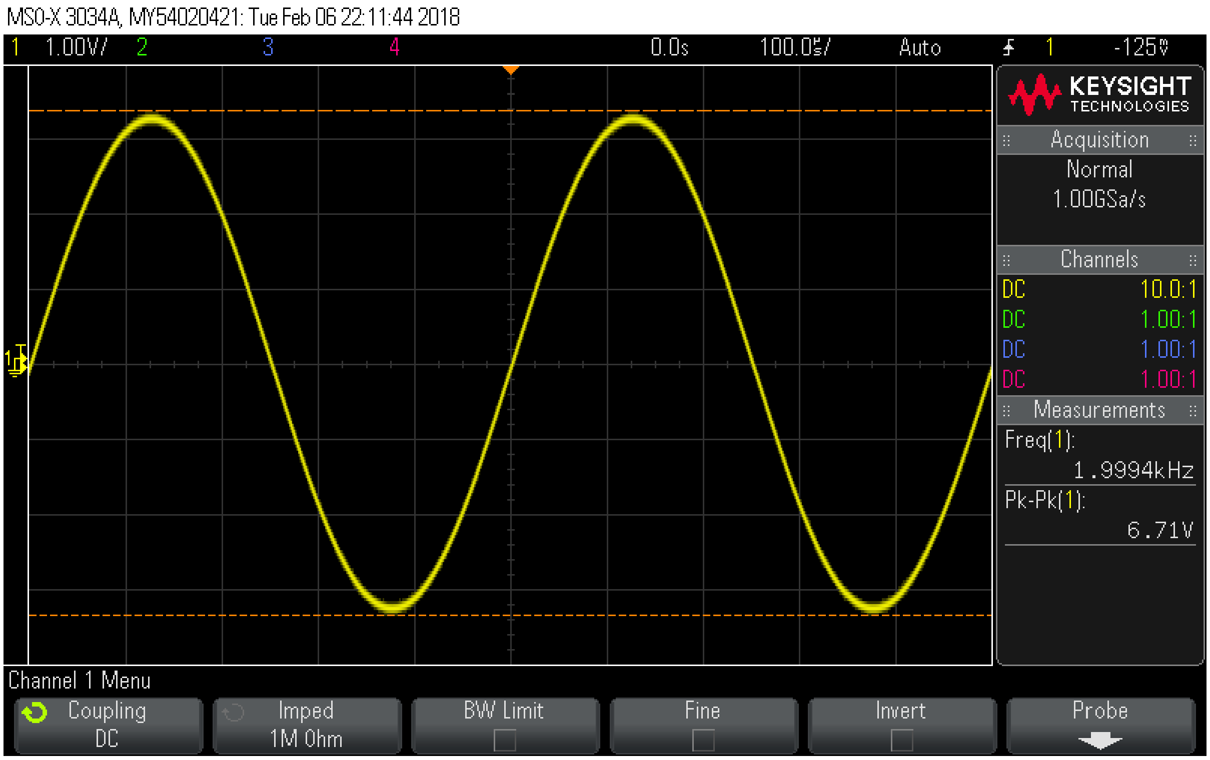
Where:

R = 1.8kΩ or 5.6kΩ or 12kΩ

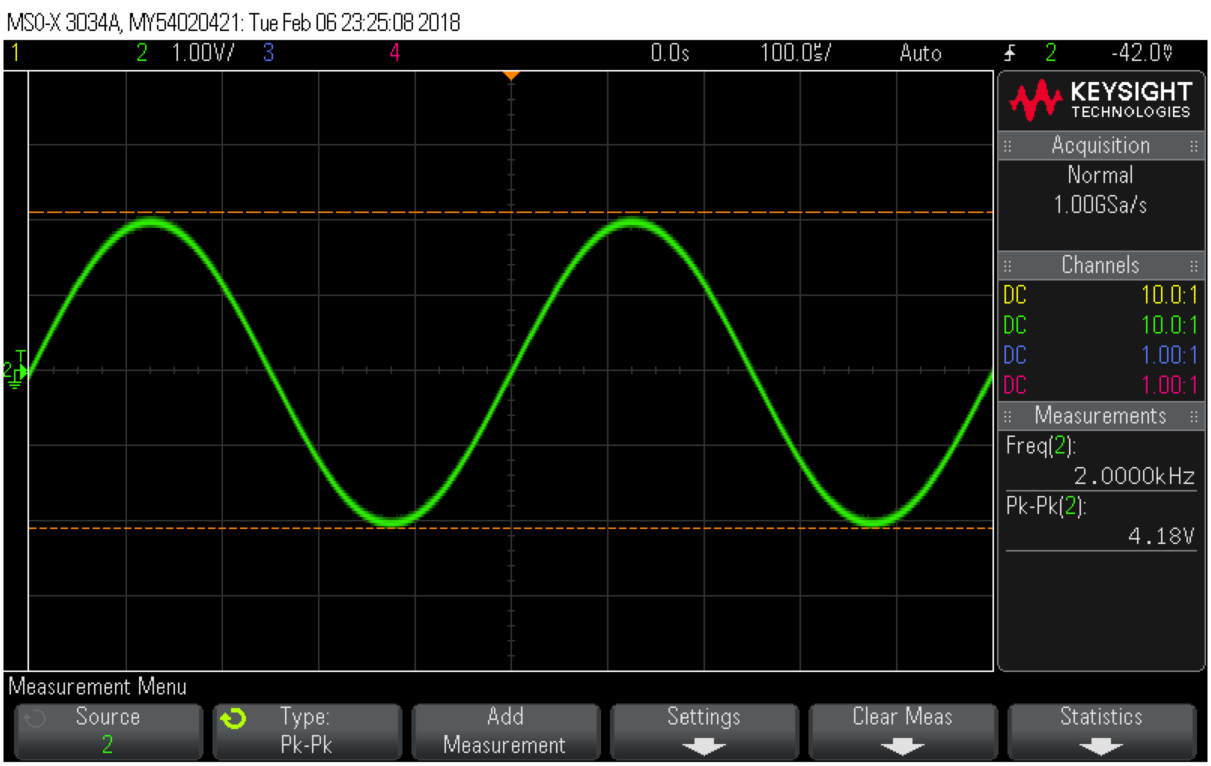
$V_G = 3.0V_{RMS}$

F = 2.0kHz

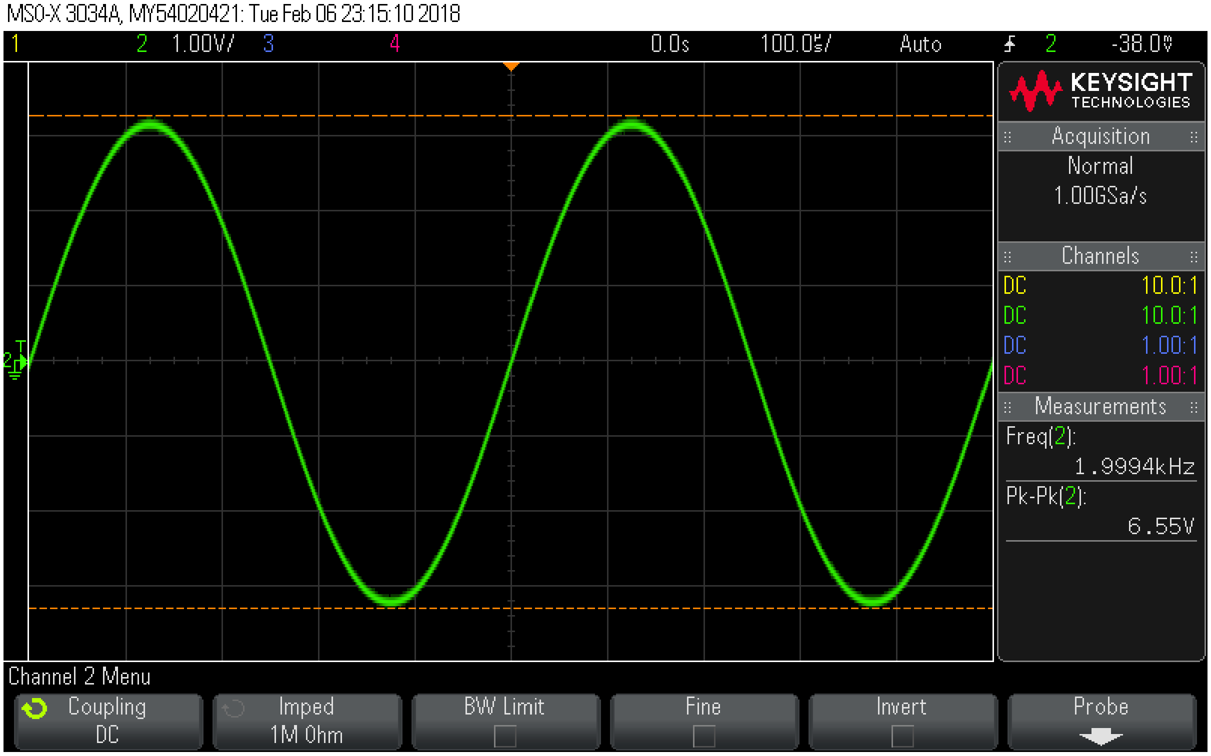
4)



Screenshot representing the voltage across the 1.8kΩ resistor (6.71Vpp = 524mV$_{RMS}$ shown above)



Screenshot representing the voltage across the 5.6kΩ resistor (4.18Vpp = 1.46mV$_{RMS}$ shown above)



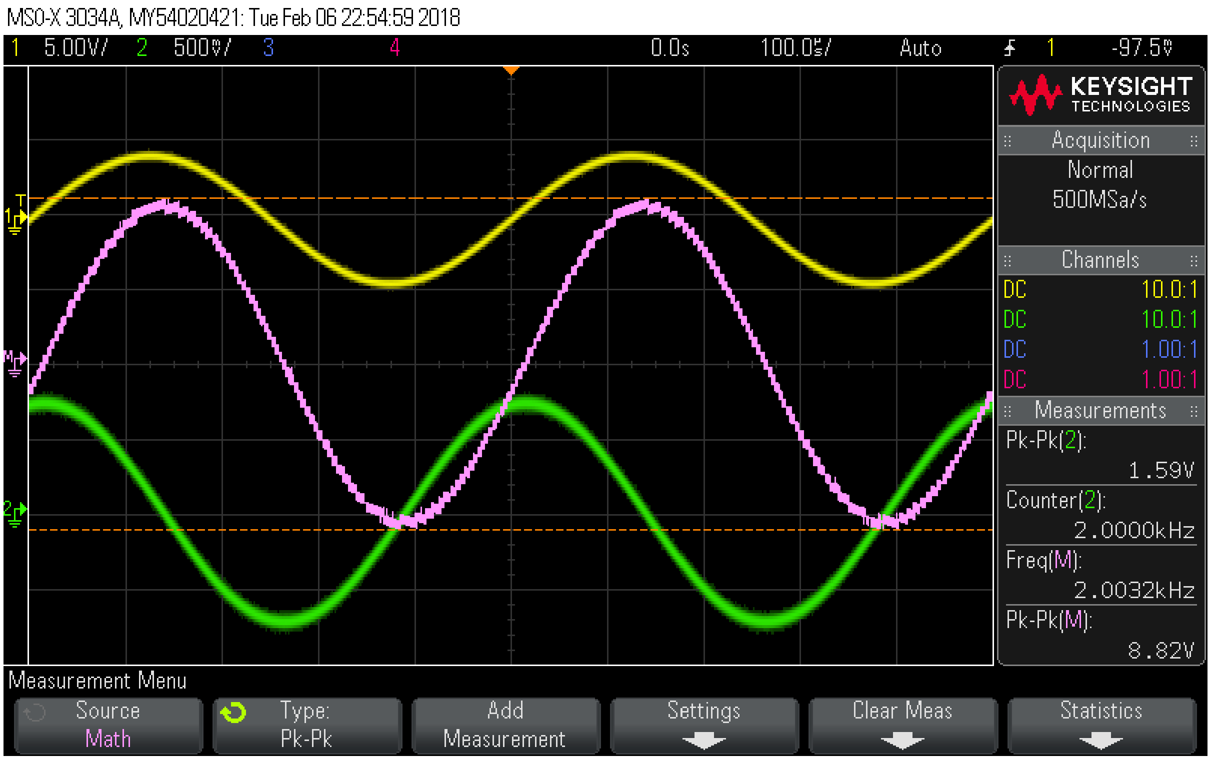
Screenshot representing the voltage across the 12kΩ resistor (6.55Vpp = 2.31mV_{RMS} shown above)

5)

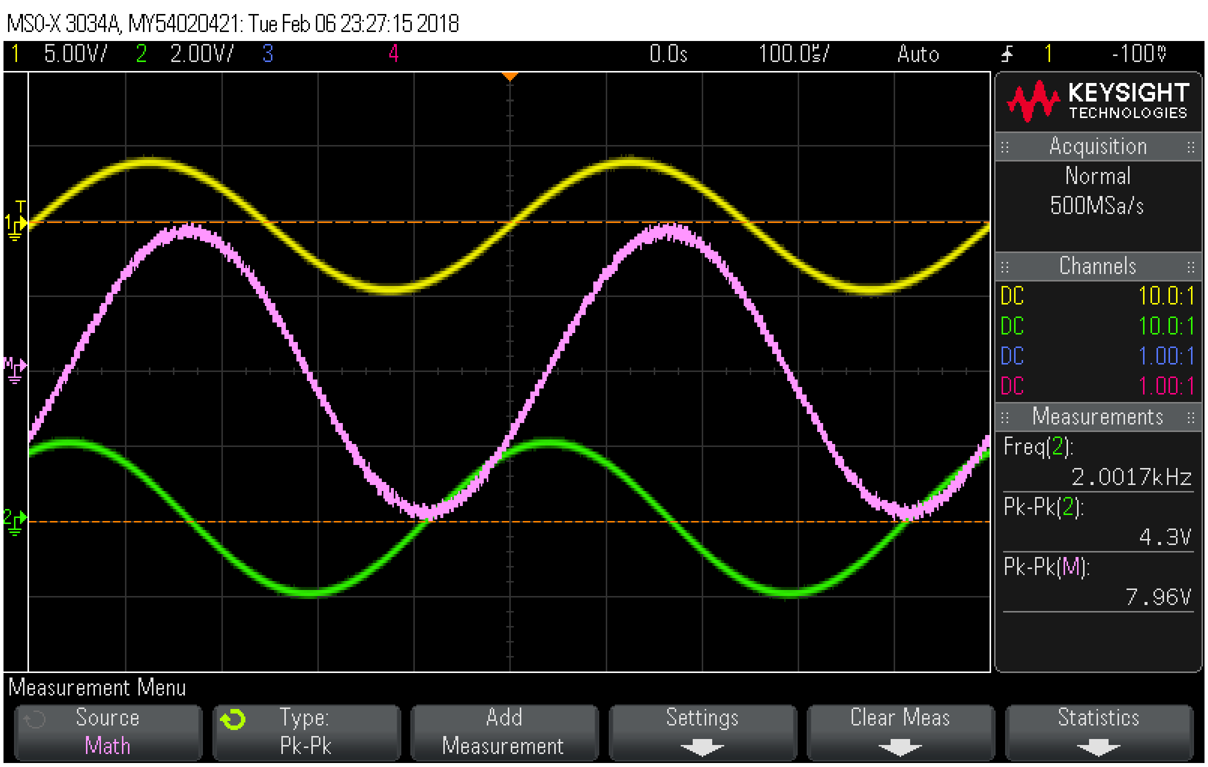
Note:

CH1-*Yellow*: Probe across 10nF capacitor (as shown in Question 3 schematic above).
CH2-*Green*: Probe across 1.8kΩ or 5.6kΩ or 12kΩ resistor (as shown in Question 3 schematic above).

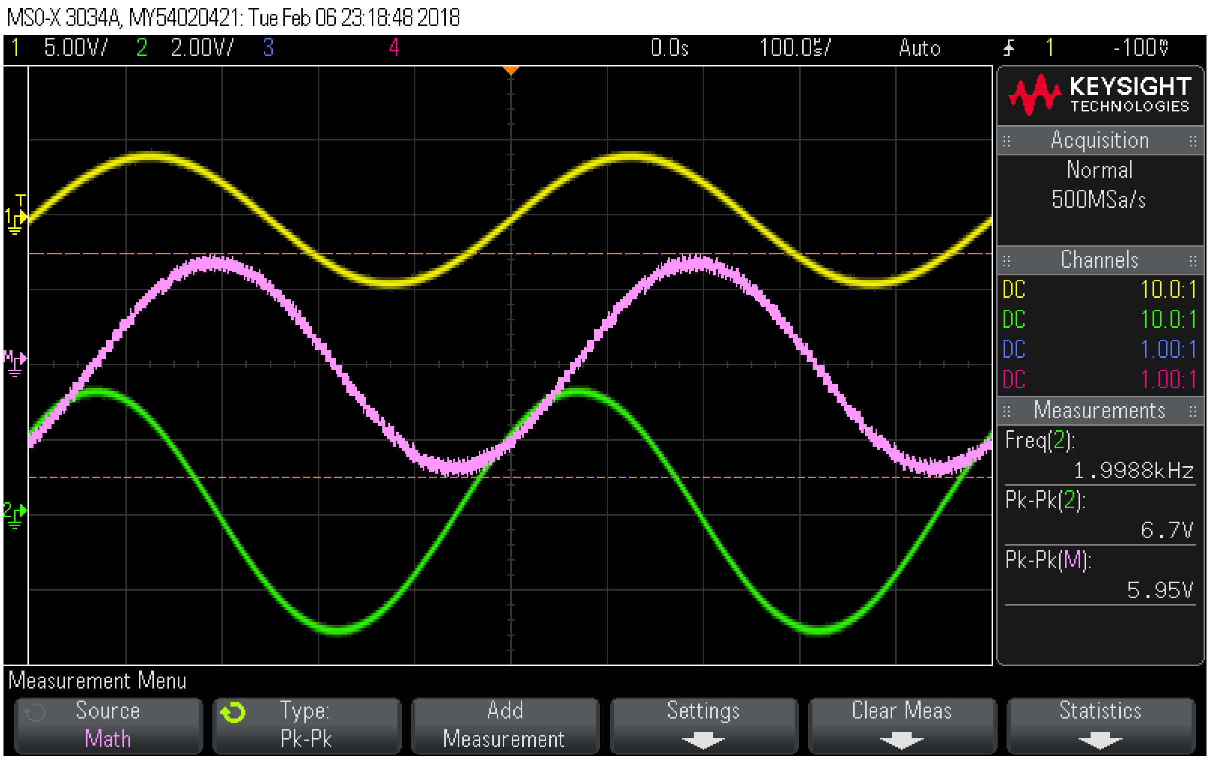
**This applies to the screenshots in <u>Question 5</u> and <u>Question 6</u>.*



The voltage across the 10nF capacitor (1.8kΩ circuit) (8.82Vpp = 3.12V_{RMS} shown above)

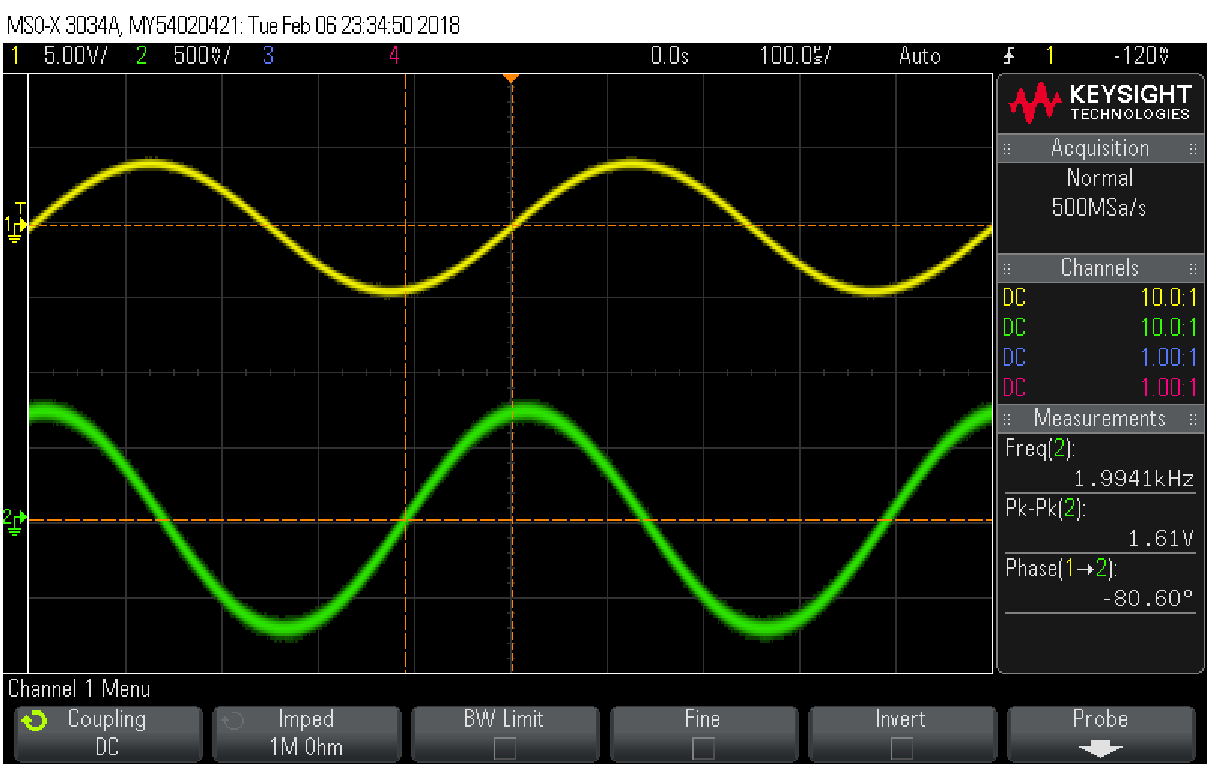


The voltage across the 10nF capacitor (5.6kΩ circuit) (7.96Vpp = 2.81V_{RMS} shown above)

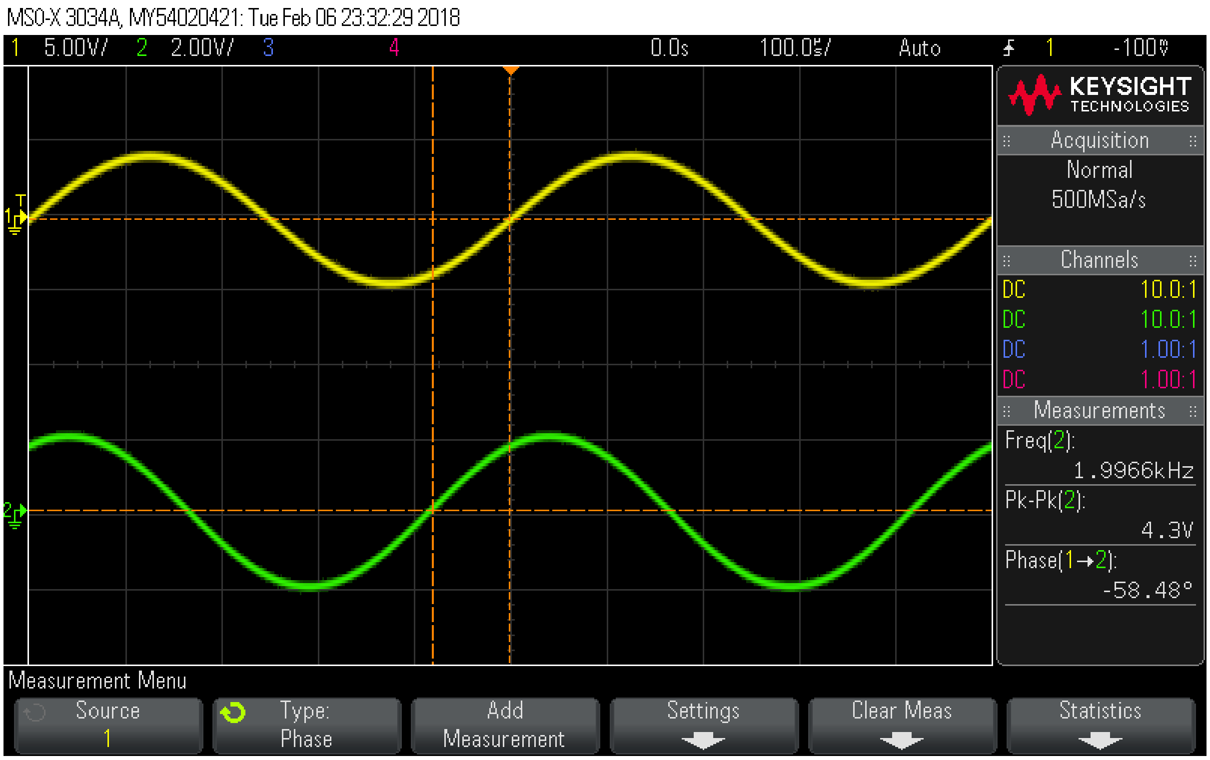


The voltage across the 10nF capacitor (12kΩ circuit) (5.95Vpp = 2.10VRMS shown above)

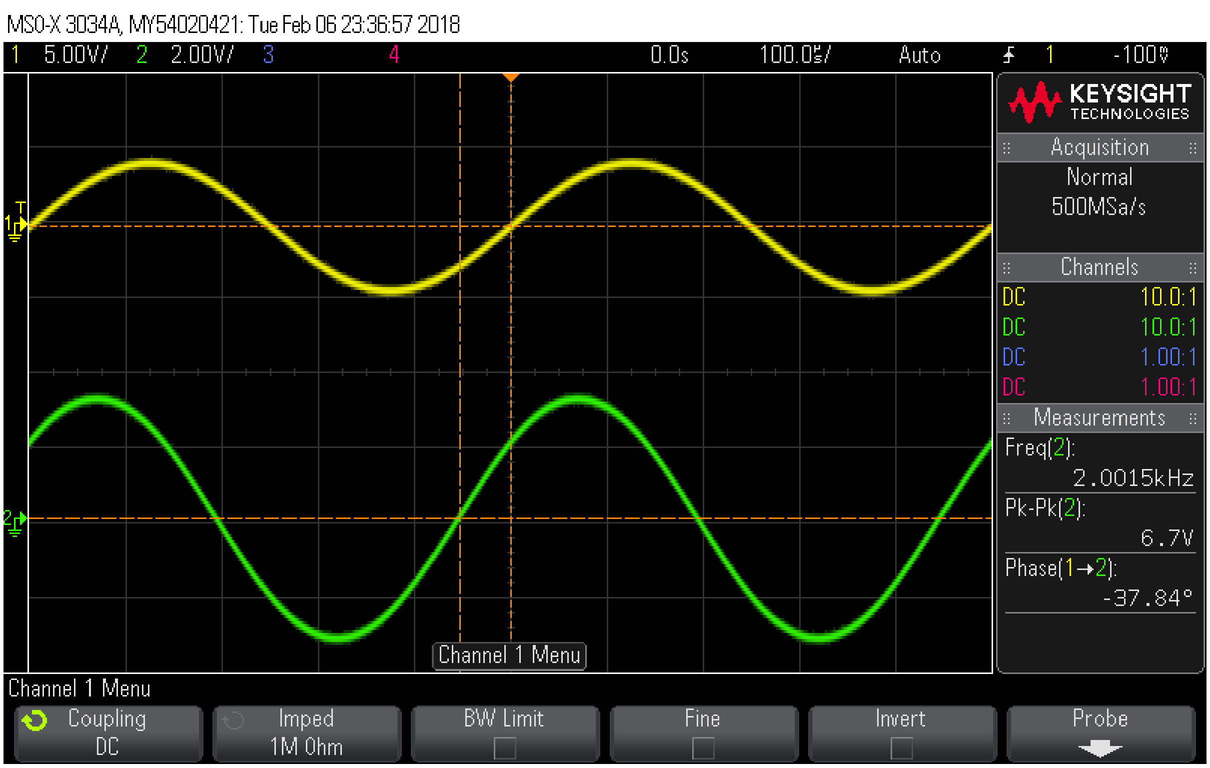
6) *Refer to note in Question 5.



Phase angle measurement for 10nF, 1.8kΩ circuit. The measured phase angle here is -80.60°.



Phase angle measurement for 10nF, 5.6kΩ circuit. The measured phase angle here is -58.48°.



Phase angle measurement for 10nF, 12kΩ circuit. The measured phase angle here is -37.84°.

Comment:
The measurement of the phase angle between the waveform generator voltage (CH1) and waveform generator current (CH2) wasn't too complicated to achieve. Using the measurement function on the scope and selecting "Phase" as the measurement, the phase difference between CH1 and CH2 resulted my measured phase angle.

7, 8, 9) Calculate the circuit impedance using the generator voltage and your calculated current.

R	1.8 kΩ	5.6 kΩ	12 kΩ
Measured V_R	***524mV$_{RMS}$***	***1.46V$_{RMS}$***	***2.31V$_{RMS}$***
Measured V_C	***3.12V$_{RMS}$***	***2.81V$_{RMS}$***	***2.10V$_{RMS}$***
Measured phase	***-80.60°***	***-57.90°***	***-37.26°***
Calculated I_g	$\mathbf{291\mu A}$	$\mathbf{260\mu A}$	$\mathbf{192\mu A}$
Calculated Z	***10.3kΩ***	***11.5kΩ***	***15.6kΩ***

Table 2 : Series RC circuit measurements and calculations

Calculations:

(for 1.8kΩ)

Calculated I_G:

$$I = \frac{V_R}{R}$$

$$I = \frac{524mV_{RMS}}{1.8k\Omega}$$

$$\boldsymbol{I = 291\mu A}$$

Calculated Z:

$$Z = \frac{V_G}{I_G}$$

$$Z = \frac{3V_{RMS}}{291\mu A}$$

$$\boldsymbol{Z = 10.3k\Omega}$$

(for 5.6kΩ)

Calculated I_G:

$$I = \frac{V_R}{R}$$

$$I = \frac{1.46V_{RMS}}{5.6k\Omega}$$

$$\boldsymbol{I = 260\mu A}$$

Calculated Z:

$$Z = \frac{V_G}{I_G}$$

$$Z = \frac{3V_{RMS}}{260\mu A}$$

$$\boldsymbol{Z = 11.5k\Omega}$$

(for 12kΩ)

Calculated I_G:

$$I = \frac{V_R}{R}$$

$$I = \frac{2.31V_{RMS}}{12k\Omega}$$

$$\boldsymbol{I = 192\mu A}$$

Calculated Z:

$$Z = \frac{V_G}{I_G}$$

$$Z = \frac{3V_{RMS}}{192\mu A}$$

$$\boldsymbol{Z = 15.6k\Omega}$$

10)

- The circuit and demonstration were shown to the instructor (Manijeh Khataie) on February 13th, 2020.

5.0 Questions

1) *The impedance would decrease due to the value of X_C.*
2) *The magnitude RC of the angle of impedance would be larger because of the properties of X_C.*
3) *R = 1.78kΩ / ϴ = 77.37°*
R = 5.59kΩ / ϴ = 54.91°
R = 12.08kΩ / ϴ = 33.37°

My calculated results compared to my measured phases are not exactly the same, but are within the accepted tolerance range.

6.0 Conclusion

- Purpose of this lab has been achieved.
- Understood how to verify current and voltage relationships in a series RC circuit.
- Understood how to measure how to measure phase angles in a series RC circuit.