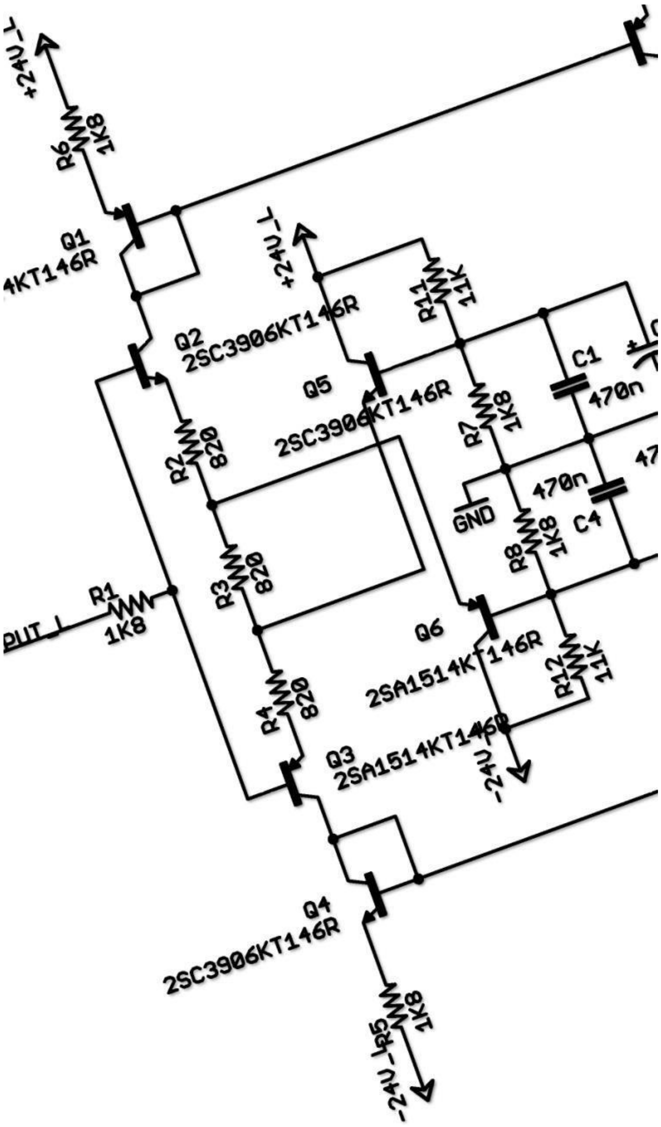
k MONASH University
Engineering

ECE2131

Electrical Circuits

Laboratory Notes



2022 Edition

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2022

4 Sinusoidal Steady State Analysis & Resonance

4.1 Learning Objectives and Introduction

Following on from the practical work with transient responses of RLC circuits covered in Laboratory 2, this experiment provides practical experience and familiarity with the sinusoidal steady state analysis and resonance of RLC series circuits. In this experiment, you will examine the current – voltage relationship for capacitors, inductors, and RLC networks in sinusoidal steady state, the impedances of capacitors, inductors and RLC networks in relation to the frequency of the sinusoidal source, and the resonance phenomenon of a RLC network.

The circuits are to be driven by a sinusoidal voltage source so that they can be analysed by the phasor domain techniques discussed in lectures. You will need to consult these lecture notes to complete the Preliminary Work and experiment tasks.

By the end of this lab you should:

- Understand how complex impedances relate to sinusoids in a circuit
- Measure phase shifts in a circuit, and understand what causes them
- Represent complex impedances by phasors, and plot these from measured values

4.2 Reference Equations

Refer to lab addendum on Moodle (and lecture notes) for derivation and full set of useful equations

$$Q = \frac{\omega_0 L}{R} = \frac{\omega_0}{\Delta\omega}$$

4.3 Equipment and Components

Provided for this laboratory session are a DSO, a sinusoidal wave generator, and:

- Breadboard
- 10 kΩ resistor
- 100 nF capacitor
- 100 mH inductor

4.4 Experimental Work

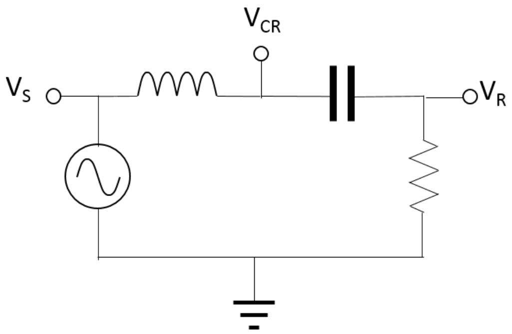
4.4.1 SERIES RLC CIRCUIT

The “common” terminal of the square wave generator and the “common” terminal of the DSO should be connected together. The series RLC circuit under study should be connected together in such a way that the voltage waveform across the element to be observed has a “common” terminal connected to the “common” of the whole circuit.

4.4.2 SINUSOIDAL SIGNAL SOURCE AND DSO CALIBRATION

The arbitrary functional generator is to be used as the source of voltage. You will need the generator to produce sinusoidal waves of $f_0/10$, f_0 and $10f_0$ Hz, where f_0 is the resonance frequency of the RLC circuit from the preliminary quiz.

4.4.3 MEASURING VOLTAGES ACROSS AND THE CURRENT THROUGH R, L AND C



$\mathbf{V_R}$, $\mathbf{V_{CR}} = \mathbf{V_C}+\mathbf{V_R}$, $\mathbf{V_S}$ and $\mathbf{I} = \mathbf{V_R}/R$ are the potentials with respect to the common ground of the circuit, and so can be directly measured using either probe of the DSO. **However, V_C, V_L, and $V_X = V_C+V_L$, cannot be directly measured by either probe since they are not defined with respect to the common ground.** (see discussion in appendix A/labs 1&3 on this).

<u>To measure the phase difference between the current **I** and these voltages, you must measure $\mathbf{V_R}$ (which is in phase with the current, as it is a resistor)and one of these voltages simultaneously</u>. Hence, you cannot move R from the ground as you did in previous two laboratory exercises. To measure phase difference between two curves, you first need to measure the time difference between their peaks or zero-crossings, Δt. The phase (in degrees) between two curves is then given by the following equation, where T is the period.

$$\phi = \frac{\Delta t}{T} x360°$$

It is also possible to use the built-in phase measure tool of the DSO.

Use the maximum values of sinusoids to measure and record the amplitudes of voltages and current.

Before you attempt your lab, think about:

- Your measurements. What are you measuring? What can you calculate from thesemeasurements? How can you then complete this lab in the most efficient way?
- What 0 degrees phase means. We are defining the current as being at 0 degrees. What implications does this have for the resistor voltage? How then can you reference your phase measurements to 0 degrees?
- What measuring the voltage between the +/- terminals of the signal generator means when connected to the circuit. What are you really measuring here? What phase do you expect this measurement to have? If you are using this as a reference, but have assumed that current is at 0 degrees phase, what will this do to your measurements?
- Impedances when the frequency is changed. If the magnitude of an elements impedance (or the series sum of several elements) is small, are you going to be able to calculate this to high accuracy when inferring this from other measurements?

Resonance frequency will give you the largest magnitude in the output?

4.4.4 FILL IN THIS TABLE FROM THE PRELIMINARY QUIZ

The following table has been provided as part of your preliminary work. You should ensure it is filled out from your preliminary quiz before your lab class begins. Enter the values of the **Impedance** (magnitude and phase angle) across R, C, L, X, CR, and S respectively for $f_0/10$, f_0, and $10f_0$.

Theory	**Current, I**	**R**	**C**	**L**	**X**	**CR**	**S**
$f=f_0/10$							
Impedance (magnitude)	N/A	10000	10000	100	9900	14142.14	14071.60
Phase angle $\angle$	0^0	0^0	-90^0	90^0	-90^0	-45^0	-44.71^0
Impedance (complex number)	N/A	$10000\ \angle 0°$	$10000\ \angle -90°$	$100\ \angle 90°$	$9900\ \angle -90°$	$14142.14\ \angle -45°$	$14071.60\ \angle -44.71°$
$f=f_0$							
Impedance (magnitude)	N/A	10000	1000	1000	0	10049.88	10000
Phase angle $\angle$	0^0	0^0	-90^0	90^0	0^0	-5.71^0	0^0
Impedance (complex number)	N/A	$10000\ \angle 0°$	$1000\ \angle -90°$	$1000\ \angle 90°$	$0\ \angle 0°$	$10049.876\ \angle -5.71°$	$10000\ \angle 0°$
$f=10f_0$							
Impedance (magnitude)	N/A	10000	100	10000	9900	10000.50	14071.60
Phase angle $\angle$	0^0	0^0	-90^0	90^0	90^0	-0.57^0	44.71^0
Impedance (complex number)	N/A	$10000\ \angle 0°$	$100\ \angle -90°$	$10000\ \angle 90°$	$9900\ \angle 90°$	$10000.50\ \angle -0.57°$	$14071.60\ \angle 44.71°$

☐ CHECKPOINT: Get a demonstrator to check your answers, and initial here

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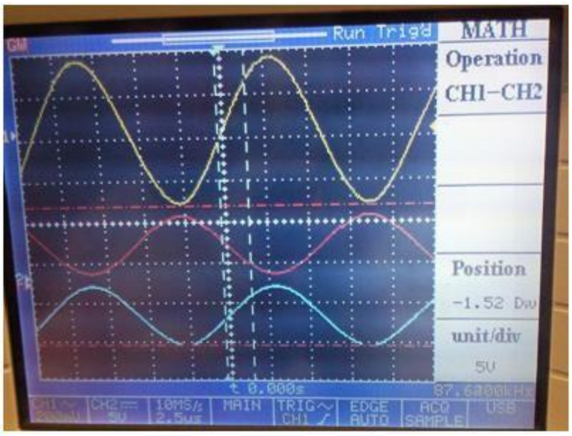


4.4.5 MEASUREMENTS AND ANALYSIS

4.4.5.1 Measure resonance frequency and resonant current

As discussed in the introduction, at resonance frequency, the source voltage $\mathbf{V_s}$ and the circuit current **I** are in phase and the current **I** is maximum.

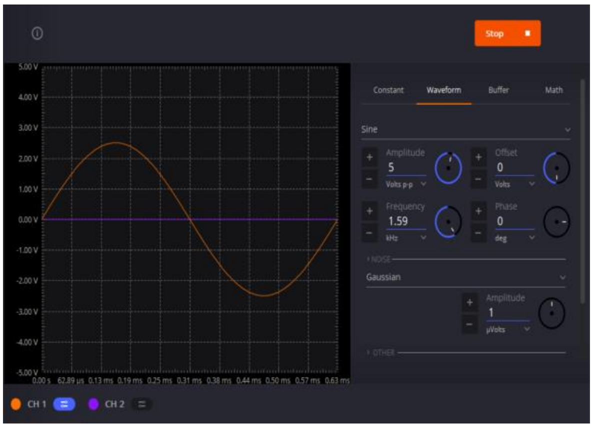
a) Vary the source frequency around the resonance frequency calculated forthe preliminary quiz, while displaying $\mathbf{V_s}$ and **I** simultaneously. From your measurements, find the frequency f_0 at which $\mathbf{V_s}$ and **I** are in phase.

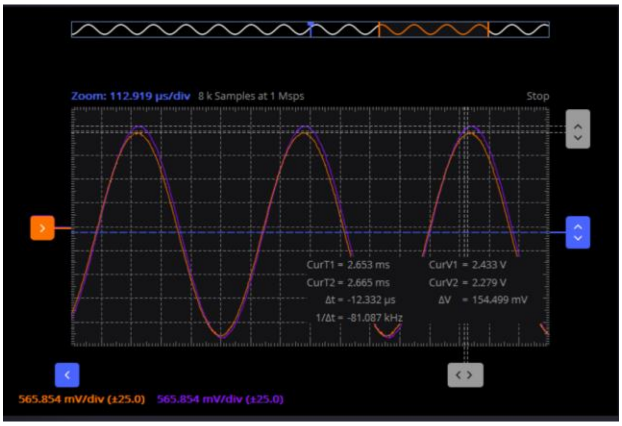
b) Write down the measured and calculated values of f_0. Comment on whether f_0 is the same as or close to the calculated resonance frequency?

c) Comment on whether **I** maximum at this frequency f_0?

d) Comment on whether the measured resonance frequency $\omega_0(=2\pi f_0)$ the same as the un-damped natural frequency of this circuit you measure in the previous lab?

Part A





Measured resonance frequency would be 1590 Hz.

☐ CHECKPOINT: Get a demonstrator to check your answers, and initial here

Part B

The calculated resonance frequency can be calculated using the formula:

$$\omega_0 = 2\pi f_0$$

Substituting $f_0 = \frac{\omega_0}{2\pi}$ into the equation above, we will get

$$f_0 = \frac{1}{\sqrt{LC} * 2 * \pi}$$

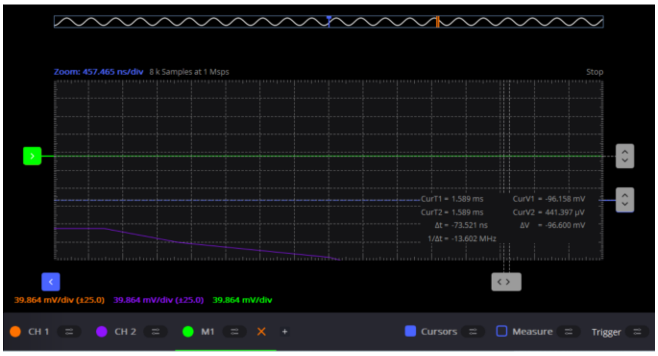
Given that L is 100 mH and C is 100 nF, we will get 1591.55 Hz as our theoretical frequency.

Comparing both the measured and theoretical value for f0, both of the value is close to each other but not the exact same value. This could be due to the misinterpretation of data made during the visual observation of the graph in Scopy.

Part C

The theoretical current can be calculated using the formula I = V / R.

From our example, we would get I = 2.5 / 10000 = 0.25 mA as our theoretical current value.



Our measured current value would be 0.2337 mA based on the visual observation of the graph. It is close to the theoretical value obtained above. Since the current flowing through the circuit can be obtained by dividing the voltage over the impedance, in which the impedance will be at its minimum value. Thus, the circuit current will be at its maximum.

Part D

Obtaining the value of undamped natural frequency from Lab 3, we will get ω_d = 9955.6 radians and ω_0 = 10000 rad/s.

The measured undamped frequency can be obtained by using the formula

$$\omega_0 = 2\pi f_0$$

We will obtain the value of 9990.26 rad/s.
The values obtained are close to the values obtained from the previous lab. This difference is obtained due to the systematic error made during the extraction of values from the graph.

4.4.5.2 Fix the source frequency f at the measured f_0, i.e. $f = f_0$, then measure and calculate the following.

Measurement	I	V_R	V_C	V_L	V_X	V_{CR}	V_S
Max value	0.2337 mA	2.337 V	0.231 V	0.282 V	0.147 V	2.334 V	2.485 V
Phase∠	0°	0°	-93.58 °	54.88 °	0.0435 °	-5.68°	0°
Calculation	N/A	$R = V_R/I$	$X_C = V_C/I$	$X_L = V_L/I$	$X = V_X/I$	$Z_{CR} = V_{CR}/I$	$Z = V_S/I$
Impedance (mag and angle)	N/A	10000 $\angle 0°$	988.45 $\angle -93.58°$	674.07 $\angle 54.88°$	629.01 $\angle 0.0435°$	9987.16 $\angle -5.68°$	10633.29 $\angle 0°$

☐ CHECKPOINT: Get a demonstrator to check your answers, and initial here

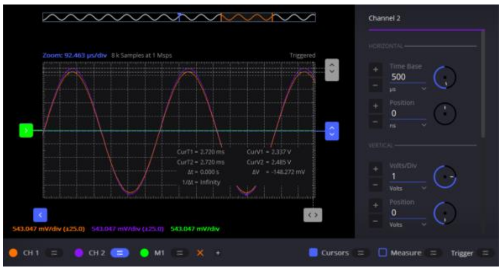
Compare with theoretical calculations in section 4.4.4 and comment on the consistence/discrepancy. Draw the phasor diagram of **all** the variables. State whether the total circuit impedance **Z** is resistive and/or capacitive/inductive?

Note: we only need to find the voltage of the source (Vs) , the voltage across the resistors(Vr) and Vcr. We can find Vc by just subtracting Vcr with Vr, Vl can be found by subtracting Vs with Vcr and Vx can be obtained by the addition of Vc and Vl.

1. Current

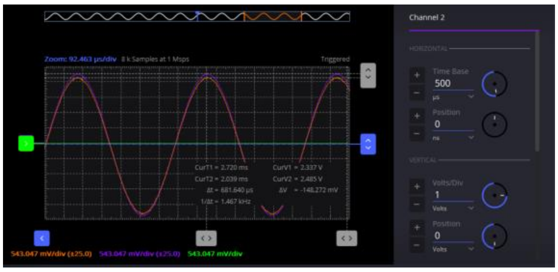
The current will be 0.2337 mA as found in the section above.

2. Resistor Voltage



The maximum voltage of the resistor will be 2.337 V

2b. The Phase Angle



The phase angle will be zero.

☐ CHECKPOINT: Get a demonstrator to check your answers, and initial here

3. Capacitor and Resistor Voltage (Vcr)

The maximum voltage will be 2.334 V

3b. The Phase Angle

$$\Delta t \times f \times 360 = -9.918\ \mu s \times 1590 \times 360 = -5.68°$$

4. Source Voltage (Vs)

The maximum Source Voltage would be 2.485 V

4b. The Phase Angle

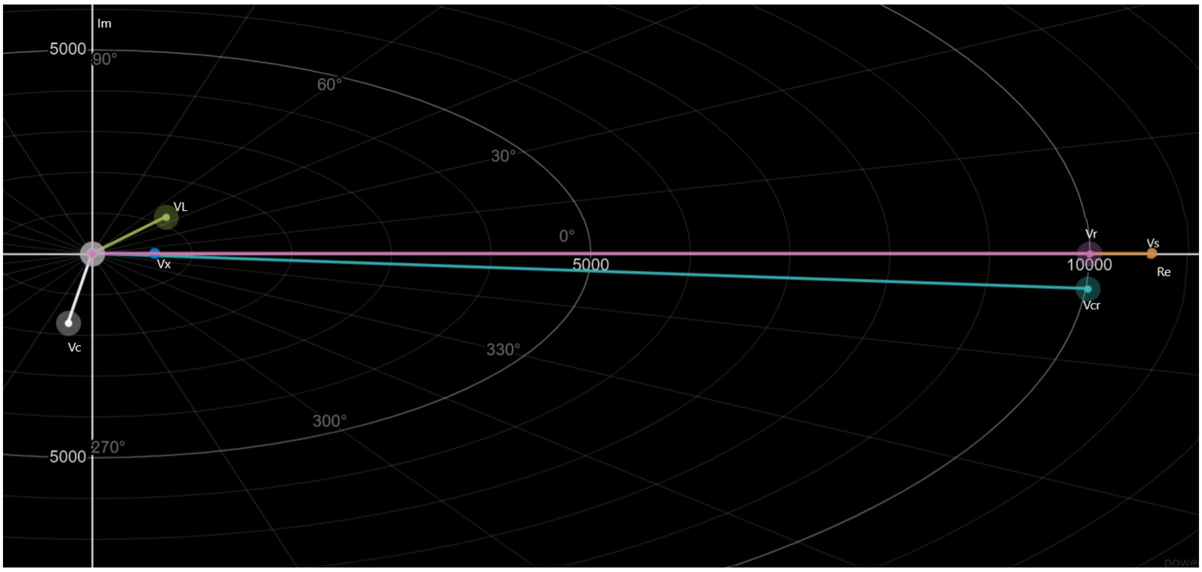
The Phase Angle will be zero.

Explanation

The theoretical values and the measured values are close to each other for most of the parts. The are discrepancies in some of the values due to the presence of internal resistance, capacitance and inductance in the circuit. There could also be systematic error made by humans and the equipment used to measure the voltage may not be very accurate.

The circuit impedance Z will be resistive since the phase angle is at 0 degrees. This is because the only impedance will come from the resistor as it is an ideal RLC circuit.

Phase Diagram



4.4.5.3 Increase the source frequency to $f = 10\ f_0$, then measure and calculate the following.

Measurement	I	V_R	V_C	V_L	V_X	V_{CR}	V_S
Max value	181.9 μA	1.819 V	0.017 V	1.799 V	1.782 V	1.821 V	2.477 V
Phase∠	0°	0	-83.57°	93.76°	93.73°	-0.536°	45.86°
Calculation	N/A	**$R = V_R/I$**	**$X_C = V_C/I$**	**$X_L = V_L/I$**	**$X = V_X/I$**	**$Z_{CR} = V_{CR}/I$**	**$Z = V_S/I$**
Impedance (mag and angle)	N/A	10000 $\angle 0°$	93.46 $\angle -83.57°$	9890.05 $\angle 93.76°$	9796.59 $\angle 93.73°$	10011.00 $\angle -0.536°$	13617.37 $\angle 45.86°$

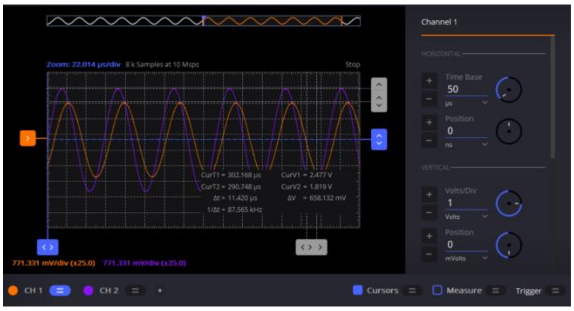
Compare with theoretical calculations in section 4.4.4 and comment on the consistence/discrepancy. Draw the phasor diagram of **all** the variables. State whether the total circuit impedance **Z** is resistive and/or capacitive/inductive?

Note: we only need to find the voltage of the source (Vs) , the voltage across the resistors(Vr) and Vcr.
We can find Vc by just subtracting Vcr with Vr, Vl can be found by subtracting Vs with Vcr and Vx can be obtained by the addition of Vc and Vl.

1. Current

The current will be 181.9 mA

2. Resistor Voltage



The resistor voltage is 1.819V.

2b. Resistor Phase Angle

The resistor phase angle will be 0

☐ CHECKPOINT: Get a demonstrator to check your answers, and initial here

3. Capacitor and Resistor Voltage (Vcr)

The maximum voltage is 1.821 V

3b. The phase angle capacitor and resistor voltage

The phase angle is $\Delta t \times f \times 360 = -0.0936\ \mu s \times 15900 \times 360 = -0.536°$

4. Source Voltage (Vs)

The maximum source voltage is 2.477 V

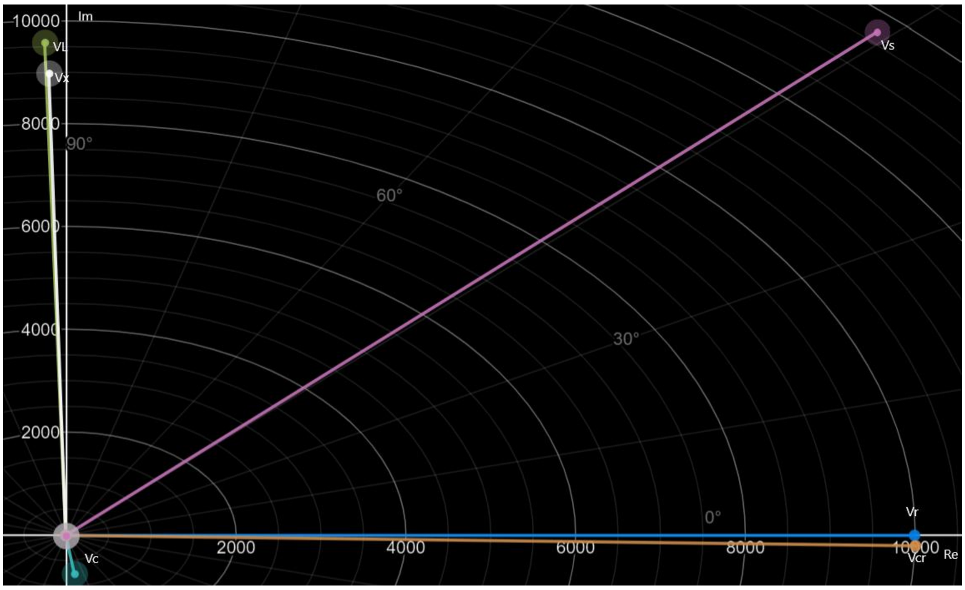
4b. The phase angle of the source voltage

The Phase angle is $\Delta t \times f \times 360 = 8.012\ \mu s \times 15900 \times 360 = 45.86$ degrees

Explanation
The theoretical values and the measured values are close to each other for most of the parts. There are discrepancies in some of the values due to the presence of internal resistance, capacitance and inductance in the circuit. There could also be systematic error made by humans and the equipment used to measure the voltage may not be very accurate.

The circuit impedance Z can be said to be resistive and inductive since there the phase angle is between 0 degrees and 90 degrees, meaning that there are non-zero values for real and imaginary parts. When the frequency is higher than the resonance frequency, the capacitor will act as a short circuit and the inductor will act as an open circuit. The voltage across the capacitor will be much lower compared with the voltage across the inductor, meaning that the circuit will be much more inductive than capacitive. The resistance value will remain the same, meaning that the circuit will be resistive.

Phase Diagram



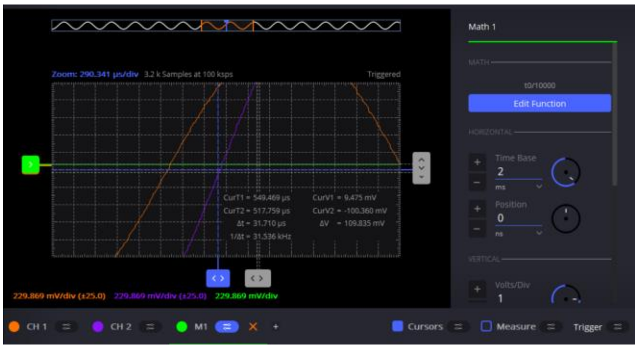
4.4.5.4 Decrease the source frequency to $f = f_0/10$, then measure and calculate the following.

Measurement	I	V_R	V_C	V_L	V_X	V_{CR}	V_S
Max value	0.1758 mA	1.758 V	1.665 V	0.132 V	1.783 V	2.402 V	2.440 V
Phase∠	0°	0°	-90.93°	118.71°	-92.91°	-43.89°	-46.89°
Calculation	N/A	$R = V_R/I$	$X_C = V_C/I$	$X_L = V_L/I$	$X = V_X/I$	$Z_{CR} = V_{CR}/I$	$Z = V_S/I$
Impedance (mag and angle)	N/A	10000 $\angle 0°$	9470.99 $\angle -90.93°$	750.85 $\angle 118.71°$	10142.21 $\angle -92.91°$	13663.25 $\angle -43.89°$	13879.41 $\angle -46.89°$

Compare with theoretical calculations in section 4.4.4 and comment on the consistence/discrepancy. Draw the phasor diagram of **all** the variables. State whether the total circuit impedance **Z** is resistive and/or capacitive/inductive?

Note: we only need to find the voltage of the source (Vs) , the voltage across the resistors(Vr) and Vcr.
We can find Vc by just subtracting Vcr with Vr, Vl can be found by subtracting Vs with Vcr and Vx can be obtained by the addition of Vc and Vl.

1. Current



The current is 0.1758 mA

2. Resistor Voltage

The maximum voltage is 1.758 V

☐ CHECKPOINT: Get a demonstrator to check your answers, and initial here

2b. The resistor phase angle

The resistor phase angle will be 0 degrees.

3. Capacitor and Resistor Voltage (Vcr)

The maximum voltage will be 2.402 V

3b. The capacitor and resistor phase angle

The phase angle is $\Delta t \times f \times 360 = -819.113\ \mu s \times 159 \times 360 = -46.89$ degrees

4. Source Voltage (Vs)

The Source Voltage is 2.440 V

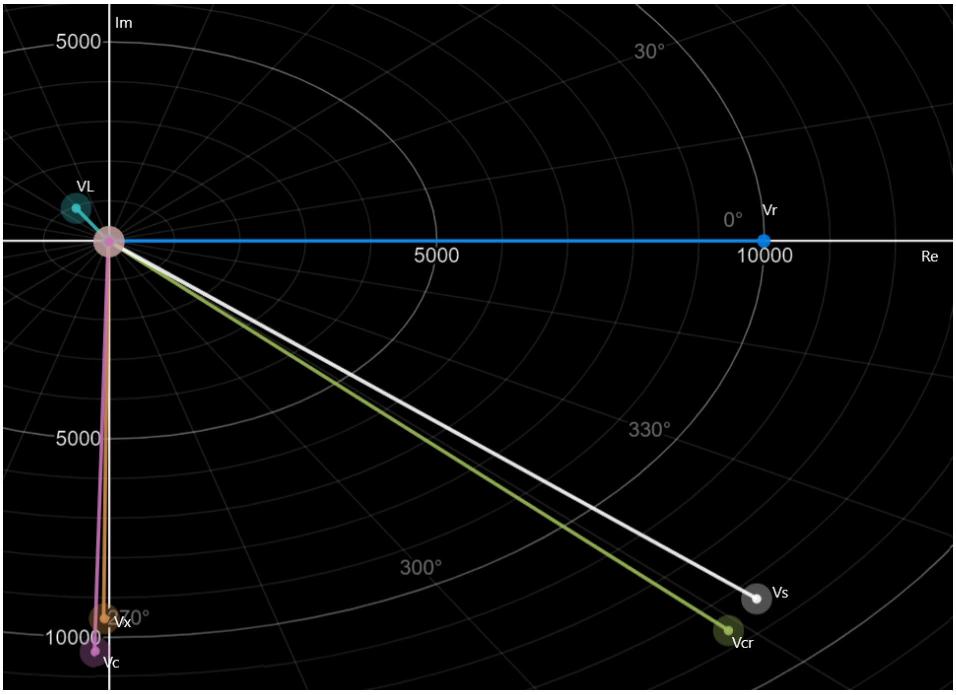
The phase angle is $\Delta t \times f \times 360 = -766.77\ \mu s \times 159 \times 360 = -43.89$ degrees

Explanation

The theoretical values and the measured values are close to each other for most of the parts. There are discrepancies in some of the values due to the presence of internal resistance, capacitance and inductance in the circuit. There could also be systematic error made by humans and the equipment used to measure the voltage may not be very accurate. There is an exception which would be the voltage of the inductor measured. This is due to the extremely small value of the voltage measured compared with the other values.

The circuit impedance Z will be resistive and capacitive when the frequency is a tenth of the resonance frequency as the phase angle is between 0 degrees and -90 degrees. When the frequency is lower than the resonance frequency, the capacitor will act as an open circuit and the inductor will act as a short circuit. This means that the voltage across the capacitor will be higher than the voltage across the inductor. This will cause the circuit to become capacitive. The circuit will also be resistive as the resistor's resistance remains the same.

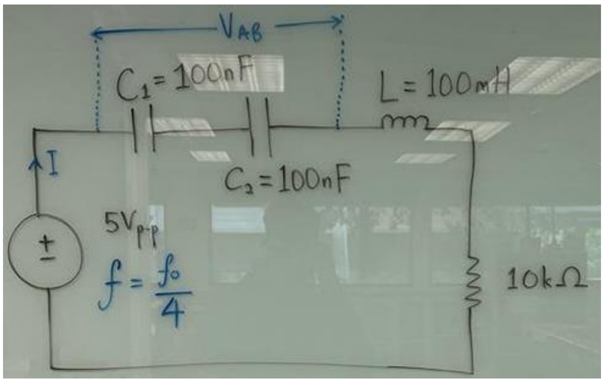
Phase Diagram



Lab Assessment

Given Circuit

1.



2. The theoretical resonance frequency can be calculated using the formula

$$f_0 = \frac{1}{\sqrt{LC} * 2 * \pi}$$

where L is the total inductance in the circuit and C is the total capacitance in the circuit

Based on the circuit above, the inductance of the circuit will be 100mH and the total capacitance in the circuit will be $\frac{1}{\frac{1}{100nF}+\frac{1}{100nF}}$ which equates to 50nF.

Substituting the value into the equation above, we will get f_0 to be 2250.79 Hz.

3. The assumption made is that the resonance frequency will be equal to the theoretical frequency.

4. The frequency value that we will be using for our signal generator will be 2250.79 / 4 which will equate to 562.7 Hz.

5.

The magnitude of current, I can be found by getting the voltage across the resistor which will be 2.264 V in this case. Since we are using a 10kOhm resistor, we can take 2.086 / 10000 which would equate to 0.2086 mA.

6. The voltage across the resistor would be 2.086 V

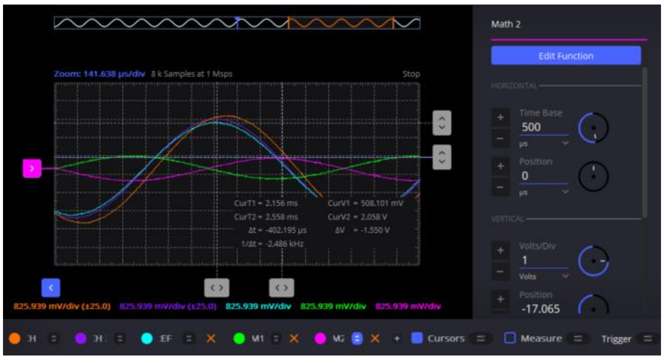
7. The magnitude of the source, Vs would be 2.264 V and the phase would be -23.21 degrees.

The magnitude of the voltage across the inductor will be 98.976 mV

The phase angle can be calculated as follow.

$$\Delta t \times f \times 360$$

562.698 * 259.386 μs * 360 = 52.5 degrees



The magnitude of the voltage across the first capacitor would be 508.101 mV and the phase angle of the first capacitor would be 562.698 Hz * - 402.195µs * 360 = -76.26 degrees.

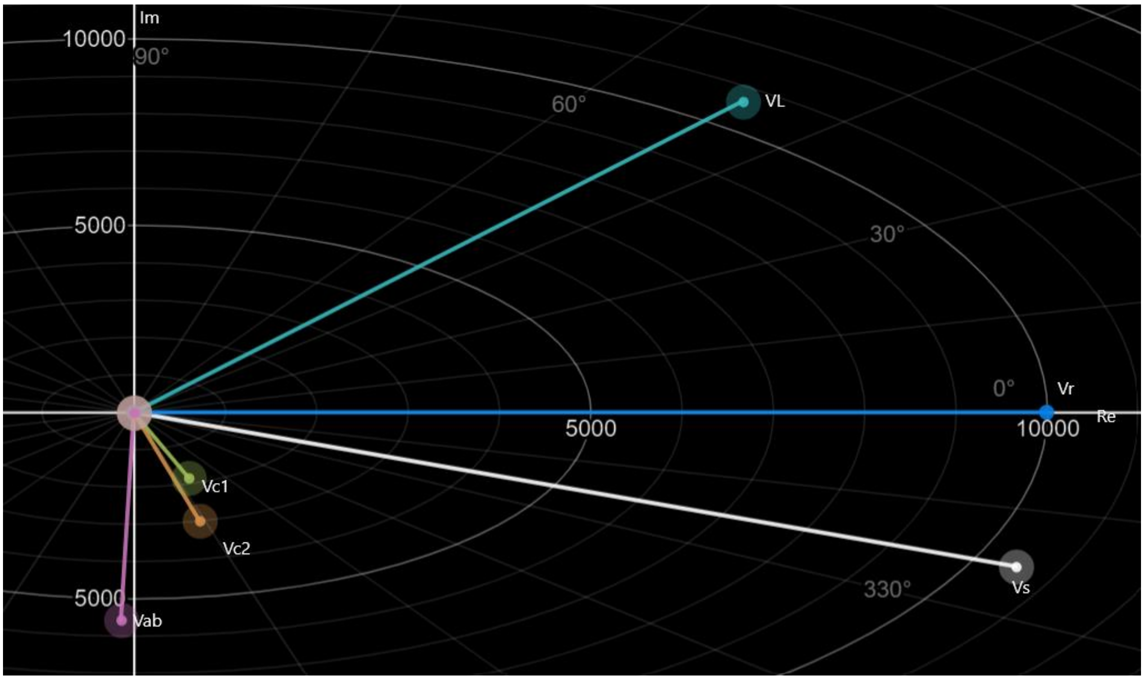
The magnitude of the voltage across the second capacitor would be 687.952 mV and the phase angle of the second capacitor would be 562.698 * -387.751µs * 360 = -78.55 degrees.

The magnitude of the voltage across AB would be 1.088 V and the phase angle of Vab would be 562.698 * -559.510µs * 360 = -91.06 degrees.

8. Calculation of the impedance

Measurement	I	V_r	V_L	V_{C1}	V_{C2}	V_{AB}	V_S
Max value	0.2086 mA	2.086 V	98.976 mV	508.101 mV	687.952 mV	1.088 V	2.264 V
Phase∠	0°	0°	52.5°	-76.26°	-78.55 °	-91.06°	-23.21°
Calculation	N/A	**R = V_R/I**	**R = V_R/I**	**X_C= V_C/I**	**X_L= V_L/I**	**X= V_X/I**	**Z= V_S/I**
Impedance (mag and angle)	N/A	10000 ∠0°	10633.29 ∠ 52.5°	2435.77 ∠ − 76.26°	3297.95 ∠ − 78.55°	5215.72 ∠ − 91.06°	10853.31 ∠ − 23.21°

9. Phasor Diagrams



ASSESSMENT

Student Statement:

I have read the university's statement on cheating and plagiarism, as described in the *Student Resource Guide*. This work is original and has not previously been submitted as part of another unit/subject/course. I have taken proper care safeguarding this work and made all reasonable effort to make sure it could not be copied. I understand the consequences for engaging in plagiarism as described in *Statue 4.1 Part III – Academic Misconduct*. **I certify that I have not plagiarized the work of others or engaged in collusion when preparing this submission.**

Student signature: Tan Jin Chun Date: 1/04/ 2022

TOTAL: ________(/7)

ASSESSOR: ________