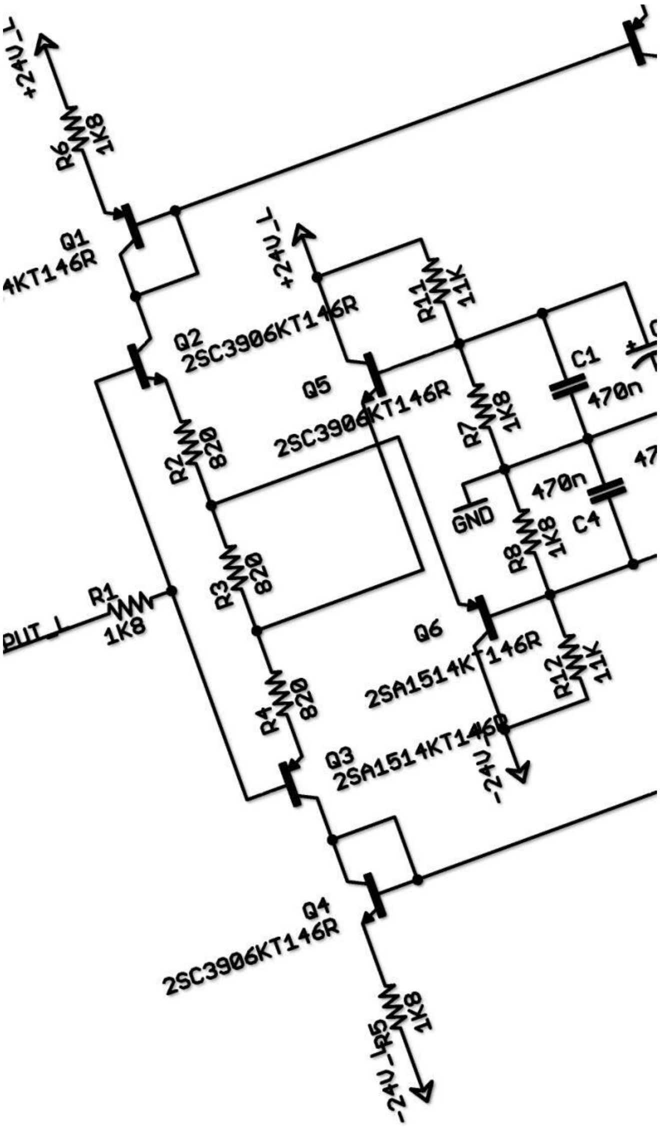
k MONASH University
Engineering

ECE2131

Electrical Circuits

Laboratory Notes



2022 Edition

Name:	Student ID:	Email:

Electrical and Computer Systems Engineering, Monash University

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

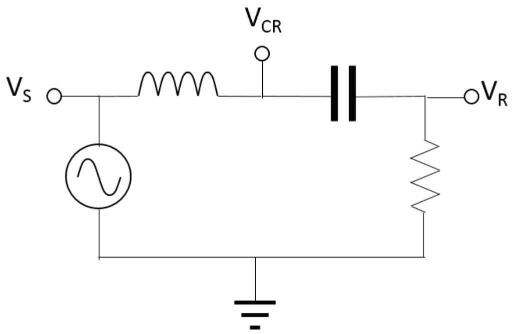
4.4.1 SERIES RLC CIRCUIT

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, $\mathbf{V_C}$, $\mathbf{V_L}$, and $\mathbf{V_X} = \mathbf{V_C}+\mathbf{V_L}$, 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).

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. 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:

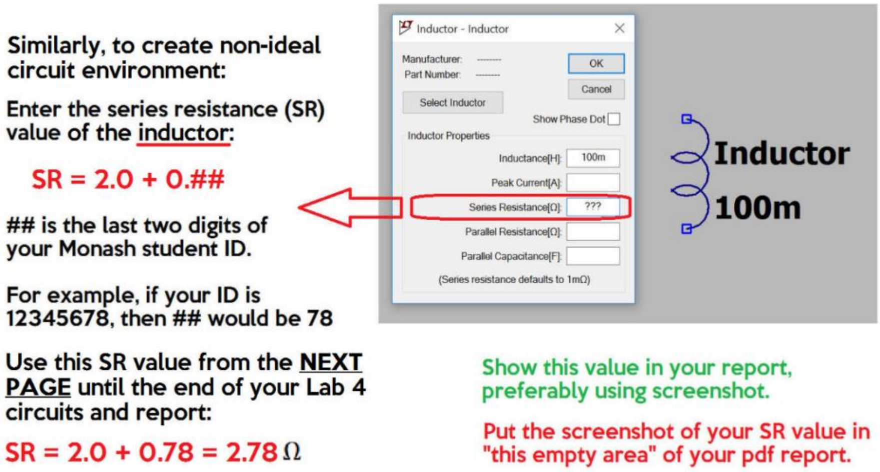
- Your measurements. What are you measuring? What can you calculate from these measurements? How can you then complete this lab in the most efficient way?
- What 0 degrees phase means. We are defining the current as being at 0 degrees. What implications does this have for the resistor voltage? How then 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?

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						
Phase angle ∠	0^0						
Impedance (complex number)	N/A						
				$f=f_0$			
Impedance (magnitude)	N/A						
Phase angle ∠	0^0						
Impedance (complex number)	N/A						
				$f=10f_0$			
Impedance (magnitude)	N/A						
Phase angle ∠	0^0						
Impedance (complex number)	N/A						

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



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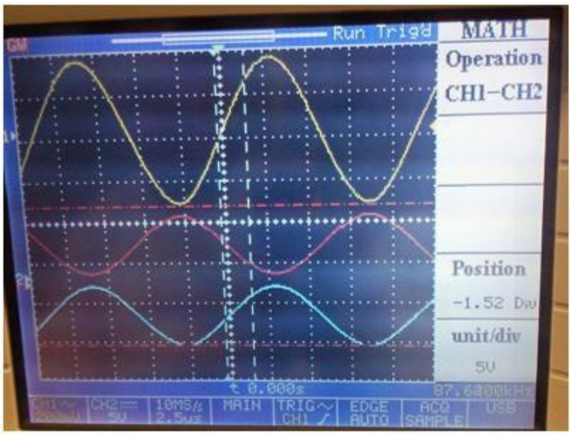


4.4.5 MEASUREMENTS AND ANALYSIS

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. <u>From your measurements, find the frequency f_0</u> at which $\mathbf{V_s}$ and **I** are in phase.

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

c) <u>Comment</u> on whether **I** maximum at this frequency f_0?

d) <u>Comment</u> 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?

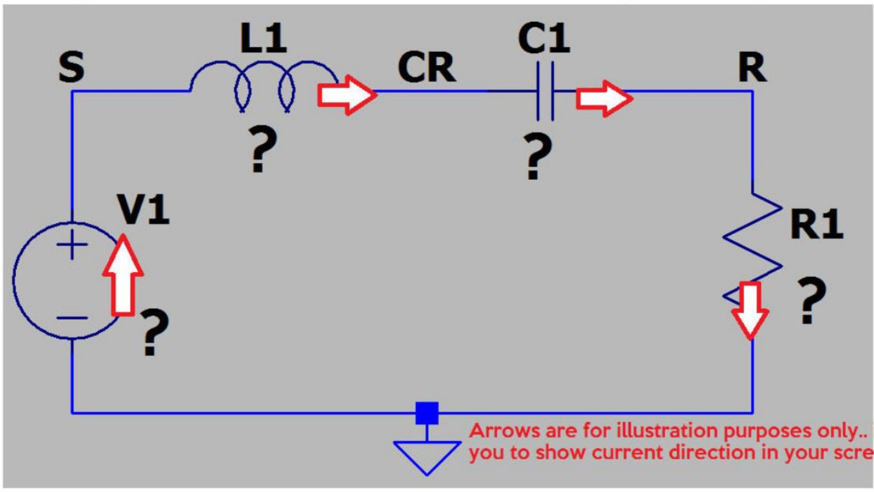
☐ CHECKPOINT: Get a demonstrator to check your answers, and initial here ________________

Remember that these Labs were made base on using oscilloscope in the lab. Hence there might be some restrictions which are offset by LTSpice. Please take note.

Refer to the end of this file for more notes...

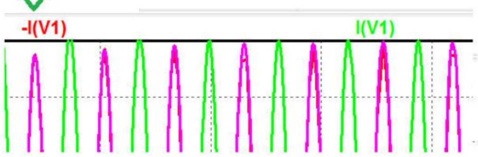
(polarity of components in LTSpice affect the simulated current direction)

When simulating this circuit, ensure curent is flowing in a single direction:



If current through a component is in opposite direction, choose either method for that component:
1. rotate the component 180 degrees
2. insert negative sign in the waveform

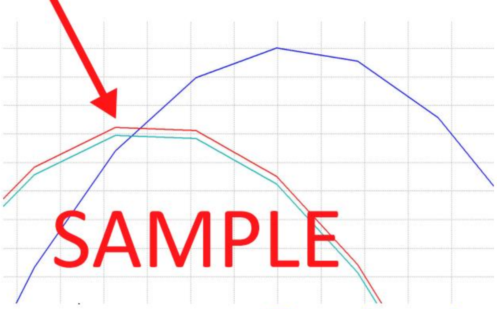
right-click and put negative sign in front



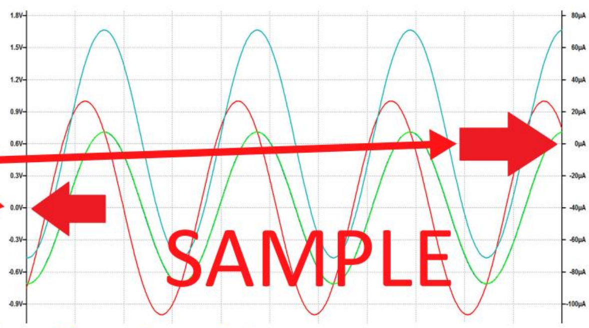
BE CAREFUL OF CURRENT DIRECTIONS IN LTSPICE!!

NOT PREFERRED way of measuring wave, because you **zoom in too much**, and the sinusoidal curve becomes straight lines. To reduce straight lines, increase timestep in simulation command of your circuit, or zoom out slightly until you see curves again.

The proper way to measure period, frequency, or phase (in LTSpice or using oscilloscope), would be to use ________________.
(Refer to lab 3)



When measuring in LTSpice, take extra caution that sometimes the zero-line for voltage and current axis might be at different grid lines



*These tips apply generally in LTSpice, not just this section or lab

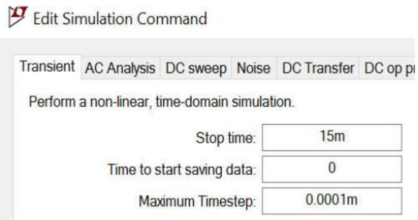
4.4.5.2 Fix the source frequency f at the measured f_0, i.e. $f = f_0$, then measure and calculate the following.

Measurement	I	V_R	V_C	V_L	V_X	V_{CR}	V_S
Max value							
Phase∠	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						

☐ 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?

Preferred simulation command **for $f = f_0$**



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FOR $f = f_0$, you must show the following LTspice screenshots for proof of measurements:
(i) measurement of **V_{CR} phase angle**
(ii) maximum/peak value of V_R

*you are allowed to show as many screenshots as you think is necessary to convince us that you made the correct measurements

For this lab, you will need to use two oscilloscope channels, CH1 and CH2 to make it easier to compare phase.

Leave one of your channel across your reference. Remember that your reference is NOT necesssarily the source. Read lab notes to understand the circuit.

You can then use the other channel to measure your variable.

If in a situation where you cannot connect a channel to your reference, then you need to ensure to take into account the additional phase differences.

*delete this image in your report. For Scopy only.

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

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							
Phase∠	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						

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?

FOR f = **10**f_0, you must show the following LTspice screenshots for proof of measurements:
(i) measurement of **V_C phase angle**
(ii) measurement of **V_X phase angle**

*you are allowed to show as many screenshots as you think is necessary to convince us that you made the correct measurements

*delete these images from your report.

For LTSpice only.

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

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							
Phase∠	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						

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?

FOR $f = f_0$**/10**, you must show the following LTspice screenshots for proof of measurements:
(i) measurement of **V_L phase angle**
(ii) measurement of **V_S phase angle**

*you are allowed to show as many screenshots as you think is necessary to convince us that you made the correct measurements

*delete these images from your report. For LTSpice only.

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

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:________________________________Date:____/____/____

TOTAL: ________(/7)

ASSESSOR: ________